Jet energy scale setting with \( \gamma + \text{Jet} \) events at LHC energies. Detailed study of the background suppression.

D.V. Bandourin\(^\dagger\), V.F. Konoplyanikov\(^*\), N.B. Skachkov\(^\dagger\)

E-mail: (1) dmv@cv.jinr.ru, (2) kon@cv.jinr.ru, (3) skachkov@cv.jinr.ru

\(^\dagger\) Laboratory of Nuclear Problems
\(^*\) Laboratory of Particle Physics

Abstract

The possibilities of the background events suppression, based on the QCD subprocesses of \( qg \), \( gg \), \( qq \) scattering with big cross sections, to the signal \( \gamma + \text{Jet} \) events are studied. Basing on the introduced selection criteria, the background suppression factors and signal events selection efficiencies and the number of the events, that can be collected at LHC with low luminosity \( L = 10^{33} \text{cm}^2 \text{s}^{-1} \) during one month of continuous work, are determined.
1. INTRODUCTION

This paper continues our previous publications [1–4], where possibilities of jet energy scale setting and calibration of the hadron calorimeter at LHC energies by using ”γ + Jet” process have been studied.

This article is devoted to the study of the background events suppression and to demonstration of the efficiency of the cuts introduced by us in paper [1] for this purpose.

2. ILLUSTRATION OF NEW CUTS EFFICIENCY

To estimate the background for the signal events, we have done the simulation with a mixture of all QCD and SM subprocesses existing in PYTHIA with large cross sections, namely: ISUB=1, 2, 11–20, 28–31, 53, 68, which can lead to a big background for our main ”signal” subprocesses (ISUB=14 and 29 in PYTHIA):

\[ qg \rightarrow q + \gamma \]  \hspace{1cm} (1a)\n
\[ q\bar{q} \rightarrow g + \gamma \]  \hspace{1cm} (1b)

Three generations (each of $50 \cdot 10^6$ events) with different values of minimal $p_t$ of hard process $p_{t\perp}$ have been done: the first one is with $p_{t\perp} = 40 \text{ GeV}/c$, while the second and the third – with $p_{t\perp} = 100$ and 200 $\text{GeV}/c$, respectively.

We have selected ”γ-candidate +1 Jet” events with $p_{t\perp} > 30 \text{ GeV}/c$ containing one γ-candidate to be identified by the detector as an isolated photon with $p_{t\gamma} \geq 40$ (100 and 200) $\text{GeV}/c$ for the generation with $p_{t\perp} \geq 40$ (100 and 200) $\text{GeV}/c$, respectively. One needs to stress that here and below, speaking about the γ-candidate, we imply in reality a signal that may be registered in the 3 by 3 ECAL crystal cell window with the highest $p_{t\gamma}$ in the center. All these photon-candidates were supposed to satisfy the isolation criteria 1–4 of Section 3.2 from paper [1] with $p_{t\text{cut}} = 2 \text{ GeV}/c$ and $\epsilon_{\gamma\text{cut}} = 5\%$. No special cuts were imposed on $\Delta\phi$, $p_{t\text{out}}$ and $p_{t\text{clus}}$ (the values of $p_{t\text{clus}}$ are automatically limited from the top since we select ”γ-candidate +1 jet” events with $p_{t\text{jet}} > 30 \text{ GeV}/c$).

The corresponding distributions for the physical observables, introduced in Sections 3.1 and 3.2 from [1], are shown separately for the signal ”γ - dir” and the background events in Figs. 1, 3, 5 and in scatter plots 2, 4, 6. First columns in these figures, denoted by ”γ - dir”, show the distributions in the signal events, i.e. in the events corresponding to the processes (1a) and (1b), having direct photons with $p_{t\gamma-dir} \geq 40 \text{ GeV}/c$. The second columns, denoted as ”γ - brem”, correspond to the events in which the photons were emitted from quarks (i.e. bremsstrahlung photons) and have passed under the imposed cuts. The distributions in the third column were built basing on the events containing ”γ-mes” photons, i.e. those photons that originate from multiphoton decays of mesons ($\pi^0, \eta, \omega, K^0_S$) and have also passed under the imposed cuts.

Firstly we see that in the case of $p_{t\gamma} \geq 200 \text{ GeV}/c$ (see Fig. 5) practically all ”signal events” have $\Delta\phi < 15\degree$, and in the case $p_{t\gamma} \geq 100 \text{ GeV}/c$ (see Fig. 6) most of them are also

1 PYTHIA 5.7 version with default CTEQ2L parametrisation of structure functions is used here.

2 A contribution of another possible NLO channel $gg \rightarrow g\gamma$ (ISUB=115 in PYTHIA) was found to be still negligible even at LHC energies.

3 CKIN(3) parameter in PYTHIA.
within $\Delta \phi < 15^\circ$. It is seen from Fig. 1 that at lower values $P_t^\gamma \geq 40 \ GeV/c$ there is still a big number (about 70%) of the signal events belonging to the interval of $\Delta \phi < 15^\circ$. From here we conclude that the upper cut $\Delta \phi < 15^\circ$ chosen in (26) of [1] is reasonable and indeed discards a lot of background events in all $P_t^\gamma$-intervals.

From the second "$\gamma$-brem" columns of Figs. 1, 3 and 5 one can also see that $P_t^{\text{clust}}$ spectra of the events with bremsstrahlung photons look quite different from the analogous $P_t^{\text{clust}}$ distributions of the signal "$\gamma$-dir" photons. The latter distributions have most of the events in the region of small $P_t^{\text{clust}}$ values.

Since the bremsstrahlung ("$\gamma$-brem") photons give the most sizable background, the found difference of the spectra prompts an idea of using a cut from the top on the value of $P_t^{\text{clust}}$ to reduce "$\gamma$-brem" background which dominates at large $P_t^{\text{clust}}$ values.

The analogous difference of $P_t^{\text{out}}$ spectra of signal "$\gamma$-dir" events (which also concentrate at low $P_t^{\text{out}}$ values) from those of the background "$\gamma$-brem" and "$\gamma$-mes" events, with longer tails at high $P_t^{\text{out}}$ enables us to impose an upper cut on the $P_t^{\text{out}}$ value.

Now from the scatter plots in Figs. 2, 4 and 6 as well as from Figs. 1, 3 and 5 we can conclude that the usage of cuts (rather soft here, but their further restriction will be discussed below):

- **on $\Delta \phi$:**
  - $\Delta \phi < 15^\circ$, for $P_t^\gamma \geq 40 \ GeV/c$
  - $\Delta \phi < 10^\circ$, for $P_t^\gamma \geq 100 \ GeV/c$
  - $\Delta \phi < 5^\circ$, for $P_t^\gamma \geq 200 \ GeV/c$

- **on $P_t^{\text{clust}}$:**
  - $P_t^{\text{clust}}_{\text{CUT}} = 15 \ GeV/c$, for $P_t^\gamma \geq 40 \ GeV/c$ and $P_t^\gamma \geq 100 \ GeV/c$,
  - $P_t^{\text{clust}}_{\text{CUT}} = 20 \ GeV/c$, for $P_t^\gamma \geq 200 \ GeV/c$,

- **on $P_t^{\text{out}}$:**
  - $P_t^{\text{out}}_{\text{CUT}} = 10 \ GeV/c$, for $P_t^\gamma \geq 40 \ GeV/c$ and $P_t^\gamma \geq 100 \ GeV/c$,
  - $P_t^{\text{out}}_{\text{CUT}} = 15 \ GeV/c$, for $P_t^\gamma \geq 200 \ GeV/c$

would allow to keep the main part of the signal "$\gamma$-dir" events and to reduce noticeably the contribution from the background "$\gamma$-brem" and "$\gamma$-mes" events.

So, these figures evidently demonstrate how new physical variables $P_t^{\text{clust}}$ and $P_t^{\text{out}}$, introduced in Sections 3.1 and 3.2 of paper [1], can be useful for separation of "$\gamma$+Jet" events with direct photons from the background ones (as the latter, in principle, are not supposed to have good balanced $P_t^\gamma$ and $P_t^{\text{Jet}}$).

### 3. DETAILED STUDY OF BACKGROUND SUPPRESSION.

The study of this Section is based on the same sample of “signal + background” events ($50 \cdot 10^6$ for each interval of minimal $P_t$ of the hard process: $\hat{p}_t^{\min} = 40, 100, 200 \ GeV/c$; see the beginning of Section 2) generated under the conditions described in the previous section and partially analyzed there. To demonstrate the way we have come to the final results, we
Fig. 1: Signal/Background: Number of events distribution over $P_{t\text{clust}}$, $P_{t\text{out}}$, $\Delta\phi (P_{t\gamma} \geq 40 \text{ GeV/c})$
Fig. 2: Signal/Background: $P_t^{\text{clust}}$ vs. $P_t^{\text{out}}$, $P_t^{\text{clust}}$ vs. $\Delta \phi$, $P_t^{\text{out}}$ vs. $\Delta \phi$ ($P_t^\gamma \geq 40\text{ GeV}/c$)
Fig. 3: Signal/Background: Number of events distribution over $P_t^{\text{clus}}$, $P_t^{\text{out}}$, $\Delta \phi \ (P_\gamma \geq 100 \text{ GeV}/c)$
Fig. 4: Signal/Background: $P_t^{\text{clust}}$ vs. $P_t^{\text{out}}$, $P_t^{\text{clust}}$ vs. $\Delta \phi$, $P_t^{\text{out}}$ vs. $\Delta \phi$ ($P_t^\gamma \geq 100 \text{GeV/c}$)
Fig. 5: Signal/Background: Number of events distribution over $P_{t^{\text{clust}}}$, $P_{t^{\text{out}}}$, $\Delta\phi$ ($P_{t^{\gamma}} \geq 200 \text{ GeV}/c$)
Fig. 6: Signal/Background: $P_t^{\text{clus}}$ vs. $P_t^{\text{out}}$, $P_t^{\text{clus}}$ vs. $\Delta \phi$, $P_t^{\text{out}}$ vs. $\Delta \phi$ ($P_t^\gamma \geq 200 \text{ GeV}/c$)
Table 1: List of the applied cuts used in Tables 2–5

| Cut | Description |
|-----|-------------|
| 0   | No cuts;    |
| 1a  | $P_t^{\gamma} \geq 40 \text{ GeV/c}$, $|\eta| \leq 2.61$; |
| 1b  | $P_t^{\gamma} \geq 40 \text{ GeV/c}$, $|\eta| \leq 2.61$; |
| 1c  | $P_t^{\gamma} \geq \hat{p}_\perp^{\min}$; |
| 1d  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 1e  | $P_t^{\gamma} \geq \hat{p}_\perp^{\min}$; |
| 2   | $\epsilon^{\gamma} \leq 15\%$; |
| 3   | $P_t^{\gamma} < 20 \text{ GeV/c}$; |
| 4   | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 5   | $P_t^{\gamma} < 2 \text{ GeV/c}$; |
| 6   | $P_t^{\gamma} < 2 \text{ GeV/c}$; |
| 7   | $\Delta \phi < 15^\circ$; |
| 8   | $\epsilon^{\gamma} \leq 5\%$; |
| 9   | $\Delta \phi < 15^\circ$; |
| 10  | $N_{\text{jet}} \leq 2$; |
| 11  | $N_{\text{jet}} \leq 2$; |
| 12  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 13  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 14  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 15  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 16  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 17  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 18  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 19  | $P_t^{\gamma} < 10 \text{ GeV/c}$; |
| 20  | $\epsilon^{\gamma} \leq 2\%$. |
| 21  | $\epsilon^{\gamma} \leq 2\%$. |

* $P_t$ of a hadron in the 5x5 ECAL cell window, containing $\gamma^{\text{dir}}$ candidate in the center.

** scalar sum of $P_t$ in the 5x5 ECAL cell window in the region out of a smaller 3x3 window, containing $\gamma$.

shall apply the following cuts on the observable physical variables one after another according to the list presented below. The influence of these cuts on the $S/B$ ratio is demonstrated in the following Tables 2–8. The numbers in the left-hand column (“Cut”≡“Selection”) of Table 2, that corresponds to $P_t^{\gamma} \geq 100 \text{ GeV/c}$, coincide with the numbers of cuts listed below, where for abbreviation reasons we shall denote the direct photon by “$\gamma$” as well as its candidate.

![Distribution of events over $P_t^{\gamma}$ in events with energetic $e^{\pm}$s – direct photon candidates for the cases $P_t^{e} \geq 100 \text{ GeV/c}$ and $P_t^{e} \geq 200 \text{ GeV/c}$ (here are used events satisfying cuts 1–3 of Table 1).](image)

From the first line of Table 3 we see that without imposing any cut, the number of the background events exceeds the number of the signal events, caused by (1a) and (1b) processes, by 5 orders. The relative isolation cut 2 ($\epsilon^{\gamma} \leq 15\%$) makes the $S/B$ ratio equal to 0.28. The cut 3 ($P_t^{\gamma} \geq \hat{p}_\perp^{\min}$) improves the $S/B$ ratio to 0.68. The relative isolation cut 5 and then the absolute isolation cut 6 make the $S/B$ ratio to be equal to 1.50 and 1.93,
respectively. The requirement of only one jet presence in the event (point 9) results in the value $S/B = 5.96$. The ratio $S/B$ is increased by the cut $\Delta \phi < 15^\circ$ up to the value 6.54 (point 10) and at the same time the number of signal events is decreased only by 5%. This is in agreement with the phenomenon of the concentration of events in the small $\Delta \phi$ angle at large $P_t$ values already mentioned in paper [2].

We have used the $P^{\text{miss}}_t \text{CUT}$ cut in paper [1] to reduce value of $P^{Jet}_t$ uncertainty due to possible presence of neutrino contribution to a jet. Here it is applied against the processes based (at the parton level) on the $q g \rightarrow q' + W^\pm$ and $q g \rightarrow g + W^\pm$ subprocesses with the subsequent decay $W^\pm \rightarrow e^\pm \nu$ and having for this reason a substantial $P^{\text{miss}}_t$ value. The distributions over $P^{\text{miss}}_t$ for two $P^{\text{e}}_t$ values are presented above. In the last column ($e^\pm$) of Table 2 it is shown how the $P^{\text{miss}}_t \text{CUT}$ cut effects the number of these events (point 11).

The reduction of $P^{\text{clus}}_t \text{CUT}$ value to 10 GeV/c (point 14) results in significant improvement of $S/B$ ratio up to 17.64. Further reduction of $P^{\text{out}}_t \text{CUT}$ value to 10 GeV/c (point 17) improves $S/B$ to 22.67. The jet isolation requirement $\epsilon_{\text{jet}} < 2\%$ (point 19), finally, gives $S/B = 31.05$.

Table 2: Values of significance and efficiencies for $\hat{p}^{\text{min}}_t = 100 \text{ GeV/c}$

| Cut | $S$ | $B$ | $\epsilon_{\text{eff}}(\%)$ | $\epsilon_{\text{eff}}(\%)$ | $S/B$ | $e^\pm$ |
|-----|-----|-----|--------------------------|--------------------------|-------|--------|
| 0   | 19420 | 5356.3E+6 | 0.00 | 3.9E+6 | 6 | |
| 1   | 19359 | 1151425 | 100.00 ± 0.00 | 100.00 ± 0.00 | 0.02 | 47061 |
| 2   | 18236 | 65839 | 94.20 ± 0.97 | 5.718 ± 0.023 | 0.28 | 8809 |
| 3   | 15197 | 22437 | 78.50 ± 0.85 | 1.949 ± 0.013 | 0.68 | 2507 |
| 4   | 15174 | 19005 | 78.38 ± 0.85 | 1.651 ± 0.012 | 0.80 | 2486 |
| 5   | 14140 | 9433 | 73.04 ± 0.81 | 0.819 ± 0.008 | 1.50 | 2210 |
| 6   | 8892 | 4618 | 45.93 ± 0.59 | 0.401 ± 0.006 | 1.93 | 1331 |
| 7   | 8572 | 3748 | 44.28 ± 0.57 | 0.326 ± 0.005 | 2.29 | 1174 |
| 8   | 7663 | 2488 | 39.58 ± 0.53 | 0.216 ± 0.004 | 3.08 | 921 |
| 9   | 4844 | 813 | 25.02 ± 0.40 | 0.071 ± 0.002 | 5.96 | 505 |
| 10  | 4634 | 709 | 23.94 ± 0.39 | 0.062 ± 0.002 | 6.54 | 406 |
| 11  | 4244 | 650 | 21.92 ± 0.37 | 0.056 ± 0.002 | 6.53 | 87 |
| 12  | 3261 | 345 | 16.84 ± 0.32 | 0.030 ± 0.002 | 9.45 | 53 |
| 13  | 2558 | 194 | 13.21 ± 0.28 | 0.017 ± 0.001 | 13.19 | 41 |
| 14  | 1605 | 91 | 8.29 ± 0.22 | 0.008 ± 0.001 | 17.64 | 26 |
| 15  | 1568 | 86 | 8.10 ± 0.21 | 0.007 ± 0.001 | 18.23 | 26 |
| 16  | 1477 | 77 | 7.63 ± 0.21 | 0.007 ± 0.001 | 19.18 | 25 |
| 17  | 1179 | 52 | 6.09 ± 0.18 | 0.005 ± 0.001 | 22.67 | 22 |
| 18  | 1125 | 46 | 5.81 ± 0.18 | 0.004 ± 0.001 | 24.46 | 21 |
| 19  | 683 | 22 | 3.53 ± 0.14 | 0.002 ± 0.000 | 31.05 | 13 |

* The background is considered here with no account of contribution from the "e± events"
In Table 3, the numbers in column “γ – direct” correspond, respectively, to the numbers of the signal events in column S of Table 2 in lines 1, 17 and 19 while the numbers in the 4-th column “γ – brems” correspond to the number of events with the photons radiated from quarks participating in the hard interactions (their $P_t^{clust}$ and $P_t^{out}$ distributions were presented in the central columns of Figs. 1–6 of Section 2). The columns from 5-th to 8-th of Table 3 illustrate the numbers of the events with the photons “γ – mes”, originated from π⁰, η, ω, $K^0_s$ meson decays (their distributions were shown in the right-hand columns of the same Figs. 1–6. The total number of the background events without an account of events with electrons (see last column), i.e. a sum over columns 4–8, for the same line of Table 3 is presented, correspondingly, in the column B of Table 2.

Table 3: Number of signal and background events remained after cuts (I)

| $\hat{p}_{\perp}^{\text{min}}$ (GeV/c) | Cuts | γ direct | γ brems | photons from the mesons | π⁰ | η | ω | $K^0_s$ | $e^\pm$ |
|---|---|---|---|---|---|---|---|---|---|
| 40 | Preselected | 7795 | 12951 | 104919 | 41845 | 10984 | 15058 | 4204 |
| | After cuts | 516 | 48 | 41 | 10 | 0 | 5 | 0 |
| | + jet isol. | 122 | 7 | 5 | 1 | 0 | 1 | 0 |
| 100 | Preselected | 19359 | 90022 | 658981 | 247644 | 69210 | 85568 | 47061 |
| | After cuts | 1179 | 34 | 13 | 4 | 1 | 0 | 22 |
| | + jet isol. | 683 | 15 | 5 | 2 | 0 | 0 | 13 |
| 200 | Preselected | 32629 | 207370 | 780190 | 288772 | 98015 | 89714 |
| | After cuts | 1074 | 18 | 2 | 4 | 0 | 0 | 10 |
| | + jet isol. | 916 | 16 | 1 | 4 | 0 | 0 | 8 |

Table 4: Efficiencies and significance values in events without jet isolation cut (I)

| $\hat{p}_{\perp}^{\text{min}}$ (GeV/c) | S | B | $Eff_s(\%)$ | $Eff_B(\%)$ | $S/B$ | $S/\sqrt{B}$ |
|---|---|---|---|---|---|---|
| 40 | 516 | 104 | 6.62 ± 0.30 | 0.056 ± 0.005 | 5.0 | 50.6 |
| 100 | 1179 | 52 | 6.09 ± 0.18 | 0.005 ± 0.001 | 22.7 | 163.5 |
| 200 | 1074 | 24 | 3.29 ± 0.10 | 0.002 ± 0.000 | 44.8 | 219.2 |

Table 5: Efficiencies and significance values in events with jet isolation cut (I)

| $\hat{p}_{\perp}^{\text{min}}$ (GeV/c) | S | B | $Eff_s(\%)$ | $Eff_B(\%)$ | $S/B$ | $S/\sqrt{B}$ |
|---|---|---|---|---|---|---|
| 40 | 122 | 14 | 1.57 ± 0.14 | 0.008 ± 0.002 | 8.7 | 32.6 |
| 100 | 683 | 22 | 3.53 ± 0.14 | 0.002 ± 0.000 | 31.1 | 145.6 |
| 200 | 916 | 21 | 2.81 ± 0.09 | 0.001 ± 0.000 | 43.6 | 199.9 |

The other lines of Table 3 for cases $\hat{p}_{\perp}^{\text{min}} = 40$ and $200 \text{ GeV/c}$ have the meaning analogous to those described above for $\hat{p}_{\perp}^{\text{min}} = 100 \text{ GeV/c}$.

The last column of Table 3 shows the number of the events with electrons which with non-zero probability can be detected as direct photon. The following columns of Table 2 define efficiencies $Eff_{s(B)}$ (and their errors) as a ratio of the number of signal (background) events that passed under some cut (1–19) to the number of the preselected events (1-st cut of...
this table). The last column of Table 2 contains the values of significances (without account of events with electrons). The numbers in Tables 4 and 5 accumulate in compact form the information of Table 3. So, for the middle line ($\hat{p}_{\perp\gamma} = 100 \text{ GeV/c}$ case) columns $S$ and $B$ contain the numbers of the signal and background events taken at the level of line 17 (for Table 4) and line 19 for Table 2). The column $E f f_S(B)$ includes the values of efficiencies and their errors.

| Table 6: Signal vs. background (II) |
|-------------------------------------|
| $\hat{p}_{\perp\gamma}$ (GeV/c) | Cuts          | $\gamma$ direct | $\gamma$ brem | photons from the mesons | $\pi^0$ | $\eta$ | $\omega$ | $K_L^0$ | $e^\pm$ |
|-----------------------------|---------------|-----------------|---------------|-------------------------|--------|--------|--------|--------|--------|
| 40                         | Preselected   | 7795            | 12951         | 104919                 | 41845 | 10984  | 15058  | 4204   |
| After cuts                 | 464           | 43              | 15             | 0                        | 0      | 0      | 0      |
| + jet isol.                | 109           | 7               | 2              | 0                        | 0      | 0      | 0      |
| 100                        | Preselected   | 19359           | 90022         | 658981                  | 247644 | 69210  | 85568  | 47061  |
| After cuts                 | 1061          | 31              | 9              | 0                        | 0      | 0      | 3      |
| + jet isol.                | 615           | 14              | 4              | 0                        | 0      | 0      | 2      |
| 200                        | Preselected   | 32629           | 207370        | 780190                  | 288772 | 82477  | 98015  | 89714  |
| After cuts                 | 967           | 16              | 2              | 0                        | 0      | 0      | 2      |
| + jet isol.                | 825           | 14              | 1              | 0                        | 0      | 0      | 1      |

| Table 7: Values of efficiencies and significance (II) |
|-----------------------------------------------|
| $\hat{p}_{\perp\gamma}$ (GeV/c) | $S$ | $B$ | $E f f_S$ (%) | $E f f_B$ (%) | $S/B$ | $S/\sqrt{B}$ |
|-----------------------------|-----|-----|---------------|---------------|-------|---------------|
| 40                         | 464 | 58  | 5.95 ± 0.28   | 0.031 ± 0.004 | 8.0   | 60.9          |
| 100                        | 1061| 43  | 5.48 ± 0.17   | 0.004 ± 0.001 | 24.7  | 161.8         |
| 200                        | 967 | 20  | 2.96 ± 0.10   | 0.002 ± 0.000 | 48.4  | 216.2         |

| Table 8: Values of efficiencies and significance with jet isolation cut (II) |
|-----------------------------------------------|
| $\hat{p}_{\perp\gamma}$ (GeV/c) | $S$ | $B$ | $E f f_S$ (%) | $E f f_B$ (%) | $S/B$ | $S/\sqrt{B}$ |
|-----------------------------|-----|-----|---------------|---------------|-------|---------------|
| 40                         | 109 | 9   | 1.40 ± 0.13   | 0.005 ± 0.002 | 12.1  | 36.3          |
| 100                        | 615 | 20  | 3.18 ± 0.13   | 0.003 ± 0.000 | 30.8  | 137.5         |
| 200                        | 825 | 16  | 2.53 ± 0.09   | 0.002 ± 0.000 | 51.6  | 206.3         |

From Table 6 it is seen that ratio $S/B$ grows while the $P_t\gamma$ value growing from 5.0 at $P_t\gamma \geq 40 \text{ GeV/c}$ to 44.8 at $P_t\gamma \geq 200 \text{ GeV/c}$. The jet isolation requirement (Table 5) sufficiently improves the situation at low $P_t$. In that case $S/B$ changes up to 8.7 at $P_t\gamma \geq 40 \text{ GeV/c}$ (and up to 31.1 at $P_t\gamma \geq 100 \text{ GeV/c}$). Here it is necessary to remind about the conclusion on the tendency of the selected events to contain an isolated jet: their number grows while the $P_t\gamma$ value increasing. Practically all jets with $P_t^{jet} \geq 200 \text{ GeV/c}$ are isolated (compare two last lines of Table 6).

4 taken as a ratio of the number of signal $S$ (background $B$) events, that passed under cut 17 or 19, to the number of the preselected events in the point 1 of Table 2.

5 see also Fig. 10 for $P_t\gamma \geq 300 \text{ GeV/c}$ from [1]
Up to now we have not used the rejection factors, that were found basing on the detector capability to discriminate the background. Let us discuss how the values in Tables 3–8 can be changed by taking into account the real behavior of processes in the detectors.

We have performed a detailed study (based on CMSIM GEANT simulation using 5000 generated decays of each source meson from Table 3) of difference between ECAL profiles of photon showers from mesons and those from direct photons for \( P_t^{\gamma} = 40 \div 100 \, \text{GeV}/c \). It has shown that the suppression factor of \( \eta, \omega, K^{0\pi}_o \)-mesons larger than 0.90 can be achieved with a selection efficiency of single photons taken to be 90\%. As for the photons from \( \pi^0 \) decays, the analogous estimations of the rejection efficiencies were done for the Endcap.

In Tables 3 and 6 we have not presented separately the background due to \( \gamma/jet \) misidentification because as it was shown in [9], \( \gamma \) and jet can be discriminated with a high precision and, secondly, as it was mentioned in Section 2 of this paper (see also Section 3.2 of [1]), we have defined the photon (or the candidate to be registered as the direct photon) as the signal in the \( 3 \times 3 \) ECAL crystal cell window satisfying cut conditions (17) – (22) of Section 3.2 of [1]. These cuts effectively discriminate the photons from jets.

In Section 2 it has been shown that even with moderate cuts on \( P_{t\text{clust}}^{\text{cut}} \) and \( P_{t\text{out}}^{\text{cut}} \) values the major part of the background events can be suppressed. A wide variation of these two cuts and their influence on the number of events (for \( L_{\text{int}} = 3 \, \text{fb}^{-1} \), and the corresponding values of the signal to background ratio \( S/B \), mean values of vector disbalance \( P_t^{\gamma + \text{jet}} \), the mean and the standard deviation values for \( (P_t^{\gamma} - P_t^{\text{jet}})/P_t^{\gamma} \) variable are presented in Tables 11–25 of Appendix. These tables are built after selections (1) – (11) of Table 1 in the beginning of Section 3. The jet in our 1-jet events was found by LUCELL jetfinder for the whole \( \eta \) region (\(|\eta|^{\text{cut}} < 5.0\)).

Tables 1–7 correspond to the simulation with \( \hat{p}_{t\text{min}}^{\text{cut}} = 40 \, \text{GeV}/c \), Tables 12–20 — to \( \hat{p}_{t\text{min}}^{\text{cut}} = 100 \, \text{GeV}/c \) and Tables 21–25 — to \( \hat{p}_{t\text{min}}^{\text{cut}} = 200 \, \text{GeV}/c \). The rows and columns of Tables 1–7 illustrate the influence of \( P_{t\text{clust}}^{\text{cut}} \) and \( P_{t\text{out}}^{\text{cut}} \) cut values on the quantities mentioned above, respectively.

All numbers in Tables 1–25 are received with account of the realistic efficiencies of \( \gamma^{\text{mes}} \) rejection and electron misidentification as a direct photon.

From Tables 12, 17, 22 and 23, 28, 37 we observe, first of all, noticeable reduction of the background while moving along the diagonal from the right-hand bottom corner to the left-hand upper one, i.e. with reinforcing \( P_{t\text{clust}}^{\text{cut}} \) and \( P_{t\text{out}}^{\text{cut}} \). So, we see that for \( \hat{p}_{t\text{min}}^{\text{cut}} = 40 \, \text{GeV}/c \) the ratio \( S/B \) changes in the cells along the diagonal from 3.2, if any limits on these two variables are absent, to 6.5 for \( P_{t\text{clust}}^{\text{cut}} = 10 \, \text{GeV}/c \) and \( P_{t\text{out}}^{\text{cut}} = 10 \, \text{GeV}/c \). Analogously, for \( \hat{p}_{t\text{min}}^{\text{cut}} = 200 \, \text{GeV}/c \) the ratio \( S/B \) changes from 12.5 to 48.4 with the same variation of \( P_{t\text{clust}}^{\text{cut}} \) and \( P_{t\text{out}}^{\text{cut}} \).

The second observation. The restriction of \( P_{t\text{clust}}^{\text{cut}} \) and \( P_{t\text{out}}^{\text{cut}} \) improves the calibration accuracy. Table 14 shows that the mean value of fraction \( F \equiv (P_t^{\gamma} - P_t^{\text{jet}})/P_t^{\gamma} \) variable decreases from 0.033 (the bottom right-hand corner) to 0.008 for \( P_{t\text{clust}}^{\text{cut}} = 10 \, \text{GeV}/c \) and \( P_{t\text{out}}^{\text{cut}} = 10 \, \text{GeV}/c \). Simultaneously (see Tables 15, 20 and 25 that include the standard deviation values), by this restriction one decreases noticeably (about by twice) the width of the gaussian \( \sigma(F) \).

The explanation is simple. The disbalance equation (29) from [1] contains 2 terms in the right-hand side: \((1 - \cos \Delta \phi)\) and \(P_t(O + \eta > 0)/P_t^{\gamma}\). The first one is negligibly small.
The distributions of the number of events for $L_{int} = 3 \, fb^{-1}$, the mean value of $(P_t^\gamma - P_t^{\text{Jet}})/P_t^\gamma (= \langle F \rangle)$ and its standard deviation $\sigma(F)$ for the cases of nonisolated (left-hand column) and isolated (right-hand column) jet and for three $P_t^\gamma$ intervals as functions of $P_t^{\text{out}}$ value (in GeV/c). $P_{t, \text{CUT}} = 10 \, GeV/c$.

[6, 8] and Barrel [6, 7] ECAL regions. They are of the order of 0.20 – 0.70 for Barrel and 0.51 – 0.75 for Endcap, depending on $P_t^\gamma$ and a bit on $\eta^\gamma$, for the same single photon selection efficiency 90%. Following [5], for our estimation needs we accept the electron track finding efficiency to be, on the average, equal to 85% for $P_t^e \geq 40 \, GeV/c$, neglecting its $\eta$ dependence. Then assuming the efficiencies, described above, we have recalculated the numbers in Tables 3–5. They are presented in new Tables 6–8 in the analogy with Tables 3–5 (the background ($B$) in Tables 6–8 differs from one in Tables 3–5 by including the events with electron candidates with the corresponding efficiencies). Comparing new tables with Tables 3–5 we observe the 50 – 60% growth of $S/B$ ratio for $P_t^\gamma \geq 40 \, GeV/c$ and about the 10% growth for $P_t^\gamma \geq 100 \, GeV/c$. 
and tends to decrease more with the growth of $P_t^\gamma$ (see Tables in Appendices of [3]). So, according to equation (29) of [1], the main source of the disbalance value is $P_t(O\gamma > 5)/P_t^\gamma$ term. While decreasing $P_t$ activity out of the jet this term is also decreased and, thus, the calibration accuracy is increased.

The behavior of the number of events for $L_{int} = 3 \, fb^{-1}$, the mean and standard deviation values of the $(P_t^\gamma - P_t^{\gamma,Jet})/P_t^\gamma$ variable are also displayed in Fig. 8 for isolated and nonisolated jets.

Thus, we can conclude that application of the two criteria introduced in Section 3.2 from [1], i.e. the cuts on the $P_t^{\text{clust}}$ and $P_t^{\text{out}}$ values, results in two important consequences: significant background reduction and essential improvement of the calibration accuracy.

In Tables 13, 18, 23 the changes of vector disbalance $P_t^\gamma + J\text{et}$ with variations of the cuts on the $P_t^{\text{clust}}$ and $P_t^{\text{out}}$ values are presented. The effect is also evident. The only obvious notice: the value of $P_t^\gamma + J\text{et}$ in the upper left-hand corner of these Tables (i.e., when a $P_t$ activity out of the jet region is almost suppressed), becomes approximately equal to the value of $P_t^{\eta > 5}$ component (see line “$P_t^{\eta > 5}$” in Appendices of [3]).

The numbers of events for different $P_t^{\text{clust}}$ and $P_t^{\text{out}}$ values are written in the cells of Tables 11, 16 and 21. One can see that even with such strict $P_t^{\text{clust}}$ and $P_t^{\text{out}}$ values as, i.e. $10 \, GeV/c$ for both, we would have a sufficient number of events (3 million, about 80 thousand and 4 thousand for $P_t^\gamma \geq 40 \, GeV/c$, $P_t^\gamma \geq 100 \, GeV/c$ and $P_t^\gamma \geq 200 \, GeV/c$, correspondingly) with low background contamination ($S/B = 6.5, 24.7, 48.4$) as well as good accuracy of the hadron calorimeter calibration during one month of continuous LHC running (i.e. $L_{int} = 3 \, fb^{-1}$).\footnote{Nevertheless, only full GEANT simulation would allow to come to a final conclusion.}

In addition, we also present Tables 26-40 for the case of the isolated jet by the complete analogy with Tables 11–25.

4. STUDY OF $P_t$ BALANCE DEPENDENCE ON PARTON $k_T$.

This Section is dedicated to the study of possible influence of the intrinsic parton transverse momentum on $P_t$ balance of the “$\gamma + J\text{et}$” system. For this aim we consider two different ranges of $P_t^\gamma$ (or $\hat{p}_{\perp}^{\min}$): $\hat{p}_{\perp}^{\min} \geq 40 \, GeV/c$ and $\hat{p}_{\perp}^{\min} \geq 200 \, GeV/c$. For these two $\hat{p}_{\perp}^{\min}$ values Tables \textit{1} and \textit{2} demonstrate the average values of $P_t^56$ and $P_t^{5+6}$ quantities, defined

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
$\langle k_T \rangle$ & \multicolumn{3}{c|}{ISR is OFF} & \multicolumn{3}{c|}{ISR is ON} \\
\hline
(GeV/c) & $\langle P_t^{56} \rangle$ & $\langle P_t^{5+6} \rangle$ & $\langle F \rangle$ & $\sigma(F)$ & $\langle P_t^{56} \rangle$ & $\langle P_t^{5+6} \rangle$ & $\langle F \rangle$ & $\sigma(F)$ \\
\hline
0.0 & 0.0 & 0.0 & -0.002 & 0.029 & 8.8 & 6.9 & 0.007 & 0.065 \\
1.0 & 1.8 & 1.3 & -0.001 & 0.036 & 9.1 & 7.0 & 0.009 & 0.069 \\
2.5 & 4.5 & 3.2 & 0.001 & 0.054 & 9.6 & 7.4 & 0.010 & 0.074 \\
5.0 & 8.7 & 6.1 & 0.014 & 0.089 & 10.4 & 7.2 & 0.015 & 0.088 \\
7.0 & 11.2 & 7.7 & 0.020 & 0.107 & 11.0 & 8.2 & 0.022 & 0.101 \\
\hline
\end{tabular}
\caption{Effect of $k_T$ on $P_t^\gamma - P_t^{\gamma,Jet}$ balance with $\hat{p}_{\perp}^{\min}=40 \, GeV/c$. $F = (P_t^\gamma - P_t^{\gamma,Jet})/P_t^\gamma$.}
\end{table}
Fig. 9: $(P_t^{\gamma}-P_t^{Jet})/P_t^{\gamma}$ as a function of primordial $k_T$ value for cases of switched on and switched off initial radiation and for $\vec{p}_{\perp}^{\text{min}} = 40$ and $\vec{p}_{\perp}^{\text{min}} = 200$ GeV/c.

Table 10: Effect of $k_T$ on $P_t^{\gamma}$-$P_t^{Jet}$ balance with $\vec{p}_{\perp}^{\text{min}}=200$ GeV/c. $F = (P_t^{\gamma}-P_t^{Jet})/P_t^{\gamma}$

| $\langle k_T \rangle$ (GeV/c) | ISR is OFF | ISR is ON |
|-------------------------------|------------|-----------|
|                              | $\langle P_t^{56} \rangle$ | $\langle P_t^{5+6} \rangle$ | $\langle F \rangle$ | $\sigma(F)$ | $\langle P_t^{56} \rangle$ | $\langle P_t^{5+6} \rangle$ | $\langle F \rangle$ | $\sigma(F)$ |
| 0.0                          | 0.0        | 11.1      | 8.4        | 0.010 | 0.001 |
| 1.0                          | 1.8        | 11.2      | 8.6        | 0.010 | 0.000 |
| 2.5                          | 4.5        | 11.8      | 8.8        | 0.010 | 0.000 |
| 5.0                          | 8.7        | 12.7      | 9.3        | 0.010 | 0.000 |
| 7.0                          | 11.2       | 13.9      | 10.4       | 0.002 | 0.000 |

* All numbers in the tables above are given in GeV/c units.

by (3) of [1], for two different cases: without including initial state radiation (“ISR is OFF”) and with its account (“ISR is ON”), and various values of parton $\langle k_T \rangle$: from its absence ($\langle k_T \rangle = 0$) up to $\langle k_T \rangle = 7$ GeV/c. The numbers in Tables 7 and 8 (obtained from the events set chosen by the following cuts: $\Delta \phi < 15^o$, $P_t^{\text{out}} = 5$ GeV/c and $P_t^{\text{cut}} = 10$ GeV/c) have shown that the values of $\langle P_t^{56} \rangle$ and $\langle P_t^{5+6} \rangle$ grow rapidly with $\langle k_T \rangle$ increasing if ISR is absent, in fact, with the values of $\langle k_T \rangle$. The picture changes when ISR is included. In this case the disbalance values become large already in the case of $\langle k_T \rangle = 0$: $\langle P_t^{56} \rangle = 8.8$ GeV/c at $\vec{p}_{\perp}^{\text{min}} = 40$ GeV/c and $\langle P_t^{5+6} \rangle = 11.1$ GeV/c at $\vec{p}_{\perp}^{\text{min}} = 200$ GeV/c. The values of $\langle P_t^{56} \rangle$ and $\langle P_t^{5+6} \rangle$ grow very slowly from their initial values at $\langle k_T \rangle = 0$ by $2-3$ GeV/c showing their practical independence on $\langle k_T \rangle$ in the range of its reasonable value $\langle k_T \rangle \leq 1$ GeV/c.

The size of relative disbalance $F = (P_t^{\gamma}-P_t^{Jet})/P_t^{\gamma}$ variation with $k_T$ is also shown in Tables 8 and 10 and in plots of Fig. 8. One can see that for reasonable values $\langle k_T \rangle \leq 1$ GeV/c...
1 GeV/c it is quite small.

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17
\[ \hat{p}_\perp^{\text{min}} = 40 \text{ GeV/c}. \]

Table 11: Number of events per \( L_{\text{int}} = 3 \text{ fb}^{-1} \)

| \( P_{t}^{\text{cut}} \) (GeV/c) | \( P_{t}^{\text{cut}} \) (GeV/c) | \( P_{t}^{\text{out}} \) (GeV/c) |
|---|---|---|
| 5 | 523000 | 885000 |
| 10 | 1399000 | 2994000 |
| 15 | 1598000 | 3809000 |
| 20 | 1678000 | 4112000 |
| 30 | 1739000 | 4328000 |

Table 12: \( S/B \)

| \( P_{t}^{\text{cut}} \) (GeV/c) | \( P_{t}^{\text{out}} \) (GeV/c) |
|---|---|
| 5 | 11.6 ± 4.2 |
| 10 | 8.0 ± 1.5 |
| 15 | 6.3 ± 1.1 |
| 20 | 6.1 ± 1.0 |
| 30 | 5.7 ± 0.9 |

Table 13: \( \langle P_{t}^{\gamma+Jet} \rangle \) (GeV/c)

| \( P_{t}^{\text{cut}} \) (GeV/c) | \( P_{t}^{\text{out}} \) (GeV/c) |
|---|---|
| 5 | 3.8 |
| 10 | 4.2 |
| 15 | 4.2 |
| 20 | 4.3 |
| 30 | 4.3 |

Table 14: \( \langle F \rangle, \quad F = (P_{t}^{\gamma} - P_{t}^{\text{Jet}}) / P_{t}^{\gamma} \)

| \( P_{t}^{\text{cut}} \) (GeV/c) | \( P_{t}^{\text{out}} \) (GeV/c) |
|---|---|
| 5 | 0.005 |
| 10 | 0.001 |
| 15 | 0.004 |
| 20 | 0.005 |
| 30 | 0.004 |

Table 15: \( \sigma(F), \quad F = (P_{t}^{\gamma} - P_{t}^{\text{Jet}}) / P_{t}^{\gamma} \)

| \( P_{t}^{\text{cut}} \) (GeV/c) | \( P_{t}^{\text{out}} \) (GeV/c) |
|---|---|
| 5 | 0.069 |
| 10 | 0.074 |
| 15 | 0.076 |
| 20 | 0.076 |
| 30 | 0.077 |
\[^{\prime}p_{\perp}^{\text{min}} = 100 \text{ GeV}/c.\]

Table 16: Number of events per \(L_{\text{int}} = 3 \text{ fb}^{-1}\)

| \(P_t^{\text{cut}} \) (\(\text{GeV}/c\)) | 5    | 10   | 15   | 20   | 30   | 1000 |
|--------------------------------------|------|------|------|------|------|------|
| 5                                   | 14100| 24600| 27000| 27200| 27300| 27400|
| 10                                  | 37700| 82400| 103800| 110600| 113500| 113600|
| 15                                  | 44900| 106300| 146800| 168500| 183300| 184200|
| 20                                  | 47100| 114600| 166600| 209900| 234300| 241400|
| 30                                  | 48900| 121200| 180600| 227900| 293900| 327200|

Table 17: \(S/B\)

| \(P_t^{\text{cut}} \) (\(\text{GeV}/c\)) | 5    | 10   | 15   | 20   | 30   | 1000 |
|--------------------------------------|------|------|------|------|------|------|
| 5                                   | 59.0±38.2| 44.3±19.2| 40.7±16.2| 41.0±16.4| 41.0±16.4| 41.0±16.4|
| 10                                  | 25.0±6.5| 24.7±4.6| 21.4±3.3| 20.5±3.0| 19.5±2.8| 19.8±2.8|
| 15                                  | 23.9±6.0| 19.3±2.9| 16.1±1.9| 15.2±1.6| 14.1±1.4| 14.1±1.4|
| 20                                  | 19.6±4.4| 15.9±2.1| 12.8±1.3| 12.0±1.1| 10.1±0.8| 9.9±0.8|
| 30                                  | 18.6±4.0| 13.6±1.7| 11.0±1.0| 9.2±0.7| 7.4±0.5| 6.8±0.4|

Table 18: \(\langle P_t^{\gamma+\text{Jet}} \rangle \) (\(\text{GeV}/c\))

| \(P_t^{\text{cut}} \) (\(\text{GeV}/c\)) | 5    | 10   | 15   | 20   | 30   | 1000 |
|--------------------------------------|------|------|------|------|------|------|
| 5                                   | 3.7  | 4.7  | 5.2  | 5.3  | 5.4  | 5.5  |
| 10                                  | 4.0  | 5.5  | 6.6  | 7.2  | 7.5  | 7.6  |
| 15                                  | 4.2  | 5.9  | 7.5  | 8.6  | 9.7  | 9.8  |
| 20                                  | 4.3  | 6.1  | 7.9  | 9.4  | 11.3 | 11.9 |
| 30                                  | 4.4  | 6.1  | 8.1  | 10.0 | 13.0 | 15.5 |

Table 19: \(\langle F \rangle, F = (\langle P_t^{\gamma+\text{Jet}} \rangle - \langle P_t^{\text{Jet}} \rangle) / P_t^{\gamma} \)

| \(P_t^{\text{cut}} \) (\(\text{GeV}/c\)) | 5    | 10   | 15   | 20   | 30   | 1000 |
|--------------------------------------|------|------|------|------|------|------|
| 5                                   | 0.002| 0.001| 0.003| 0.004| 0.004| 0.005|
| 10                                  | 0.002| 0.003| 0.005| 0.007| 0.008| 0.008|
| 15                                  | 0.001| 0.003| 0.006| 0.009| 0.013| 0.013|
| 20                                  | 0.002| 0.003| 0.006| 0.011| 0.016| 0.019|
| 30                                  | 0.002| 0.003| 0.005| 0.011| 0.019| 0.027|

Table 20: \(\sigma(F), F = (P_t^{\gamma+\text{Jet}} - P_t^{\text{Jet}})/P_t^{\gamma} \)

| \(P_t^{\text{cut}} \) (\(\text{GeV}/c\)) | 5    | 10   | 15   | 20   | 30   | 1000 |
|--------------------------------------|------|------|------|------|------|------|
| 5                                   | 0.028| 0.035| 0.038| 0.038| 0.039| 0.039|
| 10                                  | 0.028| 0.038| 0.046| 0.049| 0.052| 0.052|
| 15                                  | 0.029| 0.041| 0.051| 0.057| 0.065| 0.066|
| 20                                  | 0.030| 0.042| 0.053| 0.062| 0.075| 0.080|
| 30                                  | 0.030| 0.043| 0.055| 0.067| 0.087| 0.101|

19
\( \hat{p}_{\perp}^{\min} = 200 \text{ GeV}/c. \)

| \( P_{t\,\text{cut}} \) (GeV/c) | \( P_{t\,\text{out}} \) (GeV/c) |
|-----------------|-----------------|
| 5 | 10 | 15 | 20 | 30 | 1000 |
| 5 | 570 | 1090 | 1180 | 1210 | 1220 | 1230 |
| 10 | 1550 | 3830 | 4900 | 5360 | 5470 | 5490 |
| 15 | 1960 | 5060 | 7360 | 8710 | 9500 | 9630 |
| 20 | 2110 | 5590 | 8480 | 10550 | 12410 | 12990 |
| 30 | 2170 | 5880 | 9210 | 11830 | 15510 | 18270 |

Table 22: \( S/B \)

| \( P_{t\,\text{cut}} \) (GeV/c) | \( P_{t\,\text{out}} \) (GeV/c) |
|-----------------|-----------------|
| 5 | 10 | 15 | 20 | 30 | 1000 |
| 5 | 109 ± 109 | 173 ± 154 | 115 ± 82 | 118 ± 84 | 118 ± 84 |
| 10 | 50.7 ± 16.0 | 48.4 ± 13.3 | 44.1 ± 10.2 | 37.4 ± 7.6 | 38.2 ± 7.8 |
| 15 | 38.5 ± 13.2 | 44.1 ± 10.0 | 35.9 ± 6.2 | 27.9 ± 4.0 | 25.7 ± 3.4 |
| 20 | 29.3 ± 8.6 | 36.4 ± 7.2 | 26.5 ± 3.7 | 22.0 ± 2.6 | 18.8 ± 1.9 |
| 30 | 28.6 ± 8.2 | 28.2 ± 4.9 | 20.6 ± 2.5 | 17.4 ± 1.8 | 14.5 ± 1.2 |

Table 23: \( (P_{t\gamma+\text{Jet}}) \) (GeV/c)

| \( P_{t\,\text{cut}} \) (GeV/c) | \( P_{t\,\text{out}} \) (GeV/c) |
|-----------------|-----------------|
| 5 | 10 | 15 | 20 | 30 | 1000 |
| 5 | 4.0 | 5.0 | 5.4 | 5.6 | 5.7 | 6.1 |
| 10 | 4.5 | 6.0 | 7.0 | 7.8 | 8.1 | 8.2 |
| 15 | 4.6 | 6.2 | 7.9 | 9.2 | 10.4 | 10.7 |
| 20 | 4.7 | 6.3 | 8.2 | 9.9 | 11.9 | 13.0 |
| 30 | 4.7 | 6.4 | 8.5 | 10.4 | 13.7 | 17.5 |

Table 24: \( \langle F \rangle, F = (P_{t\gamma−P_{t\text{Jet}}})/P_{t\gamma} \)

| \( P_{t\,\text{cut}} \) (GeV/c) | \( P_{t\,\text{out}} \) (GeV/c) |
|-----------------|-----------------|
| 5 | 10 | 15 | 20 | 30 | 1000 |
| 5 | 0.003 | 0.003 | 0.003 | 0.004 | 0.004 | 0.005 |
| 10 | 0.001 | 0.001 | 0.004 | 0.005 | 0.005 | 0.005 |
| 15 | 0.001 | 0.003 | 0.006 | 0.007 | 0.008 | 0.008 |
| 20 | 0.001 | 0.003 | 0.005 | 0.007 | 0.008 | 0.010 |
| 30 | 0.001 | 0.003 | 0.005 | 0.007 | 0.009 | 0.014 |

Table 25: \( \sigma(F), F = (P_{t\gamma−P_{t\text{Jet}}})/P_{t\gamma} \)

| \( P_{t\,\text{cut}} \) (GeV/c) | \( P_{t\,\text{out}} \) (GeV/c) |
|-----------------|-----------------|
| 5 | 10 | 15 | 20 | 30 | 1000 |
| 5 | 0.015 | 0.018 | 0.020 | 0.021 | 0.023 | 0.026 |
| 10 | 0.016 | 0.021 | 0.024 | 0.027 | 0.028 | 0.029 |
| 15 | 0.016 | 0.021 | 0.027 | 0.031 | 0.035 | 0.037 |
| 20 | 0.016 | 0.022 | 0.028 | 0.033 | 0.040 | 0.044 |
| 30 | 0.016 | 0.022 | 0.029 | 0.035 | 0.046 | 0.057 |
\( \hat{p}_\perp^{\text{min}} = 40 \text{ GeV/c}, \quad \epsilon^{\text{jet}} < 2\% \).

Table 26: Number of events per \( L_{\text{int}} = 3 \text{ fb}^{-1} \)

| \( P_t^{\text{clust}} \) (GeV/c) | 5   | 10  | 15  | 20  | 30  | 1000 |
|-----------------|-----|-----|-----|-----|-----|------|
| 5               | 165000 | 278000 | 284000 | 284000 | 284000 | 284000 |
| 10              | 317000 | 652000 | 739000 | 772000 | 778000 | 778000 |
| 15              | 332000 | 737000 | 890000 | 970000 | 994000 | 994000 |
| 20              | 355000 | 779000 | 958000 | 1074000 | 1124000 | 1124000 |
| 30              | 361000 | 805000 | 1000000 | 1146000 | 1266000 | 1308000 |

Table 27: \( S/B \)

| \( P_t^{\text{clust}} \) (GeV/c) | 5   | 10  | 15  | 20  | 30  | 1000 |
|-----------------|-----|-----|-----|-----|-----|------|
| 5               | 8.6±5.0 | 12.6±6.5 | 12.3±6.2 | 12.3±6.2 | 12.3±6.2 | 12.3±6.2 |
| 10              | 12.1±5.7 | 9.6±3.0 | 8.2±2.1 | 7.8±2.0 | 7.8±2.0 | 7.8±2.0 |
| 15              | 11.2±5.0 | 8.8±2.5 | 7.1±1.7 | 6.6±1.5 | 6.3±1.4 | 6.4±1.4 |
| 20              | 10.8±4.6 | 7.9±2.1 | 6.7±1.5 | 6.2±1.3 | 5.9±1.2 | 6.0±1.2 |
| 30              | 11.0±4.7 | 7.1±1.8 | 6.0±1.3 | 5.6±1.1 | 5.2±0.9 | 4.9±0.9 |

Table 28: \( \langle P_t^{\gamma+\text{Jet}} \rangle \) (GeV/c)

| \( P_t^{\text{clust}} \) (GeV/c) | 5   | 10  | 15  | 20  | 30  | 1000 |
|-----------------|-----|-----|-----|-----|-----|------|
| 5               | 4.1 | 4.5 | 4.7 | 4.7 | 4.7 | 4.7 |
| 10              | 4.5 | 5.4 | 6.0 | 6.2 | 6.4 | 6.4 |
| 15              | 4.4 | 5.5 | 6.4 | 7.1 | 7.4 | 7.4 |
| 20              | 4.3 | 5.5 | 6.4 | 7.4 | 8.0 | 8.0 |
| 30              | 4.3 | 5.5 | 6.6 | 7.7 | 9.2 | 10.0 |

Table 29: \( \langle F \rangle, F = (P_t^{\gamma} - P_t^{\text{Jet}})/P_t^{\gamma} \)

| \( P_t^{\text{clust}} \) (GeV/c) | 5   | 10  | 15  | 20  | 30  | 1000 |
|-----------------|-----|-----|-----|-----|-----|------|
| 5               | -0.004 | -0.009 | -0.007 | -0.007 | -0.007 | -0.007 |
| 10              | -0.009 | -0.015 | -0.018 | -0.022 | -0.023 | -0.023 |
| 15              | -0.007 | -0.013 | -0.015 | -0.021 | -0.027 | -0.027 |
| 20              | -0.006 | -0.011 | -0.013 | -0.017 | -0.021 | -0.021 |
| 30              | -0.006 | -0.012 | -0.012 | -0.016 | -0.025 | -0.033 |

Table 30: \( \sigma(F), F = (P_t^{\gamma} - P_t^{\text{Jet}})/P_t^{\gamma} \)

| \( P_t^{\text{clust}} \) (GeV/c) | 5   | 10  | 15  | 20  | 30  | 1000 |
|-----------------|-----|-----|-----|-----|-----|------|
| 5               | 0.073 | 0.080 | 0.082 | 0.082 | 0.082 | 0.082 |
| 10              | 0.073 | 0.086 | 0.090 | 0.096 | 0.096 | 0.096 |
| 15              | 0.074 | 0.088 | 0.098 | 0.115 | 0.119 | 0.119 |
| 20              | 0.073 | 0.087 | 0.098 | 0.120 | 0.131 | 0.131 |
| 30              | 0.072 | 0.089 | 0.102 | 0.129 | 0.153 | 0.158 |
\[ \hat{p}_\perp^{\text{min}} = 100 \text{ GeV/c}, \quad \epsilon^{\text{jet}} < 2\%. \]

Table 31: Number of events per \( L_{\text{int}} = 3 \text{ fb}^{-1} \)

| \( P_t^{\text{cut}} \) (GeV/c) | \( P_t^{\text{cut}} = 5 \) | \( P_t^{\text{cut}} = 10 \) | \( P_t^{\text{cut}} = 15 \) | \( P_t^{\text{cut}} = 20 \) | \( P_t^{\text{cut}} = 30 \) | \( P_t^{\text{cut}} = 1000 \) |
|-----------------|---------|---------|---------|---------|---------|---------|
| 5               | 9900    | 15600   | 16900   | 17000   | 17000   | 17000   |
| 10              | 22700   | 47400   | 57700   | 60400   | 61500   | 61500   |
| 15              | 26600   | 59500   | 77700   | 86400   | 92100   | 92600   |
| 20              | 27800   | 63100   | 86100   | 99700   | 112600  | 114500  |
| 30              | 28300   | 65500   | 91600   | 108700  | 134200  | 144300  |

Table 32: \( S/B \)

| \( P_t^{\text{cut}} \) (GeV/c) | \( P_t^{\text{cut}} = 5 \) | \( P_t^{\text{cut}} = 10 \) | \( P_t^{\text{cut}} = 15 \) | \( P_t^{\text{cut}} = 20 \) | \( P_t^{\text{cut}} = 30 \) | \( P_t^{\text{cut}} = 1000 \) |
|-----------------|---------|---------|---------|---------|---------|---------|
| 5               | 58.6±45.2 | 56.8±34.4 | 55.8±32.2 | 56.0±32.3 | 56.0±32.3 | 56.0±32.3 |
| 10              | 30.6±11.8 | 30.8±8.4  | 26.7±5.7  | 27.9±6.0  | 27.3±5.8  | 27.3±5.8  |
| 15              | 32.8±12.0 | 26.5±6.0  | 21.2±3.8  | 22.2±3.9  | 20.8±3.4  | 21.1±3.4  |
| 20              | 29.0±9.9  | 21.6±4.3  | 17.2±2.7  | 17.8±2.7  | 15.5±2.1  | 15.7±2.1  |
| 30              | 27.4±9.1  | 19.7±3.8  | 16.2±2.4  | 15.4±2.1  | 12.2±1.4  | 11.5±1.2  |

Table 33: \( \langle P_t^{\gamma+\text{Jet}} \rangle \) (GeV/c)

| \( P_t^{\text{cut}} \) (GeV/c) | \( P_t^{\text{out}} = 5 \) | \( P_t^{\text{out}} = 10 \) | \( P_t^{\text{out}} = 15 \) | \( P_t^{\text{out}} = 20 \) | \( P_t^{\text{out}} = 30 \) | \( P_t^{\text{out}} = 1000 \) |
|-----------------|---------|---------|---------|---------|---------|---------|
| 5               | 3.5     | 4.5     | 5.0     | 5.0     | 5.0     | 5.0     |
| 10              | 3.9     | 5.3     | 6.4     | 6.8     | 7.0     | 7.0     |
| 15              | 4.1     | 5.7     | 7.1     | 8.1     | 8.9     | 9.0     |
| 20              | 4.3     | 5.9     | 7.5     | 8.7     | 10.2    | 10.6    |
| 30              | 4.3     | 5.9     | 7.7     | 9.1     | 11.8    | 13.4    |

Table 34: \( \langle F \rangle \), \( F = (P_t^{\gamma}-P_t^{\text{Jet}})/P_t^{\gamma} \)

| \( P_t^{\text{cut}} \) (GeV/c) | \( P_t^{\text{out}} = 5 \) | \( P_t^{\text{out}} = 10 \) | \( P_t^{\text{out}} = 15 \) | \( P_t^{\text{out}} = 20 \) | \( P_t^{\text{out}} = 30 \) | \( P_t^{\text{out}} = 1000 \) |
|-----------------|---------|---------|---------|---------|---------|---------|
| 5               | 0.000   | -0.002  | -0.001  | -0.002  | -0.002  | -0.002  |
| 10              | 0.001   | 0.000   | -0.002  | -0.002  | -0.002  | -0.002  |
| 15              | 0.001   | -0.001  | -0.003  | -0.003  | -0.003  | -0.003  |
| 20              | 0.001   | -0.004  | -0.003  | -0.002  | -0.002  | -0.003  |
| 30              | 0.001   | -0.002  | -0.004  | -0.004  | -0.004  | -0.004  |

Table 35: \( \sigma(F) \), \( F = (P_t^{\gamma}-P_t^{\text{Jet}})/P_t^{\gamma} \)

| \( P_t^{\text{cut}} \) (GeV/c) | \( P_t^{\text{out}} = 5 \) | \( P_t^{\text{out}} = 10 \) | \( P_t^{\text{out}} = 15 \) | \( P_t^{\text{out}} = 20 \) | \( P_t^{\text{out}} = 30 \) | \( P_t^{\text{out}} = 1000 \) |
|-----------------|---------|---------|---------|---------|---------|---------|
| 5               | 0.025   | 0.033   | 0.035   | 0.035   | 0.035   | 0.035   |
| 10              | 0.026   | 0.036   | 0.042   | 0.044   | 0.046   | 0.046   |
| 15              | 0.027   | 0.037   | 0.045   | 0.052   | 0.056   | 0.057   |
| 20              | 0.028   | 0.038   | 0.046   | 0.056   | 0.064   | 0.067   |
| 30              | 0.028   | 0.038   | 0.047   | 0.059   | 0.076   | 0.086   |
\[ \hat{p}_{\perp}^{\text{min}} = 200 \text{ GeV/c}, \quad \epsilon^{\text{jet}} < 2\%. \]

Table 36: Number of events per \( L_{\text{int}} = 3 \text{ fb}^{-1} \)

| \( P_t^{\text{clus}} \) (GeV/c) | 5    | 10   | 15   | 20   | 30   | 1000 |
|-------------------------------|------|------|------|------|------|------|
| 5                             | 540  | 1000 | 1090 | 1120 | 1120 | 1130 |
| 10                            | 1380 | 3260 | 4130 | 4480 | 4550 | 4560 |
| 15                            | 1710 | 4200 | 5980 | 6900 | 7410 | 7460 |
| 20                            | 1800 | 4570 | 6730 | 8150 | 9340 | 9650 |
| 30                            | 1840 | 4770 | 7200 | 8970 | 11240| 12680|

Table 37: \( S/B \)

| \( P_t^{\text{clus}} \) (GeV/c) | 5    | 10   | 15   | 20   | 30   | 1000 |
|-------------------------------|------|------|------|------|------|------|
| 5                             | 104\(\pm 104\) | 177\(\pm 167\) | 114\(\pm 84\) | 116\(\pm 85\) | 116\(\pm 85\) | 116\(\pm 85\) |
| 10                            | 45.6\(\pm 20.0\) | 51.6\(\pm 14.9\) | 45.4\(\pm 11.2\) | 41.7\(\pm 9.7\) | 41.7\(\pm 9.7\) | 42.4\(\pm 9.7\) |
| 15                            | 39.8\(\pm 14.8\) | 45.6\(\pm 11.5\) | 41.5\(\pm 8.4\) | 33.8\(\pm 5.8\) | 30.4\(\pm 4.9\) | 21.4\(\pm 2.6\) |
| 20                            | 34.8\(\pm 11.9\) | 40.0\(\pm 9.1\) | 33.1\(\pm 5.7\) | 27.9\(\pm 4.1\) | 23.2\(\pm 3.0\) | 21.4\(\pm 2.6\) |
| 30                            | 35.7\(\pm 12.2\) | 33.2\(\pm 6.9\) | 27.3\(\pm 4.2\) | 22.9\(\pm 3.0\) | 19.1\(\pm 2.1\) | 16.4\(\pm 1.6\) |

Table 38: \( \langle P_t^{\gamma+\text{Jet}} \rangle \) (GeV/c)

| \( P_t^{\text{clus}} \) (GeV/c) | 5    | 10   | 15   | 20   | 30   | 1000 |
|-------------------------------|------|------|------|------|------|------|
| 5                             | 4.0  | 4.8  | 5.3  | 5.4  | 5.5  | 5.8  |
| 10                            | 4.5  | 5.9  | 6.9  | 7.6  | 7.8  | 7.9  |
| 15                            | 4.6  | 6.1  | 7.7  | 8.9  | 9.8  | 10.0 |
| 20                            | 4.7  | 6.3  | 8.0  | 9.5  | 11.2 | 12.0 |
| 30                            | 4.7  | 6.3  | 8.2  | 9.9  | 12.8 | 15.7 |

Table 39: \( \langle F \rangle \), \( F = (P_t^{\gamma} - P_t^{\text{Jet}})/P_t^{\gamma} \)

| \( P_t^{\text{clus}} \) (GeV/c) | 5    | 10   | 15   | 20   | 30   | 1000 |
|-------------------------------|------|------|------|------|------|------|
| 5                             | 0.003| 0.002| 0.003| 0.003| 0.003| 0.003|
| 10                            | 0.001| 0.002| 0.003| 0.003| 0.003| 0.003|
| 15                            | 0.001| 0.002| 0.004| 0.004| 0.004| 0.004|
| 20                            | 0.001| 0.002| 0.003| 0.004| 0.003| 0.003|
| 30                            | 0.001| 0.002| 0.003| 0.004| 0.003| 0.002|

Table 40: \( \sigma(F) \), \( F = (P_t^{\gamma} - P_t^{\text{Jet}})/P_t^{\gamma} \)

| \( P_t^{\text{clus}} \) (GeV/c) | 5    | 10   | 15   | 20   | 30   | 1000 |
|-------------------------------|------|------|------|------|------|------|
| 5                             | 0.015| 0.018| 0.020| 0.021| 0.022| 0.023|
| 10                            | 0.016| 0.020| 0.023| 0.026| 0.027| 0.027|
| 15                            | 0.016| 0.021| 0.026| 0.030| 0.033| 0.034|
| 20                            | 0.016| 0.021| 0.027| 0.031| 0.038| 0.041|
| 30                            | 0.016| 0.021| 0.027| 0.033| 0.043| 0.050|