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Comments and Reply

Comments and Reply on: "Study of multi-muon events produced in $p\bar{p}$ interactions at $\sqrt{s} = 1.96$ TeV"; T. Aaltonen et al. (The CDF Collaboration)

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Abstract The European Physical Journal C—Particles and Fields—publishes scientific manuscripts of relevance to the scientific community following careful and strict peer reviewing and, whenever appropriate and necessary, through discussion with the authors, so as to optimise scientific content and style of presentation prior to publication. In some cases significant disagreement between authors and referees (and/or editors) of the journal cannot be resolved despite all efforts and best of intentions. While the journal—notwithstanding any appeals—retains the right to reject such manuscripts, the editors of this journal may decide, in cases deemed of exceptional interest and potential significance for the field, to accept the manuscript for publication, to amend it by "comments" of the editor(s) in charge and, if appropriate, by a "reply" of the authors of the commented manuscript.

The present comment is on "Study of multi-muon events produced in $p\bar{p}$ interactions at $\sqrt{s} = 1.96$ TeV" by T. Aaltonen et al. (the CDF Collaboration, Eur. Phys. J. C, 2010, doi:10.1140/epjc/s10052-010-1336-0).

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1 Comments: introductory statements

The "Study on multi muon events..." by the CDF collaboration is a case of significant disagreement between the authors, i.e. about 400 respected scientists who signed the paper, and several referees who have trustfully been asked by EPJC to evaluate the manuscript. According to the belief of the editors, the paper contains scientific information which may be of high interest to the scientific community as a whole, notwithstanding the remaining doubts of the referees which are, in large parts, shared by the editors of the journal. EPJC therefore has decided to publish the manuscript, named "article" in the following, but to amend it with the following comments:

2 Comments of the editors

The authors report about an excess of events recorded with the CDF detector at the Tevatron collider using a dimuon trigger and data selection as previously applied in studies of heavy flavour production. An excess of 153895 events (of a total of 743006 triggered) is claimed which cannot be explained by known standard sources. The standard sources, including prompt plus heavy flavour contribution, are called "P+HF" by the authors, and are defined by a subset of the same data where additional vertex quality requirements, so-called "tight SVX", are applied to the muon candidates. Assuming an efficiency of 24.4% of the "tight SVX" selection, the observed amount of 143743 events after those additional cuts correspond to an expectation of 589111 events without those cuts, leading to an excess of $743006 - 589111 = 153895$ (± 4829) events in the total event sample.

These excess events, collectively called "ghost events" by the authors, explain the disagreement between previous studies of the inclusive production cross section of b-quark events, which gave too high values if compared to the theoretical QCD expectation with no vertex constraints of the muons were applied, while being in good agreement with QCD if vertex constraints were used.

The authors also report on studies of the general nature of these "ghost events", like their impact parameter distributions, the number of additional muons and their properties in turn (invariant mass distributions and impact parameter distributions), which cannot be explained by the authors in terms of their current understanding of the detector, the trigger and the event reconstruction.

The referees mainly criticise and comment on the following issues:

– the applicability of the 24.4% efficiency for dimuons with tight SVX constraints, obtained from data and simulations, to define the "p+HF" part of the dimuon sample without SVX constraint is questioned. Phrased differently, there is doubt that the efficiency of selecting dimuons from standard "P+HF" sources, including heavy quarkonia decays but also in- flight decays of kaons and pions as well as punch-through and scattering processes in the detector material, will be independent of applying SVX constraints.
– in the course of describing their studies of the nature of the "ghost" events, the authors admit that standard processes other than heavy quarkonia decays, i.e. (as listed above) in-flight decays, scattering and punch-through, are able to explain about 50% of the number of "ghost" events, and even a full account of "ghost" events by these processes cannot currently be excluded. Unless these backgrounds cannot be estimated with a precision and reliability much better than suggested by those remarks, the basic theme of the paper is in doubt.
– If the additional background to the "ghost" events cannot be reliably modelled, it may be no surprise that such events have properties that do not conform to the (standard P+HF) expectations.

The referees suggest that the only possible conclusion within the limitations of the present background estimate is that "ghost" events are most likely due to ordinary sources. While this assumption cannot be proven by the referees nor can it be disproven by the authors, the editors of this journal find it necessary and adequate, especially in view of the upcoming data from experiments at the Large Hadron Collider, to officially spread the knowledge of a potential source of disagreements between collider data and the standard model expectation at the Tevatron. It was therefore decided to accept a short version of the paper for publication, and to amend it with supplementary material consisting of a longer and more detailed version of this manuscript. The supplement is accessible as Electronic Supplementary Material of the published article [1], and is not by itself a peer-reviewed article of this journal.

3 Reply: introductory statements

The CDF Collaboration acknowledges that there has been significant disagreement between the authors and reviewers of this manuscript.

We thank the editors of this journal for their willingness to publish this manuscript and wholeheartedly agree that this work, and the issues that are associated with it, should be presented to the community. Furthermore, we appreciate the opportunity to respond to the Editors' comments on the manuscript.

4 Responses to the editors' comments

After a concise, accurate description of the manuscript, the editors raise three main criticisms of the analysis. We will address each of these.

– *On the applicability of the 24.4% efficiency calculated for "tight" SVX muons.*

The efficiency for the "tight" SVX selection is measured directly from data, using samples of muons from known signatures (e.g. $J/\psi \to \mu^+\mu^-$, $\Upsilon \to \mu^+\mu^-$, etc.). The muons are identified without the use of microvertex information, then we simply ask what fraction of these muons have the relevant requirements to be "tight" SVX muons. We then make a small [$\mathcal{O}(1\%)$] correction to the efficiency to account for the different kinematics of the control samples.

Given that the "tight" SVX efficiency is derived directly from data using extremely pure samples of muons, we have no reason to doubt its validity. As a crosscheck, we show in the manuscript that we can release the tight SVX requirements and correctly predict the number of $J/\psi \to \mu^+\mu^-$ events which pass the "loose" SVX criteria.

Since we explicitly measure the SVX efficiency using samples of muons, we agree with the point that the "tight" SVX efficiency might be different for hadrons that produce fake muons either by punch-through or in-flight decays. As we describe in the manuscript, we assess each of these sources separately.

Finally, the motivation of this manuscript is to point out that the "ghost" background was unaccounted for in prior analyses. The comparison of the 24.4% efficiency for muons to the 19.3% observed efficiency is in fact the first indication that there is an additional background in the sample that was not previously identified.

– *On the possibility that the entire ghost sample can be explained by in-flight decay.*

The in-flight decay background is estimated from a Monte Carlo (MC) simulation of generic $2 \to 2$ processes. The editors correctly state that we admit that this background estimation is limited in its reliability. Although the in-flight decay rate derived from MC accounts for approximately $1/3$ of the ghost sample, in terms of *rate only*, it is possible that the entire ghost sample could be explained by in-flight decays of kaons and pions.

However, we have significantly more information than simply the number of ghost events. In particular, two other very important aspects argue that the ghost sample cannot be explained by in-flight decays alone:

- The impact parameter distribution of the ghost muons is significantly different than that of the in-flight decay MC. This is shown in Fig. 10 of the longer manuscript [1]. Although we do not have great confidence in the MC in-flight decay rate, we have no reason to believe that the MC would misrepresent the kinematics of kaon and pion in-flight decays so severely.
- In-flight decays arise from a random process, so we can safely apply a "per track" in-flight decay probability. Given that the in-flight decay probability per hadron which will ultimately be reconstructed as a muon is of order 10^{-3}. Therefore, events with two muons from in-flight decays are suppressed and events with more then two muons from in-flight decays will show an even greater suppression. However, when we isolate the ghost sample, we find a muon multiplicity that is *four times higher* than that of "P+HF" events.

So while we agree with the referees' assessment that in-flight decays could describe the ghost sample in terms of event rate, we see no way that in-flight decays can explain the ghost sample in its entirety. We state this point explicitly in the manuscript.

- *"If the additional background to the 'ghost' events cannot be reliably modelled, it may be no surprise that such events have properties that do not conform to the (standard P+HF) expectations."*

This paper was motivated by a contribution to the dimuon triggered sample that was not understood. We felt it important to report this result because of its effect on several *b*-physics measurements that have been made using dilepton samples. The fact that these measurements were affected by this previously unidentified background is independent of whether or not we are currently able to model the background.

Furthermore, we find the correlation between muon multiplicity and impact parameter to be particularly curious. In this analysis, the control sample consists of dimuon events that are well measured in silicon microvertex detector (tight SVX). When we identify the ghost sample based how the muons are measured within the microvertex detector, we find a subsample of events that have a number of strange features relative to the control sample, including a significantly larger muon multiplicity. Through a number of detailed crosschecks, we have identified no mechanism that can account for the correlation between muon impact parameter and muon multiplicity. Simply because we cannot model this background does not mean that it is not interesting and relevant to other measurements.

Finally, the editors point out that the "*...referees suggest that the only possible conclusion within the limitations of the present background estimate is that 'ghost' events are most likely due to ordinary sources*." We do not dispute this point, nor does our manuscript make any claim otherwise.

To summarize, we have isolated a source of background events in our dimuon triggered sample that was not previously identified. This background affected prior measurements of $\bar{\chi}$, the $b\bar{b}$ cross section and $b\bar{b}$ production correlations. Our paper documents the existence of this background and presents some of its properties. We carefully compare this background to a control sample derived from the same dimuon triggered sample and point out that we cannot explain all of the properties of the background.

We state that we cannot fully explain the background, we do not claim that it is inexplicable by standard processes.

We again thank the editors for their willingness to publish this manuscript.

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