CDF note 8623

Production of photons and b jets in CDF using a dedicated trigger

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We present a measurement of photon+b-jet production cross section using the CDF-II detector at Fermilab. In contrast with previous analyses performed on the same final state, this study is based on a dedicated dataset collected with a specific trigger. The on-line tracking capabilities of CDF II allow the measurement of the track impact parameter with a precision comparable to what is obtained off-line. Specific triggers have been designed to exploit this capability and produce b-specific datasets, including a trigger that requires a track with large impact parameter and a photon-like object of transverse energy larger than 12 GeV. The analysis of this dataset, presented in this note, allows therefore to extend considerably the phase space of the photon+b production from photon transverse energies of 25 GeV (as was the case for previously used datasets, that have no track requirements) to less than half this value.

I. INTRODUCTION

Most of the hypotheses for new physics involve production of very heavy particles that decay into more standard constituents such as vector bosons, quarks, or photons. In particular, production of heavy quarks is favored by most theories, and photons are a common decay product of radiative decays of heavy states.

The photon + heavy flavor system is promising to look for deviations from the standard model; as an example, it is expected to receive contributions from SUSY models with production of chargino-neutralino pairs $\tilde{\chi_1}^+\tilde{\chi}_2^0$ decaying into $bc\tilde{\chi}_1^0\gamma\tilde{\chi}_1^0$ through intermediate stop production, initially invoked to explain the anomalous event with two electrons, two photons and missing energy observed in Run I [1].

Even if no deviations from the standard model are observed, production of heavy quarks and photons is an interesting process to study in the framework of QCD. The cross section for this process is sensitive to the b-quark content of the proton, whose PDF is only indirectly extracted from gluon density measurements. Even if the present Tevatron statistics is not sufficient to use this measurement to measure PDF's, it can be used as an experimental cross-check of these extrapolations [2].

II. ANALYSIS STRATEGY

The main trigger used for this analysis requires a photon with transverse energy larger than 12 GeV, a jet with transverse energy larger than 20 GeV, and a track that has been identified by the online tracker (SVT) to have an impact parameter larger than 120 μm and a transverse momentum larger than 2 GeV. The analysis is performed in parallel on another dataset, and the comparison of the two is used to measure the trigger efficiency. This unbiased dataset has no requirements on the track nor the jet, but just a photon (using the same photon identification cuts as the previous trigger), with a transverse energy of at least 25 GeV. If we assume that there is no correlation between the photon and the hadronic part of the event, it is possible to factorize the efficiency of the photon identification and of the requirement to have the track with large impact patameter, so the efficiency of the tighter trigger with respect to the looser one can be measured directly from data, as the percentage of events with the SVT-based bit on the unbiased-photon dataset where the photon is in the barrel region. Measuring the efficiency of the SVT-part of the trigger as the ratio in the overlap region with a much simpler trigger system removes the necessity of relying onto a complex simulation of the SVT, to account for different trigger configuration for various running periods, and to use specific b-tagging efficiency scale factors. In practice the analysis can be performed in the "traditional" way using unbiased quantities, then applying the trigger correction factors found in the high photon E_T region to the whole range. Since this correction will be as a function of jet E_T, also the correlation between photon and jet E_T is correctly taken into account.

The analysis is performed in 13 transverse energy bins, both for photon and jet. Raws and columns of this square matrix are multiplied by efficiencies and purities for jet and photon quantities, respectively, and background is subtracted on a bin-by-bin basis.

III. DETAILED IMPLEMENTATION OF THE TRIGGERS

We consider data taken between February 2002 and April 2003 for a total integrated luminosity of 208$\pm$ 12 pb^{-1}. The unbiased photon trigger requires a photon with a minimal transverse energy of 25 GeV and the following isolation cuts:

- $E_{Had}/E_{Em} < 0.125$
- Isolation $E_T < 3.0$ GeV OR Isolation $E_T < 0.1 \times E_T$

The Isolation E_T is calculated by dedicated trigger cards from calorimeter towers nearby that of maximal energy deposition. This dataset has no cuts on the track nor on the jet, has the advantage of a high trigger efficiency, relatively easy to calculate, for photons above 25 GeV both in barrel and in the plug region. It has been used by the first analysis of this channel on Run II [3], following a similar approach to what was done for the Run I analysis [4]. Applying at trigger level some requirements on the jet part can lower the 25 GeV threshold. The dataset used in this analysis has been explicitly designed to exploit the information from the SVT and the jet requirements to push the photon threshold down to 12 GeV. Already at Level 2 events have to pass combined cuts on the photon and the large impact-parameter track. Track requirements are the following:

- $\chi^2 < 25$

- $p_T > 2$ GeV
- 120 $\mu m < d_0 < 1$ mm

where d_0 is the track impact parameter. During data taking, these initial cuts have been modified to reduce the trigger bandwidth; the two subsequent versions have as further requirements:

- Isolation < 1 GeV (no E_T dependence)
- χ^2 of SVT tracks < 15

At level 3, more detailed isolation requirements are imposed on the photon, and two additional requirements are present on the hadronic part:

- a JetClu jets (radius 0.4) with E_T >10 GeV
- a Level 3 track is matched ($\Delta d_0(L3 - SVT) < 0.015$, $\Delta curv(L3 - SVT)$ <0.00015) with the SVT track

The last cut is performed looping over all combinations between tracks identified by the online trigger tracker (SVT) and those obtained by the Level 3 processors, that are running the same algorithm as the offline, and requires that at least one Level 3 track is matched to the SVT one in terms of difference of d_0 and curvature. This requirement largely reduces the number of fake tracks coming from random hit coincidences in the SVT.

In the same period when the Level 2 trigger code was switched to the tighter version, an additional Level 3 requirement on the matched track is imposed:

- impact parameter at Level 3 > 80 μm.

The trigger efficiency is calculated as the fraction of events passing the dedicated trigger with respect to those with a photon in the barrel passing the unbiased trigger. This efficiency, as a function of jet E_T, is shown in figure 1.

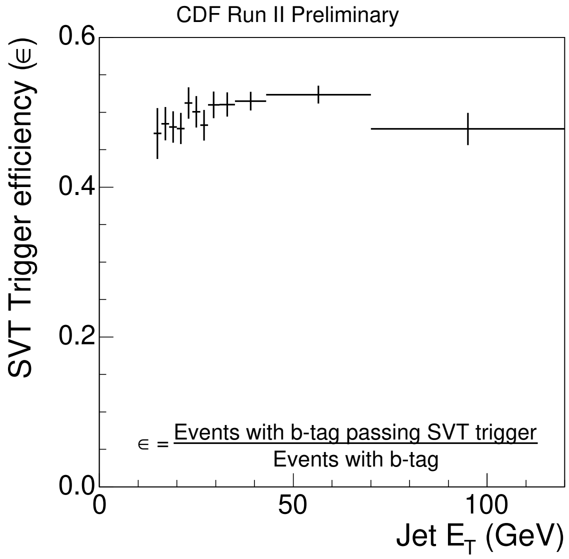

FIG. 1: Efficiency of the impact parameter trigger cut, calculated as the fraction of events passing the impact parameter-based trigger to those passing the unbiased photon trigger, as a function of jet E_T.

IV. PHOTON SELECTION

The fiducial region for this measurement is $|\eta| < 1.5$ for jets and $|\eta| < 1.1$ for photons. The photon and the jet are also required to have $\Delta R > 0.7$. The analysis requires the events to have a tagged jet with corrected transverse energy larger than 20 GeV, and a photon with corrected transverse energy larger than 12 GeV, in their respective fiducial regions and with the required separation. To reject the large π^0 background, standard CDF photon cuts are used. They require the photon to be an isolated electromagnetic object, with small hadronic activity, no nearby track compatible with the cluster energy and that this photon is quite central with respect to the calorimeter tower. The efficiency as a function of photon E_T is shown in figure 2. This efficiency is calculated from the Monte Carlo, and can be split in two parts: the probability of finding an electromagnetic object within $\Delta R < 0.1$ of the generated photon, and the probability for this object to pass the standard trigger and photon identification cuts. This latter presents some discontinuities as a function of E_T, since the cuts to insure the photon to be central inside each calorimeter tower are energy-dependent. These cuts are however necessary if we want to use the information from the shower shape detectors inside the calorimeter to determine the photon purity. Information of shape in the preshower and in the shower maximum detectors are compared to standard shapes taken from test-beam data and used to create weights for the cluster to be a real photon. These weights can be also used to calculate the statistical error on the method, that will account for the reduced purity of the photon sample. The fraction of true photons as a function of photon E_T is given in figure 3.

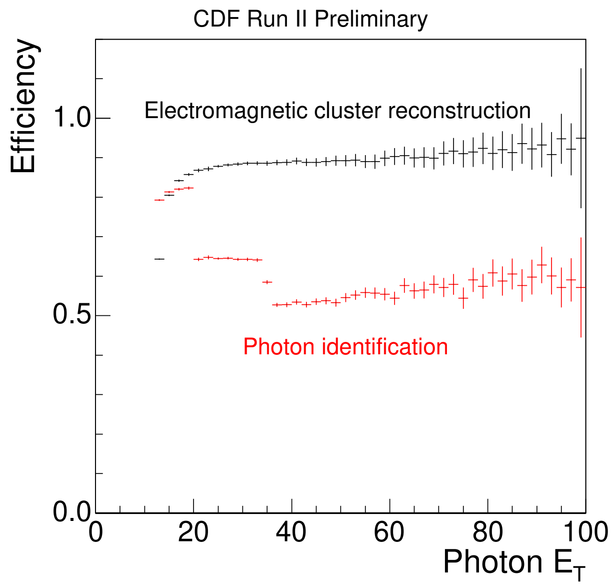

FIG. 2: The two contributions to the photon efficiency as a function of photon E_T

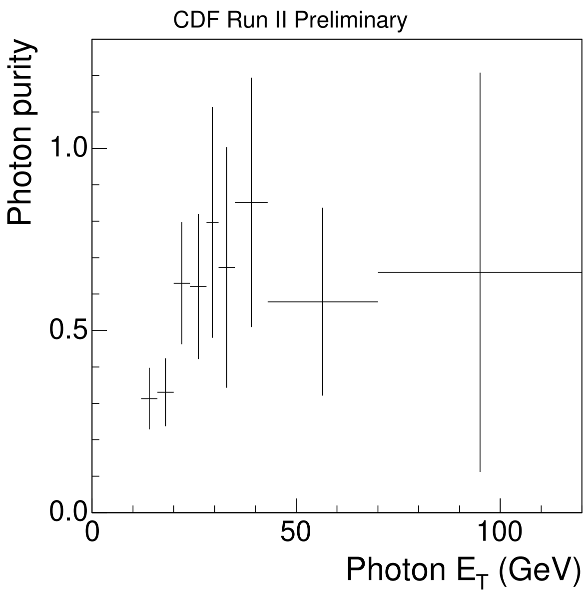

FIG. 3: Photon purity estimated from the CES/CPR methods, as a function of photon E_T.

Jet efficiency is calculated as the ratio of the energy distribution of hadron-level jets in the fiducial volume and that of reconstructed ones within a 0.4 cone size of the generated one. This efficiency is shown in figure 4 for charm (blue) and beauty quarks (black).

V. DETERMINATION OF THE B FRACTION FOR THE VARIOUS SAMPLES

The percentage of b jets in the tagged sample is determined, as in similar analyses, fitting the invariant mass of the tracks coming from the secondary vertex with mass templates determined from Monte Carlo. Since the vertex mass depends on jet E_T, especially for b quarks, the Monte Carlo templates have been generated for the jet E_T bins used in the analysis. We fit the invariant mass distribution of our candidate events to extract the light, charm and beauty fractions as a function of jet E_T. The results are shown in figure 5, for b-photon candidates (blue) as well as normal QCD events from the Jet20 dataset (green). The invariant masse distributions for b-photon data events are shown in figure 6, together with the result of the fit from the Monte Carlo.

VI. B-PHOTON RESULTS

We just saw from figure 5 that the b fraction for b-photon events is different from that of normal QCD events. This has to be taken into account in the determination of our cross-section, since QCD events with an energetic π^0

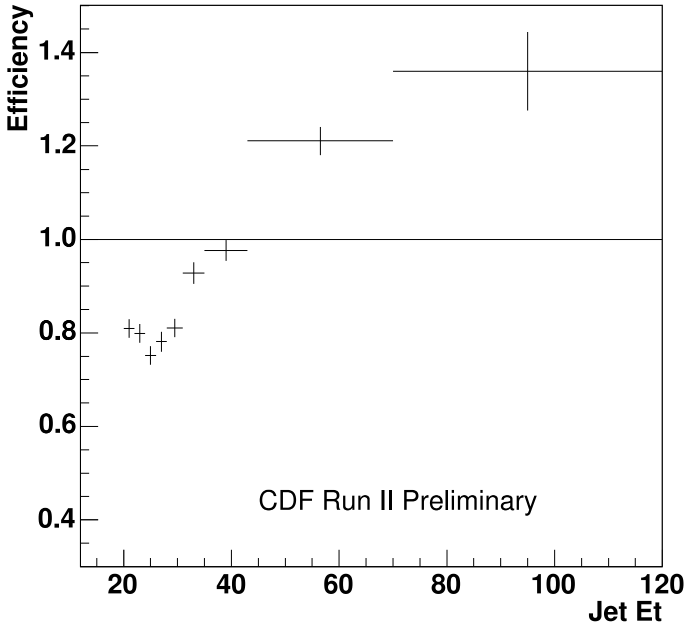

FIG. 4: Jet efficiency calculated as the ratio of the transverse energy distribution for generated and reconstructed jets associated to beauty quarks

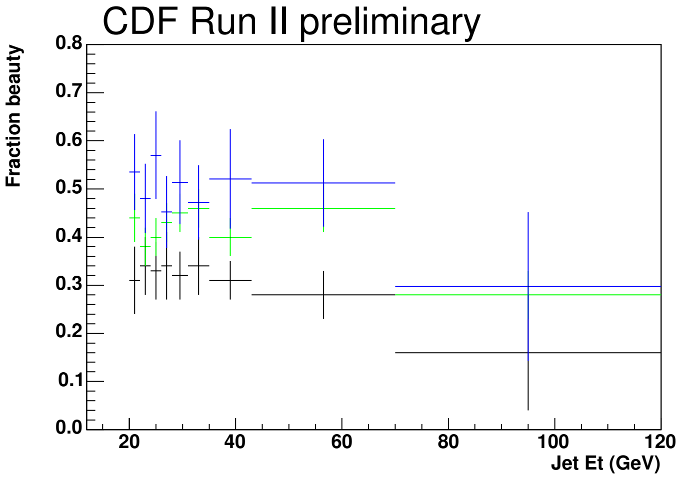

FIG. 5: Fraction beauty quarks in tagged jets for b-photon events (blue) as well as QCD events from Jet20 dataset (green) and b-photon Monte Carlo (black), as a function of jet E_T.

are the main source of background to our photon sample. We assume that the b fraction of events with an energetic π^0 is the same as generic QCD events. If we define as c_1 the total number of candidates found in a given (E_T^γ, E_T^{jet}) bin, c_γ the expected number of photons in that bin from the CES/CPR methods, f_b^{ISO} and f_b^{QCD} the respective b fractions, the number of b candidates in that bin will be

$$N_b = \frac{f_b^{ISO} \times c_1 - (f_b^{QCD} \times (c_1 - c_\gamma))}{\epsilon_{ISO}^{tag}}$$

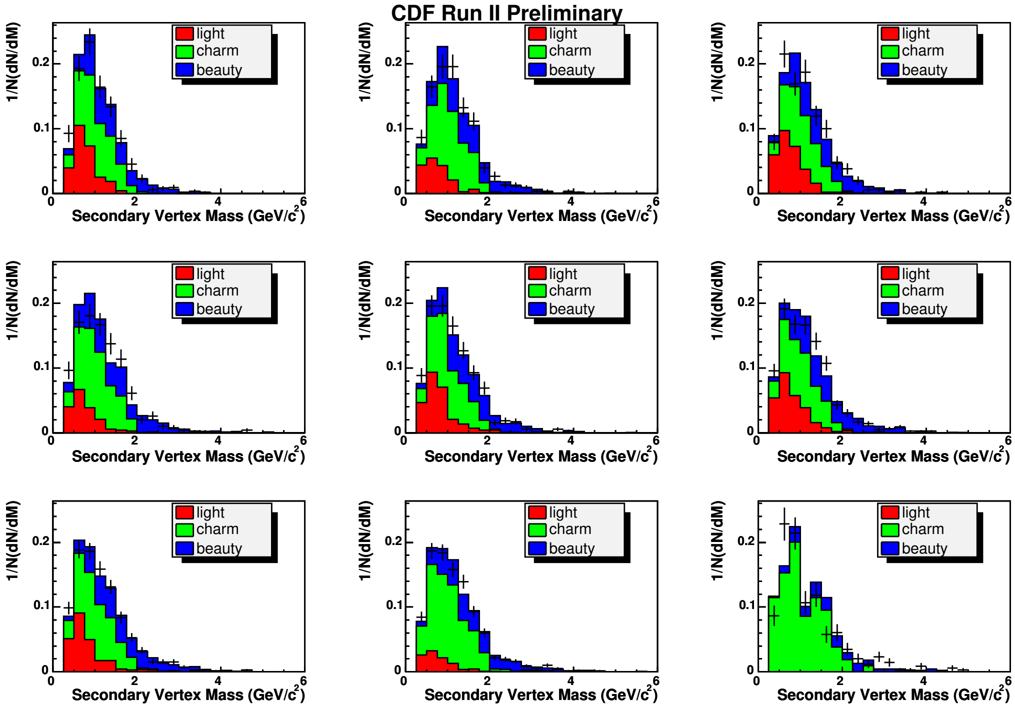

FIG. 6: Invariant masses for the jet E_T ranges considered (starting from 20 GeV) for b-photon data (crosses) and the result of the fit to Monte Carlo template(solid histograms)

The tagging efficiency ϵ_{ISO}^{tag} is extracted from Monte Carlo and shown in figure 7, similar to what was found by other groups in similar measurements. This efficiency includes a scale factor of 0.91 ± 0.03 [6], to account for the different b-tagging efficiency found between data and Monte Carlo on b-enriched samples tagged with leptons.

Statistical errors from the CES/CPR methods for photon purity, from the determination of the b fraction and of the trigger efficiency are propagated to each bin and then summed up. Finally, the measured cross section for production of b jets with $|\eta| < 1.5$ and $E_t > 20$ GeV and photons with $|\eta| < 1.1$ and $E_t > 12$ GeV is found to be 90.5$\pm$ 6.0 pb, to be compared to a theoretical prediction (Pythia) of 69.3 pb. The differential cross sections as a function of photon and jet E_T are shown in figures 8 and 9 respectively, together with predictions from Pythia.

VII. CROSS-CHECKS

The analysis is based on the assumption that the jet characteristics are the same independently of the photon energy. The extrapolation of the quantities calculated for photon energies above 25 GeV to lower values can be tested comparing for instance the b fraction obtained from the vertex mass fit for events with photon E_T above and below 25 GeV. These quantities are shown in figure 10, and no relevant difference is observed.

We also checked the stability of the cross section as a function of run number, and do not notice any relevant variation within the list of good runs used to perform the measurement.

VIII. SYSTEMATIC UNCERTAINTIES

A cross section measurement is directly sensitive to systematic effects due to luminosity uncertainty ($\pm$6%). This measurement is also directly sensitive to the uncertainty in the determination of the scale factor for the b-tagging ($\pm$3%). Jets originated by gluon splitting can have a b pair reconstructed as a single b jet. It was studied in [7] that the b-tagging efficiency for such events is about 20% larger than for events containing a single b; however the percentage of those events is relatively small and does not change too much between Pythia and NLO estimation, and the systematic error assigned to this effect is 2%. The determination of the b fraction using mass templates is very sensitive to the good understanding of the mass scale and track multiplicity. A 3% measured difference in tracking

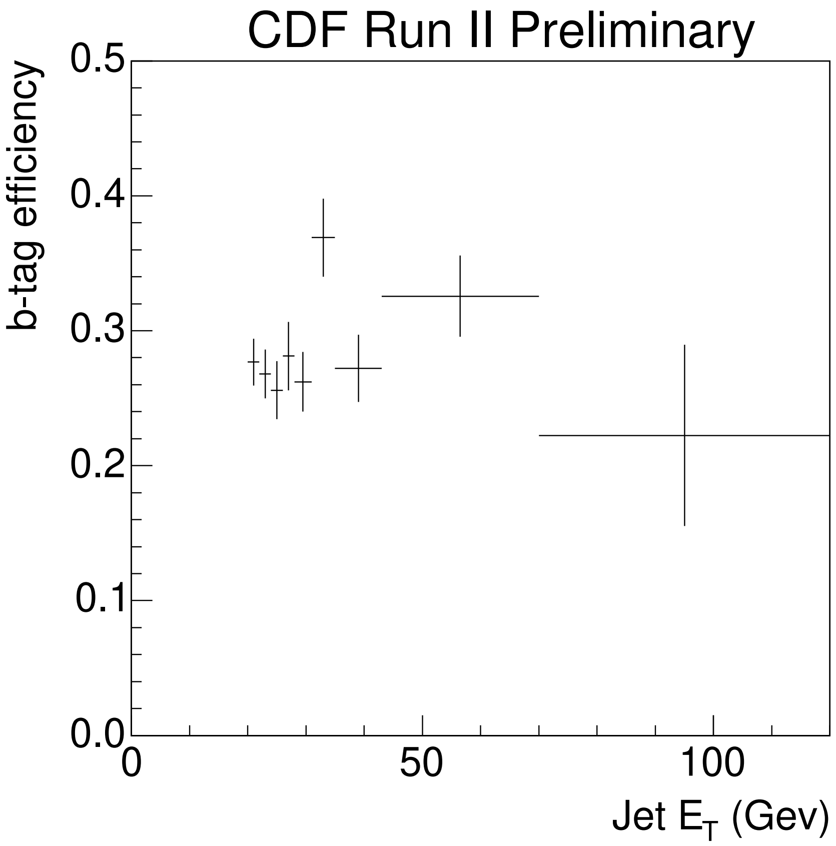

FIG. 7: Tagging efficiency for beauty quarks

efficiency between data and Monte Carlo has been reported for this data taking period [8]. Taking the full difference as a systematics, this leads to the largest uncertainty of this measurement ($+20\%, -10\%$, on average 15%). Another systematics comes from the uncertainty on the jet energy scale. Varying by $\pm 1\sigma$ the jet energy scale, the measured total cross section varies by $\pm 4\%$. We assign a $\pm 10\%$ conservative error on the extrapolation of the trigger efficiency in the signal region. The error associated to the CPR/CES information to get the photon background estimate is obtained by the CPR/CES method themselves and is around $\pm 5\%$, while that for the photon efficiency comes from a study of electrons from Z decays [9] and is $\pm 1\%$. Summing all these errors in quadrature, i.e. assuming they are independent, we have an asymmetric systematic error of +24% -17%, shown as a rectangular light blue boxes in figures 8 and 9.

IX. CONCLUSIONS

The use of the online tracking in high-p_T measurements opens the way to lowering trigger thresholds in channels involving heavy flavor productions. The difficulty of a precise understanding of the trigger can be overcome using a control sample with large overlap with the dataset under investigation. For this measurement, the unbiased dataset only requiring the presence of a high-E_T photon is used to determine the trigger efficiency. Like many similar measurements, the total cross section is already systematics-dominated with about 208 pb^{-1} of collected data. The measured cross section is 90.5 $\pm$6.0 (stat.) $^{+21.7}_{-15.4}$ (syst.) pb.

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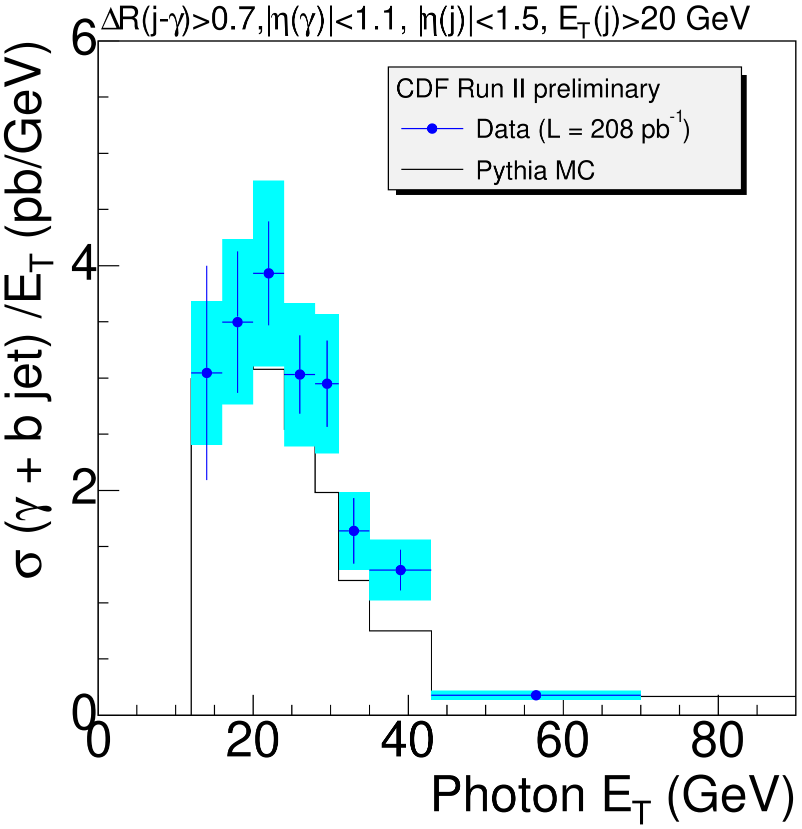

FIG. 8: Measured differential b-gamma cross section as a function of photon E_T. The points are the results from this analysis, the full histogram are PYTHIA predictions. Systematic uncertainties are indicated by light blue rectangles.

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[4] CDF collaboration, Phys. Rev. **D** 65, 052006 (2002)
[5] see for instance http://www-cdf.fnal.gov/internal/physics/photon/docs/CesCprMethod.html
[6] see CDF note 8060
[7] see CDF note 7806
[8] see CDF note 6894
[9] see CDF note 7947

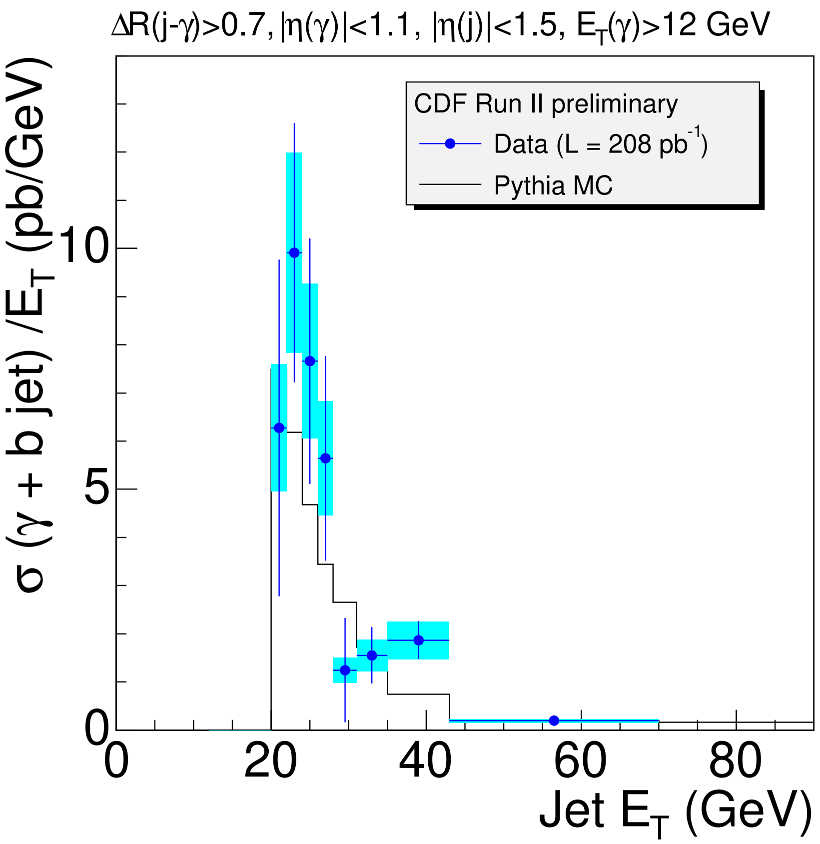

FIG. 9: Measured differential b-gamma cross section as a function of jet E_T (black points). The full histogram are PYTHIA predictions, and the blue rectangles the systematic uncertainties.

Source of systematics	(%)
Luminosity	± 6
b-tagging scale factor	± 3
$b\bar{b}$ fraction	± 2
Trigger extrapolation	± 10
Energy scale	± 4
Track efficiency	$^{+20}_{-10}$
Photon efficiency	± 1
Photon background	$^{+4}_{-6}$
Total	$^{+24}_{-17}$

TABLE I: Summary of systematic errors for the total cross section

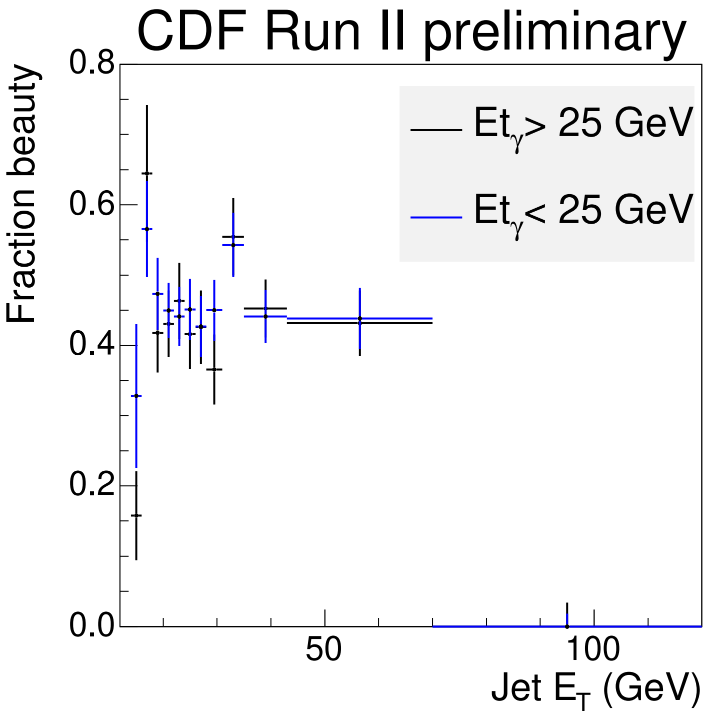

FIG. 10: b fractions from the fit of the mass of secondary verteces, for events with photons above (black) and below (blue) 25 GeV of transverse energy.