Measurement of the $b\bar{b}$ Cross Section at CDF

Sofia Vallecorsa[1]

1- University of Geneva - Departement de physique Nucleaire e Corpuscolaire
Geneva - Switzerland

We present a $b\bar{b}$ jet cross section measurement based on about 260 pb^{-1} of data, collected by CDF Run II until September 2004. The analysis strongly relies on the CDF detector good tracking capabilities both at trigger level, as data is selected requiring two displaced tracks at Level 2, and offline, since b-tagging is performed reconstructing secondary vertices inside the jet. Jets are reconstructed using a cone algorithm and the cross section is measured in the central region ($|\eta| < 1.2$) as a function of leading jet E_T, of the $b\bar{b}$ pair invariant mass and the azimuthal angle between the two jets ($\Delta\phi$). Results are corrected to the hadron level and compared to leading order Monte Carlo (Pythia and Herwig) and NLO prediction (MC@NLO).

1 Introduction

The dominant b production mechanism at the Tevatron is believed to be pair production through the strong interaction and the study of $b\bar{b}$ correlation is useful to get a deeper insight into the effective production mechanisms and the leading order and next-to-leading order contributions [2].

For example, the lowest order QCD $b\bar{b}$ production diagrams contain only b and $\bar{b}$ quarks in the final state, for which momentum conservation requires the quarks to be produced back-to-back in azimuthal opening angle. However when higher order QCD processes are considered , the presence of additional light quarks and gluons in the final state allows the $\Delta\phi$ distribution to spread. The NLO QCD calculation of $b\bar{b}$ production includes diagrams up to $O(\alpha_s^3)$ some of which - flavor excitation and gluon splitting - provide a contribution of approximately the same magnitude as the lowest order diagrams, $O(\alpha_s^2)$.

The CDF II detector has a cylindrical symmetry around the beam-line, making it convenient to use a cylindrical coordinate system with the z axis along the proton beam direction. A detailed description can be found in [3].

2 Data Sample & Event Selection

The data sample is selected on-line using a three level trigger specifically designed to select events rich in heavy flavor making use of the Silicon Vertex Trigger (SVT, [3]) at level 2.

In the first level trigger two central calorimeter towers with E_T above 5 GeV are required together with two low resolution tracks reconstructed in the tracking chamber (p_T above 2 GeV/c); in the second level trigger, calorimeter clusters are formed around the level 1 trigger towers and events are selected to have 2 clusters with E_T greater than 15 GeV. At this level tracks are reconstructed using the SVT, which adds to the low resolution L1 tracks the information from the silicon detectors. The tracks impact parameter is measured with respect to the interaction point, with a resolution of the order of 35 μm. Events pass the level 2 selection if two SVT tracks are found which have impact parameter larger than 100 μm. In the third level trigger, jets are reconstructed using the CDF run I cone algorithm and the events are required to have at least two jets with E_T above 20 GeV. Tracks are also reconstructed and events are selected if at least two of the $E_T > 20$ GeV jets are associated to two large impact parameter SVT tracks.

Offline events are requested to have at least one reconstructed primary vertex with z-position within 60 cm of the nominal interaction point: this preliminary requirement removes beam-related backgrounds and ensures a well-understood event-by-event jet kinematics.

Jets are reconstructed using a cone algorithm with a radius equal to 0.4 in the η-ϕ plane. Further selection requires: two jets with transverse energy greater than 35 GeV and 32 GeV respectively in the central pseudo-rapidity region ($|\eta| < 1.2$), each geometrically matched to a track reconstructed by the SVT trigger and confirmed by the silicon system and by the central tracker system; these tracks have high impact parameter, $|d_0| > 120\ \mu m$, and $p_T > 2$ GeV/c: two such jet will be defined, in the following, as "SVT-tagged" jets. Heavy flavor jets are identified in data and Monte Carlo events via the presence of a secondary vertex (displaced with respect to the primary interaction point and originated in the decay of the long lived B hadron) using a b-tagging algorithm based on the selection of tracks with significant impact parameter in the transverse plane.

The measured jet transverse energy in the calorimeter systematically underestimates the value obtained at the hadron level (i.e. in the Monte Carlo running the same jet clustering algorithm on stable final state particles), due to energy losses in partially instrumented regions of the detector and calorimeter non linearities. This analysis makes use of the jet energy correction calculated for generic jets [4] by the collaboration.

An additional correction (of the order of 5%), specific to "SVT-tagged" jets , is calculated matching (in the η, ϕ plane) calorimeter level jets and hadronic level jets in the Monte Carlo and fitting the energy correlation $< E_{T,cal} >$ vs $< E_{T,had} >$, to a third order polynomial. The result is an average correction which is applied jet by jet to obtain the corrected transverse energy, $E_{T,corr}$ to take into account the different features of b-jets, such as a harder fragmentation or the presence of B hadron decays inside the jet cone.

Monte Carlo samples are used to measure the efficiency of the event selection and the unfolding factors to correct the cross section to the hadron level. Generated events are passed through a full detector simulation and the same reconstruction and analysis code used on data. Inclusive jet samples and $b\bar{b}$ jet samples as well as $c\bar{c}$ jet samples are generated with Pythia, using CTEQ5L Parton Distribution Functions and different parton P_T threshold. A special tuning is used to run Pythia: "Tune A", based on dedicated studies on the underlying event using Run I CDF data.

A Next-to-Leading Order prediction is calculated using MC@NLO generator [6], together with Herwig Parton Shower. The underlying event is generated using JIMMY 4.3 [5], a generator that links to Herwig and produces multi-parton interactions. Jimmy is used to generate the MC@NLO and Herwig $b\bar{b}$ samples.

2.1 Identifying b-jets using the Secondary Vertex tagging algorithm

The b-tagging algorithm reconstructs the B decay secondary vertex inside the jet. Once the vertex is found an additional cut is imposed on the two dimensional decay lenght L_{xy}, calculated as the projection on the jet axis, in the $r - \phi$ plane, of the vector pointing from the primary vertex to the secondary vertex.

The tagged jet sample includes background from charm and light quarks and gluon jets, that can be separated from the b-jet signal using the distribution of the invariant mass of the tracks associated to the secondary vertex. A full reconstruction of the invariant mass would allow a precise separation of the b-jet sample from the background but the presence of neutral particles and the ambiguities in associating tracks to primary or secondary vertexes, limit the reconstruction of the original b mass. Nevertheless the shape of the mass distribution is different according to the flavor of the jet and mass templates are built using the Monte Carlo simulated events and they are used to fit the data distribution.

The b-tagging efficiency is defined, here, as the ratio between the number of events with 2 b-jets and 2 SVT-tagged b-jets: it is calculated using Pythia $b\bar{b}$ events requiring the two reconstructed b-jets in the central region $|\eta| < 1.2$. The result is summarized in the Fig. 1 as function of the highest energy jet E_T. The efficiency is scaled to data using a correction factor.

The b-jet purity of the double tag sample is estimated directly from data fitting the shape of the sum of the two SVT-tagged jets secondary vertex invariant masses, using template distributions from Pythia samples. A two components fit is performed using a "signal" template distribution, describing the $b\bar{b}$ case, and a "background" template, merging all the other possible contributions: $c\bar{c}$, $b\bar{c}$, $b\bar{l}$, and so on.

Figure 1), shows the fraction resulting from the fit: the 2 SVT-tagged jet sample has a very high purity (about 87%), the requirement of a SVT track matched to a b-tagged jet enhances this fraction compared to simple b-tagged jet case.

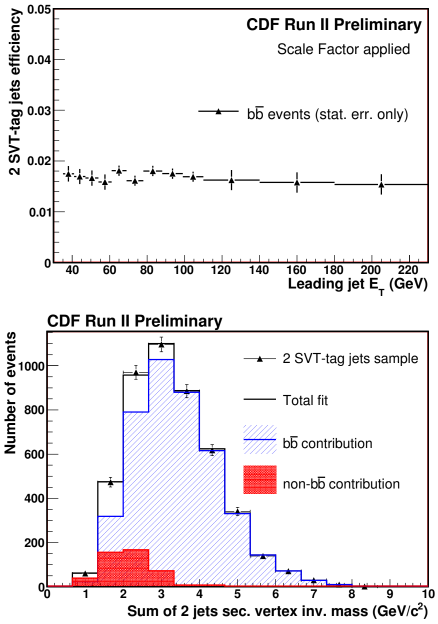

Figure 1: Efficiency for requiring two SVT-tagged jets in the event as a function of the E_T of the highest energy jet in the couple(top). Result from the fit: data is overlapped to fit prediction and Monte Carlo templates (bottom)

3 Results

The differential cross section is calculated over an integrated luminosity of about 260 pb^{-1}. It is corrected to the hadron level using "per-bin" unfolding factors, $C_i = \frac{d^2\sigma_{Had}/dE_{T,Had}}{d^2\sigma_{Cal}/dE_{T,Cal}}$, extracted from the Monte Carlo. The unfolded cross section is compared to LO Pythia and Herwig Monte Carlo and to Next-to-Leading-Order prediction, in Fig. 2 as a function of the leading jet E_T and the di-jet azimuthal difference.

The main systematic uncertainty contributions are originated by different sources: the uncertainty on the jet energy scale, which represents the main contribution (about 15-20%); the uncertainty on the luminosity (6 %); and finally the contributions related to the estimate of the tagging efficiency and the b-jet purity which are of the order of 7-8 % each.

4 Conclusion

We've presented a measurement of the $b\bar{b}$ jet cross section performed at CDF on a integrated luminosity of about 260 pb^{-1}. The events have been selected requiring two jets in the central region $|\eta| < 1.2$ with $E_T^{corr} > 35$ and $E_T > 32$ GeV, identified as b-jets using the two-dimensional Secondary Vertex algorithm and matched to two Silicon Vertex Trigger tracks with $|d_0| > 120$ μm. The differential cross section have been measured as a function of the leading jet transverse energy, the azimuthal angle between the jets and the invariant mass of the two jets. The curves have been corrected to hadron level and compared to leading order prediction by Pythia (CTEQ5L) and Herwig (CTEQ5L) and to NLO order MC@NLO events. The azimuthal angle distribution peaks at large angles, corresponding to leading order flavor creation processes, but shows a large excess at small opening angles, with respect to LO prediction (both Pythia and Herwig), suggesting the contribution from higher order processes cannot be neglected. Overall data shows a good agreement to MC@NLO prediction.

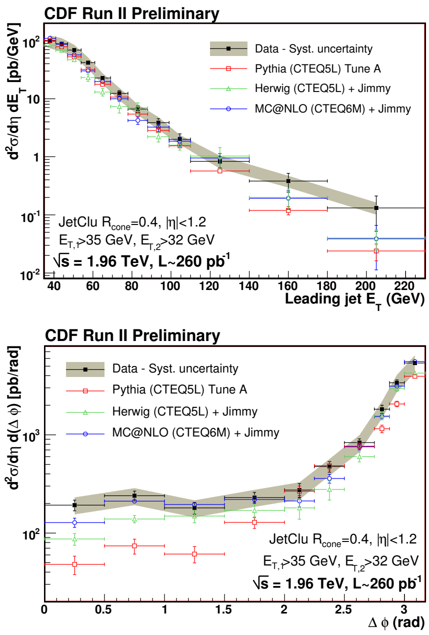

Figure 2: $b\bar{b}$ differential jet cross section as function of leading jet E_t (top) and the di-jet $\Delta\phi$ (bottom). Data is compared to hadron level cross sections obtained using: MC@NLO+JIMMY (blue), Pythia (red) and Herwig + JIMMY (green). The shaded area represents the systematic total uncertainty on the data.

5 Bibliography

References

[1] Slides:
`http://indico.cern.ch/contributionDisplay.py?contribId=222&sessionId=6&confId=9499`

[2] M. Cacciari, P. Nason, Is there a significant excess in bottom Hadroproduction at the Tevatron?, Phys. Rev. Lett. 89,122003 (2002).

[3] The CDFII Detector Technical Design Report, Fermilab-Pub-96/390-E

[4] A. Bhatti *et al.*, Determination of the Jet Energy Scale at the Collider Detector at Fermilab, Nucl. Instrum. Method A 566 (2006) 375-412

[5] J.M. Butterworth, J.R. Forshaw, M.H. Seymour, Multi-parton interactions in photo-production at HERA.

[6] S. Frixione, B.R. Webber, Matching NLO QCD computations and parton shower simulations, JHEP 0206 (2002) 029 [hep-ph/0204244].