Response to the Referee for Physical Review DG8044

We would like to thank the referee for the effort he has put into his report. We agree with many of the referee's comments and we now realize that there are many points that we need to explain more clearly. We will respond to each of the referee's comments below.

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Referee report:

The investigation presented in this paper is valuable and should eventually be
published. The paper needs a very serious revision for different reasons:

1. some of the experimental procedures are not sufficiently described. This
applies in particular a description of how one has calculated the corrections
for tracking efficiency or overlays, possible downscaling of minimum bias
triggers, etc...
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Reply: Because the rate for the Min-Bias trigger is very high (> 200 kHz), the accept rate is limited. That makes it very difficult to know the luminosity normalization for the sample, so cross sections cannot be determined. Instead, we study correlations within the events as a function of the momentum of the leading charged jet, PT1. The JET20 trigger dataset is used to extend the study to higher PT1. The JET20 data was collected by requiring at least 20 GeV of energy (charged plus neutral) in a cluster of calorimeter cells. We do not use the calorimeter information, but instead look only at the charged particles measured in the central tracker (CTC) exactly as we do for the Min-Bias data. The JET20 data is, of course, biased for low PT1 jets and we do not show the JET20 data below PT1 of around 20 GeV/c. At large PT1 values the JET20 data becomes unbiased and, in fact, we know this occurs at around 20 GeV/c because it is here that it agrees with the (unbiased) Min-Bias data. We have modified Section II to make it clearer.

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2. The presentation is very sloppy, with figure captions scrambled and
unreadable, several variables undefined, and several english mistakes. Even if
corrected, the figures should be drawn with a more professional sofware. (Has
this paper really gone through the CDF collaboration in the form in which I
received it?) The use of jargon should really be carefully eliminated.
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Reply: Clearly the referee does not like our Microsoft Excel figures. We have redone the data plots using ROOT, which is the Unix based software package.

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3. There is a profound conceptual problem in the description of the origin of
final state hadrons. There should be a clear distinction between quantities that
can be defined experimentally and unambiguously, and concepts that belong to
Monte-Carlo modelling. This is due to the fact that hadron production is ruled
by quantum mechanics and confinment, so that it is generally impossible to
relate a particular hadron to a particular parton. (even in the case of heavy
quarks, only the b-hadron can be associated with a b-quark, almost without
ambiguity, all other particles originate fom the fragmentation of a complex
system)

"underlying event, beam-beam breakups, hard scatter etc...", for instance, are
Monte-Carlo concepts. Assigning particles to any of these would require that a
purely experimental definition of them is elaborated instead, but this is not
done in this paper. In general it is however unnecessary to assign particles to
partons, one can perfectly -- and probably better -- understand the problem if
one does not attempt to do it. I gave specific examples in the more detailed
comments below.
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Reply: From a certain point of view there is no such thing as an "underlying event" in a proton-antiproton collision. There is only an "event" and for a given particle in the event one cannot say where it originated. As the referee points out quantum mechanics forbids knowing the origins of the outgoing particles. On the other hand, hard scattering collider "jet" events have a distinct topology. Because QCD is an asymptotically free theory at short distance (large transverse momentum) the incoming beam particles look like a collection of free partons and sometimes a hard 2-to-2 collision among the partons occurs while the other beam partons continue along as spectators. At long distances (long time scale) hadronization occurs (related to complicated color separations) and on an event-by-event bases one does not know the origins of the outgoing particles. However, on the average, the outgoing hadrons "remember" the underlying the 2-to-2 hard scattering subprocess. The outgoing particles are not distributed uniformly in eta-phi space. Instead an average hard scattering event consists of a collection (or burst) of hadrons traveling roughly in the direction of the initial beam particles (referred to as the break-up of the two incoming beam hadrons) and two collections (or bursts) of hadrons with large transverse momentum. The two bursts with large transverse momentum are referred to as the outgoing "jets" and are, on the average, roughly back to back in azimuthal angle. This topology is the result of the hard 2-to-2 parton-parton collision. Of course there is always some ambiguity in defining "jets" and one never knows if one has really assigned the correct particles to the "jet". Nevertheless, the event topology is clear. Defining the "underlying event" suffers the same ambiguity as defining "jets". The "underlying event" in a collider event is everything that is left over after removing the two leading large transverse momentum "jets". We do this by removing the "toward" and "away" regions in eta-phi space leaving the "transverse" region. The "toward" region contains, on the average, most of the leading "jet" and the "away" region contains, on the average, most of the second large transverse momentum "jet" (or away-side jet). Fig. 15 and Fig. 16 show the azimuthal angle, phi, distribution of particles and PTsum relative to the leading jet. The "transverse" region is perpendicular to the plane formed by the beam particles and the leading large transverse momentum "jet" and Fig. 15 and Fig. 16 suggest that the contribution to the "transverse" region from the leading two large transverse momentum jets is small. Because of this we believe that the "transverse" region is very sensitively to the "underlying event" and, of course, the Monte-Carlo models support this assumption.

Yes, the "underlying event" and "beam-beam remnants" are Monte-Carlo model concepts, and we are using them as such. The point is to use experimental observables to understand the validity of the Monte-Carlo models and to learn where they can be improved to describe the data. The ultimate goal is to understand the physics of the "underlying event", but since this is very complicated (as the referee points out) and it involves non-perturbative as well as perturbative QCD it seems unlikely this will happen soon. In the mean time we would like to tune the Monte-Carlo models to do a better job fitting the "underlying event" (i.e. the "transverse" region). We want to tune the Monte-Carlo models to fit the overall collider event, not just the leading jet properties. To find "new" physics at a collider it is crucial to have Monte-Carlo models that simulate accurately "ordinary" hard-scattering collider events. In this paper we discuss in detail the possible reasons that the Monte-Carlo models disagree with the data on the "underlying event" and in a future publication we will tune the Monte-Carlo models to fit the data.

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abstract:
first person is used. (We see evidence..)
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Reply: corrected this… Thanks.

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Jargon is used in abstract (Min-Bias, JET20 data....
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Reply: We agree this is jargon and we have removed it from the Abstract. However, in Section IIA (and Table 1) we define "Min-Bias" and "JET20" use it in the paper thereafter.

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the captions and labels of figures 2 5  6 7 8 9 10 12 13 14  15 16 17 18
19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 are all scrambled.
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Reply: We do not know why the labels are scrambled. We have upgraded to RevTeX 4 and we hope this improves the quality of the manuscript.

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abstract and page 7, 24:
'Also,a number of global observables are examined,where to fit the observable
the QCD Monte-Carlo models have to describe correctly the overal proton-
antiproton event structure.'is this sentence understandable? does this mean: We
have examined also a number of distributions of observables, which are more
sensitive to the overal proton-antiproton event structure.'?
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Reply: A "global observable" is an observable that is sensitive to the overall proton-antiproton event structure. However, there is no need to define observables as "local" and "global" so we have removed these words from the paper.

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Why is the analysis only using charged particles? This gives additional
sensitivity to the charged to neutral particle ratio and its fluctuations, which
are known (e.g.at LEP) not to be very well reproduced by the models. I think a
word of justification is mandatory.
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Reply: At low momentum, neutral particles cannot be detected with high efficiency or good resolution. Our philosophy in the paper is to take advantage of the fact that the CTC (central charged particle tracker) is very efficient for charged particles in the region PT > 0.5 GeV/c and |eta| < 1 for charged particle jets with PT1 < 50 GeV/c. For this region "what you see is what you get"… almost. Detector simulations show that our impact parameter cut removes most of the spurious particles and hence except for a 9% correction for efficiency (which we apply to the Monte-Carlo models) "what you see is what you get". If we were to use the calorimeter data (for neutrals) we would have to do a detailed detector simulation and we would not be able to compare so directly with the Monte-Carlo models. Most collider observables are not "clean"! Here we take advantage of this "clean" region for charged particles. We are using the leading charged jet to define the direction of the leading total jet (i.e. to define the topology). When you ask for a large transverse momentum charged jet you bias yourself in favor of total jets that are mostly charged. We have made this clearer in Section II.

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p 7 The axis system with respect to which angles, transverse momentum and
pseudo-rapidity are counted is not given. These could be the jet axis or the
detector axis. Which?
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Reply: Transverse momentum and pseudo-rapidity are with respect to the beam axis. The azimuthal angle phi is measured with respect to the leading charged jet direction (very important!). We have added words to the text and a footnote to clarify this.

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What is the 'beam-beam remnant contribution to the underlying event'??? I doubt
this concept is physical, e.g. Lorentz invariant.
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Reply: Good question! It is what is left over after a parton is knocked out of each of the initial two beam hadrons. It is the reason hadron-hadron collisions are more difficult to analyze than electron-positron annihilations. As discussed by Feynman & Field many years ago, no one really knows how to model this. Nonetheless, it is an important ingredient in all the QCD Monte-Carlo models (each with a different way of modeling it). For the Monte-Carlo models it is an important component of the "underlying event" (and they do not get it right!). In the early days (and some of the Monte-Carlo models still do this), the "beam-beam" remnants were assumed to look like ordinary "soft" (i.e. Min-Bias) collisions at a center-of-mass energy equal to the initial beam-beam energy minus the energy of the removed partons. Our analysis shows that this approach is wrong. We have added a few words to the text explaining more carefully the "beam-beam remnants". Of course, in the QCD Monte-Carlo models the "underlying event" also receives contributions from initial and final-state radiation and from the outgoing jets.

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Last sentence of page 7 is nice but one could elaborate: does this refer to the
W mass and top mass measurements?
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Reply: We are not sure that our page numbers match with the referee's. However, if the referee is referring to our statement that "some of the observables presented here do, of course, depend on the definition of a jet", than our reply is that basically any observable that uses "jets" depends on the jet definition. For example the "jet" cross section, "jet" multiplicity, "jet" mass, "dijet" mass, "jet" size, etc. The key point is that one must apply the same jet definition to both the QCD Monte-Carlo Models and the data, as we have done.

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page 9 the figures are naive cartoons of a possible view of the processes, with
no respect for momentum conservation  or Lorentz invariance....They give a false
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impression that one knows what is happening in some classes of events, which is of course not true. Is there an unambiguous definition of event classes that does not have this flaw? I dont think these figures are desirable, unless the figure caption and description are made more carefully.

Reply: Fig. 1 and Fig. 2 are "cartoons"! They illustrate the various components of a hard-scattering process as modeled by the perturbative QCD Monte-Carlo models. Of course, the components are not directly measurable experimentally. We have rewritten the figure captions.
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page 11 line 5 (dpt /pt2 < .002 (GeV/c)-1) is this a required condition or a typical resolution? Rewrite to eliminate ambiguity.

Reply: This is the typical resolution. We have added words to clarify.

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page 11 line 6 requiring *that* at least one particle

Reply: Fixed… Thanks.
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page 11 paragraph 2 and 3 please give dimensions of the luminous region. Has the effect of parasitic overlaps been corrected for? It should be of course. In any case this should be included in the error. There is no garantee that the procedure of d0 variation provides an appropriate estimate of the bias nor of the error introduced by spurious tracks. These two paragraphs give the (possibly false) impression of very sloppy experimental procedures.

Reply: The effect of parasitic overlaps (and other backgrounds) are included in the systematic error. We have included the dimensions of the luminous region as requested, and clarified the description of the experimental procedure.
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page 12 Each of the QCD Monte-Carlo approaches modelS the beam-beam remnants (each is singular)

Reply: Fixed… Thanks.
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page 12 the sentence
'For example, of the 74 charged particles produced,.... and only about 5 charged particles are, on the average, in the region p T >0 .5GeV /c and |? |<1.'
There are three 'and' in this sentence, one too many.

Reply: Fixed… Thanks.

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p 14 4 lines to end we apply an 92% =>we apply a 92%
Reply: Fixed… Thanks.

Is there a justification for the 8% tracking inefficiency? Is this topology dependent? Is this well understood? Since it is argued that there is a systematic error of 5% this should be justified in more detail.

Reply: We have restricted this analysis to charged particles measured by the CTC in the region PT > 0.5 GeV and |eta| < 1. Studies show that for this region the efficiency of the CTC is uniform (i.e. independent of the PT and eta of the track) and equal to 92% (i.e. 8% inefficient). Yes this number does depend on the topology, but not over the range of change jet momentum, PT1, considered in this analysis. Detector simulations show the CTC looses efficiency for dense jets (lots of particles) and this occurs for PT1 above about 75 GeV/c. Hence, we have restricted ourselves to PT1 values less that 50 GeV/c where the central tracker efficiency is uniform and around 92%. The 5% systematic error on the QCD Monte-Carlo curves comes from two sources. The first is because we correct the QCD Monte-Carlo models by 8% for the CTC efficiency, which is uniform within about 2%. We have quoted a 5% uncertainty on the QCD Monte-Carlo curves to take into account small error that might occur in drawing smooth curves through the generated Monte-Carlo points. We also include systematic uncertainties on the data points. Studies with full detector simulation verify that these uncertainties are appropriate. We have made this clearer in the text.

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p15 first line: but should one not require jet20 for MC samples when comparing
them with data taken with Jet20?
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Reply: The JET20 data were collected by requiring at least 20 GeV of energy (charged plus neutral) in a cluster of calorimeter cells. We do not use the calorimeter information, but instead look only at the charged particles measured in the central tracker (CTC) exactly as we do for the Min-Bias data. The JET20 data is, of course, biased for low PT1 jets and we do not show the JET20 data below PT1 of around 20 GeV/c. For leading charged jets in the range 0.5 < PT1 < 20 GeV the JET20 data does not agree with the Min-Bias data. This is because in this region the JET20 data is a biased subset of the (unbiased) Min-Bias data. At large PT1 values the JET20 data becomes unbiased and, in fact, we know this occurs at around 20 GeV/c because it is here that it agrees with the (unbiased) Min-Bias data. In addition, all QCD Monte-Carlo events with PT1 > 5 GeV/c satisfy the Min-Bias trigger.

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P15 section III line 3; this sentence: [Jets] 'contain charged particles from
the underlying event as well as particles which originate from the fragmentation
of high pT outgoing partons'. seem to imply that the particles in an event
originate from two or more different sources. This is a potentially deep error.
Particles are generated, from what is understood today, by the breakup of a
color neutral system of partons. The assignment to jets is an unambiguous and
correct, but arbitrary and purely experimental procedure. A single parton cannot
in itself generate particles. Although it is true that the decription in the
text can be conceptually valid in some cases (production of a color neutral W
decaying hadronically, for instance) it will not be true in general (scattering
of quarks or gluons). This is a serious conceptual mistake. The paper should not
be published unless the concept is corrected. I suggest eliminating any such
sentence from the paper.
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Reply: The reason for the statement that our "jets" contain charged particles from the "underlying event" as well as particles which originate from the fragmentation of high PT outgoing partons is to explain that we have not attempted to "remove the underlying event" from the "jets". In most CDF "jet" publications a correction is made to the jet transverse energy to account for the "underlying event". The contribution to the "jet" transverse energy from the underlying event is removed. Of course, this can only be attempted on the average (fluctuations are neglected) and is done by subtracting the average transverse energy in a cone of radius R = 0.7 in eta-phi space that is observed in "soft" (i.e. Min-Bias) collisions. Our study of the "underlying event" in this analysis should help improve the "jet energy correction" procedure. We have reworded the paragraph.

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comment on figure 3. This is a funny algorithm. The three jets at smallest phi
would actually fit within a radius of r=0.7! So be it.
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Reply: Our algorithm applied to both data and Monte-Carlo provides a consist approach that facilitates comparison at both low and high PT. It, of course, does not have the same goals as the usual jet algorithms (e.g. transverse energy measurements).

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fig 4: Are the lines (models) obtained with a trigger selection imposed? should
this not matter?
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Reply: The Monte-Carlo models are required to satisfy the CDF Min-Bias trigger explained in Section IIA. This, however, is only important a small jet transverse momentum. For charged particle jets with PT above around 5 GeV/c essentially all the Monte-Carlo events satisfy the trigger (i.e. above 5 GeV/c you get the same result with or without the trigger requirement).

Also, the binning here is irrelevant and should not be marked on the vertical axis, it is confusing.

Reply: This is an interesting point. We labeled the y-axis to signify that the plot is not a normal plot (and does depend on the bin size). In a normal histogram the y-axis corresponds to the number of points in the x-bin. In Fig. 4 (and many other figures in the paper) each x-bin corresponds to a distribution of values (e.g. Nchg(jet1)) and what is plotted is the average of this distribution (i.e. a "profile plot"). Here the error is not the square root of the number of points, N, but instead is related to the root mean-square deviation from the mean, sigma, of the distribution in each x-bin; sigma/sqrt(N-1). For this reason we think we have labeled the y-axis properly. It really is the mean value in a 1 GeV/c bin of PT(chgjet1)! The observables examined in the paper are correlations of one type or another among the outgoing hadrons.

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page 17 section B line 4 and allows -> and this allows

Reply: Fixed… Thanks.

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line 5 Looking at the figure 4, it would appear that in the region of overlap, the min bias events are far less numerous than the jet20 ones. However it is said earlier that 'essentially all high pT jet events satisfy the min-bias trigger'. This contradiction is not explained in the paper. Is there a downscaling factor?

Reply: Yes, both are downscaled, or they would swamp the data taking. The normalization is therefore essentially arbitrary. As explained above the normalizations are not relevant for these studies.

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page 19 section c line 2. " The size of jets...." Clearly there would be many ways to define such a thing, not just two! I suggest "Two definitions of the size of a jet were used to study this quantity."

Reply: Fixed… Thanks.

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page 20 Pt(sum) is not defined.

Reply: Fixed… Thanks.

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page 21 the label of figure 9 says Nchg distribution when the caption says pt(sum) (maybe these result from scrambling)

Reply: Fixed… Thanks.

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p22: the sentence

"Furthermore,some of the charged particles within the leading jets originate from the underlying event and we can never be sure that we have included all the particles that come from the outgoing high transverse momentum parton." is not

OK. See comment above. Particles within the leading jet are by definition within the leading jet. period.

Reply: Fixed… We agree! See above.

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page 23
"This is exactly the behavior expected from a true fragmentation function." should be accompanied by a reference to a similar studies in e+e- annihilation of Deep Inelastic Scattering of muons or neutrinos.

Reply: We have added a reference to the expected behavior of fragmentation functions.

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legend of figure 14
Each region,toward,transverse,and away covers the same range |Dphi|X|Deta|=2 X 120 OK, except that the range is really -1<eta<1 and Dphi=120 degrees. The way this is written is wrong.

Reply: Fixed… The point is the each of the three regions covers the same "area" in eta-phi space so that if a collider event produced particles uniformly in eta and phi than all three regions would be equally populated. Of course this is not what happens, but the reason the "transverse" region has less particles, on the average, is not because it covers less eta-phi space.
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... ...

page 35 this sentence:
"The away region is a mixture of the underlying event and the away-side outgoing hard scattering jet. This can be seen in Fig.27 where the predictions of ISAJET for the away region are divided into three categories: beam-beam remnants,initial-state radiation,and outgoing jets plus initial-state radiation." is a case in point: particles in the "away" region (please keep the qualifier in italics or in quotes) are presumably related with the fragmentation of a parton system including a hard scattered parton emmitted in the opposite hemisphere, and possibly partons from one or both initial beam particles, or the same side parton itself -- one cannot tell so easily!. Once quantum mechanics and confinment are included in the way one thinks about particle production such sentences dont make sense, and the conclusions should be spelled out more carefully. The fact that ISAJET models things in a particular way to perform an approximate representation of reality does not mean that the ingredients of the model are physical concepts! In fact ISAJET does not reproduce the distribution at high Pt. The last statements of this paragraph are of course completely related to a particular implementation of what is called a hard parton in Monte-Carlo.

Reply: Okay we will keep "toward", "away", and "transverse" in quotes. We will also put "beam-beam remnants", etc. in quotes. Of course, the components of ISAJET ("beam-beam remnants", "initial-state radiation", etc.) are not directly observable experimentally. We are looking at the QCD Monte-Carlo models to get an idea of what our observables are sensitive to in the Monte-Carlo model. We have added words to make this more clear.

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page 40 similarly it is impossible for profound reasons to tell whether a gluon is initial or final state radiation. So how can one be so sure as to conclude "This is clearly the case as can be seen in Fig 32..."? Because ISAJET separates initial and final state radiation *somehow* does not mean this is a physical distinction, (these diagrammes even

interfere) let alone that it makes sense to tell that a final state hadron comes from this or that, gluons are not color singlets.

Reply: Of course, it is only because the models approximate higher-order effects by using the leading log approximation that one can know which parton chose to radiate. In addition, for ISAJET with independent fragmentation can one identify the particles coming from initial and final-state radiation. Physically this, of course, does not make sense. We have added words to make this clearer.

>From the plots of fig 34, I would conclude that "it looks as if" none of the MCs proposes an adequate representation of what happens in these events beyond the leading jet and the side opposite to it.

Reply: Okay…thanks.

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page 50 parag: the underlying event

I understand well that this is not so easy to formulate but the wording of the first two sentences of this paragraph is not acceptable: once again one cannot tell where hadrons come from, except from "a hadronic system as a whole in which some partons are emmitted at large angles either because of i)single or multiple parton-parton scattering or ii) initial or final state radiation, while some others remain roughly aligned with the initial beam particles"

Reply: We have improved this paragraph.

I think a solution to this problem would be to define "the underlying event" in a completely experimental way e.g. "the region of phase space which is neither in the phi-eta region of the leading jet nor in the opposite region".

Reply: This is precisely what we have done, but obviously we did not explain it well enough. We have rewritten parts of the paper to make it more clear and added to Fig. 14. Fig. 14 now shows clearly that the "transverse" region excludes leading "jets" with R = 0.7. The "transverse" region corresponds to a distance in eta-phi away from the leading charged particle jet of at least 1.047 (i.e. 60 degrees). Actually, Fig 6 shows that the leading charged particle jet is, on the average, smaller than R = 0.7. Since the "away-side" jet is roughly 180 degrees away from the leading jet, the "transverse" region also excludes most it as well.

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page 51

"PYTHIA 6.115 has about the right amount of activity in the underlying event, but as a result produces too much overall charged multiplicity." I dont think this is demonstrated by the paper. These two facts cannot be considered a consequence of each other.

Reply: Actually in PYTHIA they are related. In PYTHIA the "beam-beam remnants" (including multiple parton interactions, MPI) produce particles that are essentially independent of the direction of the leading charged particle jet and hence populate the three regions "toward", "transverse", and "away" roughly equally. More "beam-beam remanats" and MPI in the "transverse" region implies more "beam-beam remanats" and MPI in the "toward" and "away" regions as well. The overall multiplicity is, of course, the sum of the three regions. However, since this point is not obvious we have change the sentence.

In general in the rest of page 51 the conclusions are far too definitive. Reading the paper I would conclude that "This or that experimental distribution is not reproduced by the various Monte-Carlos. A detailed

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analysis of the modelling involved in each MC shows that one could hope
to reconcile them with data by modifying the model in this and that
way." Please avoid to assign an element of physical reality to such
concepts as "underlying event", "beam-beam remnant" "initial state
radiation" and the assignment of particles to this or that component.
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Reply: We understand the referee's point of view and for the most part we agree. However, there is a physical reality to average topology of hard scattering collider "jet" events. In this paper we study this topology by looking at the correlations among the outgoing hadrons. The observables examined in the paper are correlations of one type or another among the outgoing hadrons. The QCD Monte-Carlo models agree well with the properties of the leading charged particle jet. However, they do not produce the right number (with the correct momentum) of charged particles that are out of the plane formed by the beams and the leading charged particle jet (i.e. the "transverse" region). This "transverse" region is very sensitive to the way the QCD Monte-Carlo models parameterize the "beam-beam remnants" and to the way they handle "initial-state" radiation (i.e. the way they construct parton-showers). This suggests that the particles in the "transverse" region are, on the average, related to (or influenced by) the break-up of the beam hadrons and to gluon radiation (initial and final-state). We do know that modifying the way the QCD Monte-Carlo models model the "beam-beam remnants" improves the fit to the data. We also know that PYTHIA and HERWIG, which modify the leading log approach by incorporating "angle ordering" in their parton-showers, do a better job in describing the data than does ISAJET (leading log only). We have rewritten our conclusions to make them more clear.
