

# Direct photon measurements in pp collisions at $\sqrt{s} = 7$ TeV with ALICE

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**Abstract.** The production of direct photons in pp collisions via Compton scattering and  $q\bar{q}$  annihilation leading order processes is of great interest to test pQCD predictions and also to study parton fragmentation. The fragmentation of the recoil scattered parton can be studied using correlation between the photon and the charged particles emitted in the opposite direction. We present the study of the parton fragmentation in pp collisions at  $\sqrt{s} = 7$  TeV measuring the imbalance parameter  $x_E = -\vec{p}_T^h \cdot \vec{p}_T^\gamma / |\vec{p}_T^\gamma|^2$ . Furthermore, a first uncorrected direct photon spectrum measured with the ALICE electromagnetic calorimeter (EMCal) is shown. These measurements open the way to a straightforward comparison between pp and Pb-Pb collisions concerning parton fragmentation and direct photon production.

## 1. Introduction

In pp collisions, direct photon measurements can provide strong constraints on parton distribution functions (PDF) [1, 2]. Compton scattering ( $qg \rightarrow \gamma q$ ) is the dominant channel of direct photon production at LHC energies (in the  $p_T$  range investigated here: 8-50 GeV/c) making the cross-section QCD predictions very sensitive to the poorly known gluon PDF and then opening the opportunity to better constrain it. The  $\gamma$ -jet events are naturally pointed out to study the modification of the fragmentation functions that occurs in heavy-ion collisions [3]. Indeed, the photon is a colorless particle that does not interact strongly with the hot and dense medium created [4]. Therefore the direct photon is a reliable reference to study the fragmentation of the oppositely scattered parton in both pp and heavy-ion collisions. From the experimental point of view, direct photons are not discernable from higher order processes (i.e., bremsstrahlung). Nevertheless, isolation techniques provide a strong discrimination between them and other photon production channels (dominated by meson decays). We present first experimental details as well as the direct photon selection techniques used. Then we report on two different analyses: the  $\gamma$ -hadron correlation measurements and the direct photon analysis.

## 2. Experimental details and direct photon selection

Both analyses are based on pp collisions at  $\sqrt{s} = 7$  TeV from data taken in year 2011. The photons are measured in the ALICE Electromagnetic Calorimeter (EMCal) [5] which is a sampling calorimeter (Pb-Scintillator) with an acceptance of  $\Delta\varphi = 100^\circ$  and  $|\eta| < 0.7$  and a pseudorapidity  $\times$  azimuth granularity of  $\delta\eta \times \delta\varphi = 0.143 \times 0.143$ . The tracks of charged hadrons are measured in the Inner Tracking System and the ALICE Time Projection Chamber [6]



( $\Delta\varphi = 360^\circ$  and  $|\eta| < 0.9$ ). The EMCal L0 trigger is used to select events with high energy deposition ( $> 5$  GeV) in a 4x4 EMCal tower patch. It reduces the data volume as well as the detector dead time allowing to enhance the integrated luminosity recorded.

Particles deposit their energy in the calorimeter creating clusters (groups of neighboring fired cells). Direct photon candidates are selected from those clusters using various requirements. The clusters produced by charged particles are rejected using a track extrapolation technique. But the main background comes from neutral meson decays ( $\pi^0$ ,  $\eta$ ). In the  $p_T$  range considered (8-50 GeV/c) these decay photons more likely merge into single elongated clusters. Then the selection is also based on the shape of the electromagnetic shower in the calorimeter requiring  $\lambda_0^2 < 0.3$  with:

$$\lambda_0^2 = 0.5 \times (d_{\eta\eta} + d_{\varphi\varphi}) + \sqrt{0.25 \times (d_{\eta\eta} - d_{\varphi\varphi})^2 + d_{\eta\varphi}^2} \quad (1)$$

where  $d_{\eta\eta}$ ,  $d_{\varphi\varphi}$  and  $d_{\eta\varphi}$  are given by:  $d_{AB} = \frac{\sum_i w_i A_i B_i}{\sum_i w_i} - \frac{(\sum_i w_i A_i)(\sum_i w_i B_i)}{(\sum_i w_i)^2}$ , where  $A_i$  and  $B_i$  are the coordinates of the cell  $i$  (in  $\eta$  or  $\varphi$ ) and for each cell,  $w_i = 4.5 - \log(\frac{E_i}{E_{cluster}})$  are weights based on their energy  $E_i$ . Isolation techniques also decrease contamination from decay photons and reject most of fragmentation photons [7]. Indeed, produced inside a jet, these photons are surrounded by hadronic activity. Different isolation criteria were used for the two analyses described below: to have no cluster or no track with  $p_T > 0.5$  GeV/c in a cone radius of  $R = \sqrt{\Delta^2\phi + \Delta^2\eta} = 0.4$  with  $\Delta\phi = \varphi - \varphi_{photon}$  and  $\Delta\eta = \eta - \eta_{photon}$  ( $x_E$  analysis, **section 3**) and that  $\sum E_T < 2$  GeV in the same cone radius (direct photon spectrum, **section 4**).

### 3. Direct photon imbalance parameter measurement

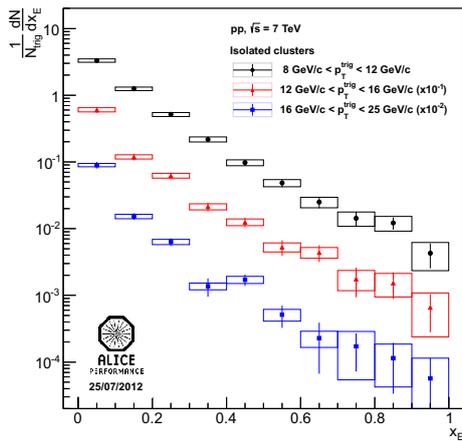
Two-particle correlations can be used to study parton fragmentation in both pp and Pb-Pb collisions [8, 9]. In this analysis ( $\sim 10$  millions events) we use the imbalance parameter  $x_E = -\vec{p}_T^h \cdot \vec{p}_T^\gamma / |\vec{p}_T^\gamma|^2$  that correlates a photon candidate with its associated charged hadrons in the opposite hemisphere where  $\vec{p}_T^\gamma$  and  $\vec{p}_T^h$  are respectively their transverse momentum. This measurement provides a good approximation of fragmentation function [10] in  $x_E \in [0.2-0.8]$  [11]. Experimentally the uncorrected  $\gamma$ -hadron correlation is computed using:

$$x_E^{cluster\ iso} = -\frac{p_T^h}{p_T^\gamma} \cos(\Delta\Phi) - x_E^{UE} \quad (2)$$

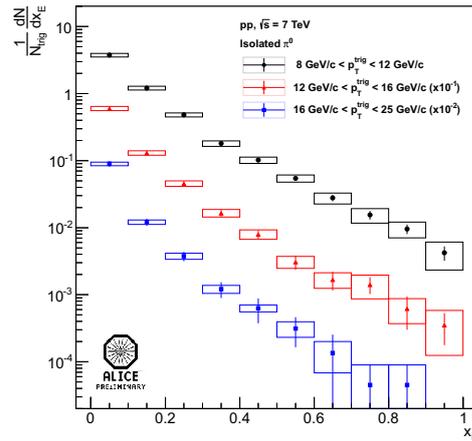
where  $\Delta\Phi = |\phi_\gamma - \phi_{hadron}|$ . Figure 1 shows the measurement of  $x_E^{cluster\ iso}$  selecting tracks within  $2\pi/3 < \Delta\Phi < 4\pi/3$  and subtracting the underlying event [12] contribution ( $x_E^{UE}$ ) estimated in  $\pi/3 < \Delta\Phi < 2\pi/3$  and  $4\pi/3 < \Delta\Phi < 5\pi/3$ . But, even after identification ( $\lambda_0^2$  cut and isolation), the direct photon candidate sample still contains a contamination that comes mainly from  $\pi^0$  decays. The following formula, where  $p$  is the purity of direct photon sample, allows to extract the  $x_E^{\gamma\ iso}$  distribution of direct photons by subtracting the isolated  $\pi^0$  contribution ( $x_E^{\pi^0\ iso}$ ):

$$x_E^{\gamma\ iso} \approx \frac{1}{p} x_E^{cluster\ iso} - \frac{(1-p)}{p} x_E^{\pi^0\ iso} \quad (3)$$

The  $x_E^{\pi^0\ iso}$  distribution shown on figure 2 has been obtained identifying clusters as  $\pi^0$  by an invariant mass analysis of distinct clusters. The purity estimation method is based on the difference of cluster shower shape profile ( $\lambda_0^2$ ) between direct photons and background particles. The signal template is estimated using  $\gamma$ -jet events simulated with PYTHIA [13] tracked through the detector using GEANT3 [14]. The background template is derived from data: the shower shape of particles that failed the isolation criterion has been used. The result presented on figure 3 shows the combined fit of background plus direct photon templates (for the bin [12-16] GeV/c). The purity is extracted from these two distributions by evaluating them in the same  $\lambda_0^2$  range

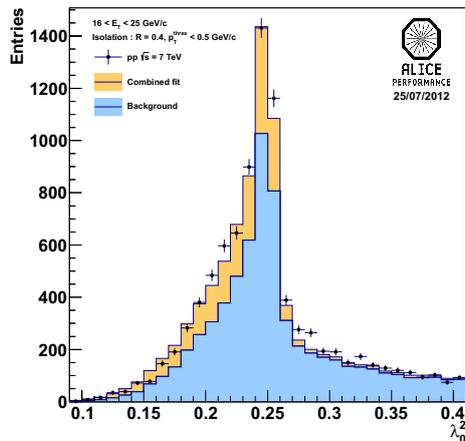


**Figure 1.**  $x_E$  distributions of isolated clusters for 3 different  $p_T$  bins [8-12], [12-16] and [16-25] GeV/c.

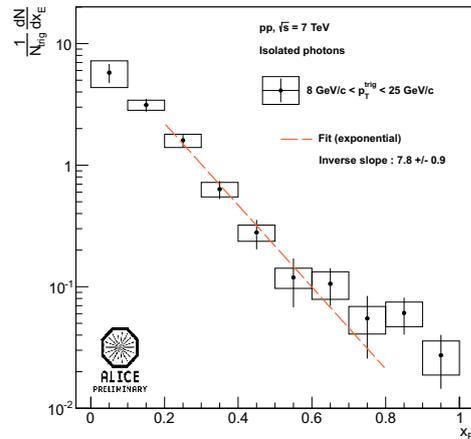


**Figure 2.**  $x_E$  distributions of isolated  $\pi^0$  for 3 different  $p_T$  bins [8-12], [12-16] and [16-25] GeV/c.

than the one used for photon selection. Finally, combining these results with formula (3) the  $x_E^{\gamma^{iso}}$  distribution is obtained (figure 4). This distribution and its exponential slope will serve as baselines to study medium induced parton fragmentation modification in Pb-Pb collisions.



**Figure 3.** Fit result of the shower shape template method for a leading particle with  $12 < p_T < 16$  GeV/c.

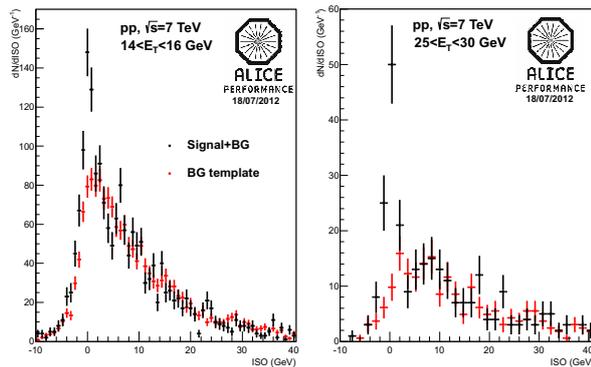


**Figure 4.**  $x_E$  distribution of isolated photons for  $p_T$  8-25 GeV/c (3 bins combined) fitted by an exponential in the range  $x_E \in [0.2-0.8]$ .

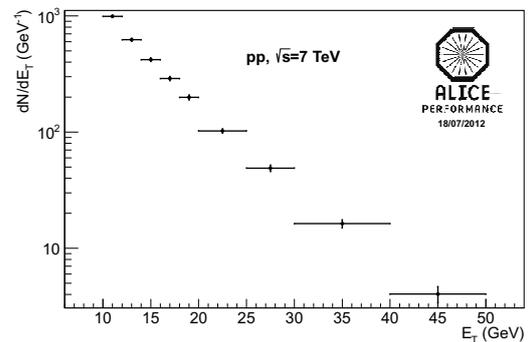
#### 4. Direct photon spectrum measurement

Beyond correlation studies, the measurement of direct photon cross-section in pp collisions is also an important goal. The complementarity of ALICE and other LHC experiments (ATLAS and CMS) in terms of energy range is valuable to test QCD predictions [15] and to strongly constrain the PDF determination. The pp isolated cluster spectrum at  $\sqrt{s} = 7$  TeV measured with ALICE is presented here. The main differences of this analysis compared to the correlation study are firstly that the full available statistics is used (less constraints on TPC acceptance) and

secondly that a strict fiducial cut ( $\Delta\eta = 0.3$  and  $\Delta\varphi = 54^\circ$ ) is established so that the isolation cone is always contained in the EMCal acceptance. Figure 5 presents the yield extraction procedure performed with a data driven method. The background template (BG) is estimated from clusters having a large shower shape ( $0.5 < \lambda_0^2 < 2$ ) and the signal plus background template (Signal+BG) comes from clusters with  $0.1 < \lambda_0^2 < 0.3$ . For both templates the  $E_T^{cone} - E_T^{UE}$  (ISO) distribution has been computed where  $E_T^{cone}$  is the transverse energy in the isolation cone and  $E_T^{UE}$  is the underlying event estimated in a different  $\eta$  range than the cone. The yield shown on figure 6 is obtained by subtracting the BG distribution (normalized with tails: ISO > 15 GeV) from the Signal+BG one. This result shows the expected performance for direct photon cross-section measurement using 2011 data. To obtain it, the next step will be to correct and normalize the raw spectrum (purity, efficiency, systematic errors).



**figure 5.** ISO distributions ( $E_T^{cone} - E_T^{UE}$ ) for signal and background for 2 different  $E_T$  bins [14-16] (left panel) [25-30] GeV (right panel).



**Figure 6.** Isolated cluster distribution for pp collisions at 7 TeV.

## 5. Conclusion

The results summarized here show the potential of the ALICE-EMCal calorimeter to provide direct photon measurements. Moreover, the direct photon imbalance parameter analysis presented gives perspective to study parton fragmentation modification in Pb-Pb collisions using  $\gamma$ -jet events. Finally a first step toward the measurement of a direct photon cross-section in pp collisions has been shown. These results, among others, will enable to quantify the medium induced modification of PDF and fragmentation functions in Pb-Pb collisions in ALICE.

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