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Two $\tilde{\mathrm{b}}$ or not two $\tilde{\mathrm{b}}$?

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In this note, further investigations are reported on the excess of $\mathrm{e^+e^-} \rightarrow \mathrm{b\overline{b}}$ events with subsequent semileptonic decays into two opposite-charge letpons [1]. In total 56 events were observed with 33.6 expected from standard model processes at energies at and above 161 GeV. This excess, which could be compatible with a supersymmetric scenario where the super-partner of the bottom quark is light and long-lived, was presented at the July LEPC [2].

A selection similar to that in which the excess was observed [1] was carried out. A particular care was given to the electron identification criteria, since the aforementioned excess was mainly concerning events with electrons. The data samples collected in 1998 and 1999 at $\sqrt{s}$ =189, 196 and 200 GeV amounting to 176.3, 79.9 and 86.3 pb^{-1} respectively were used. All available standard model Monte Carlo background samples including four fermions and $\gamma\gamma \rightarrow \mathrm{q\overline{q}}$ were considered.

Preselection

Events are first required to be hadronic (Class 16) with at least two loosely identified leptons (with energies, $\mathrm{E}_{\ell_1,\ell_2} > 1\%\sqrt{\mathrm{s}}$): QMUIDO identification flag $\mathrm{ID_{muon}}>10$ for muons; $R_T > -3$ and $3 > R_L > -3$ for electrons. For events with three leptons or more, only the most energetic three are considered. The two most energetic leptons in opposite hemispheres are considered as originating from a semileptonic decay. Well contained $\mathrm{q\overline{q}}$ events are selected by requiring a thrust value greater than 0.9 and the polar angle of the thrust axis larger than 25^o. To reject radiative returns to the Z, only events with s'/s larger than 0.4 are selected.

When this preselection is applied, 790.0 events from standard model processes are expected with 855 observed in the data. This excess of 65 events corresponds to a 2.3

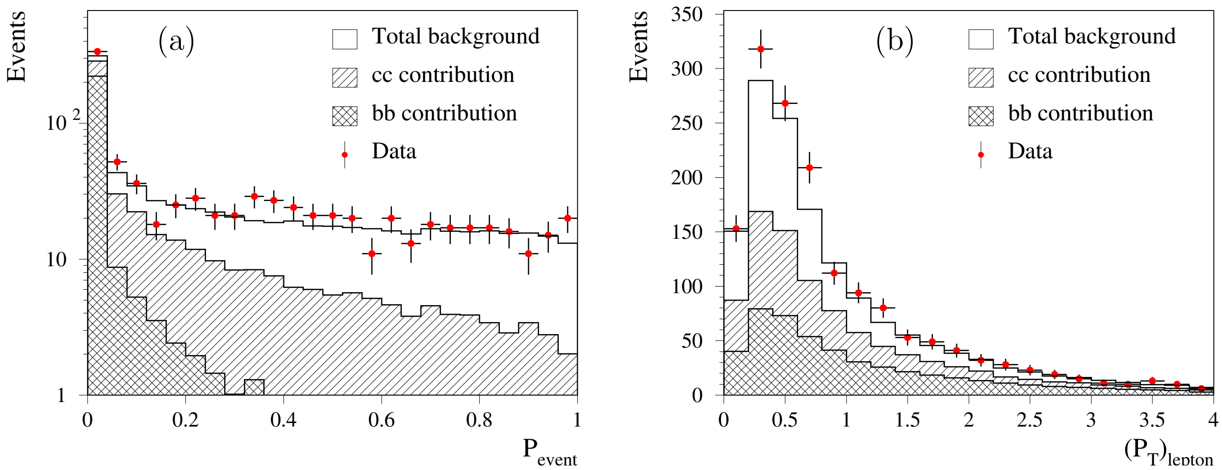

Figure 1: Distributions of (a) the QIPBTAG event probability and (b) the lepton transverse momentum. The $e^+e^- \to b\overline{b}$ and $e^+e^- \to c\overline{c}$ contributions are also indicated.

standard deviations excess (1.7, 1.4 and 0.8 standard deviations for the data sets taken at 189, 196 and 200 GeV respectively). The $q\overline{q}$ purity amounts to 90.7% with 33.4% light-flavour-quark (uds) pairs, 31.0% are c-quark pairs and 35.6% are b-quark pairs. The remaining 9.3% non-$q\overline{q}$ backgrounds are mainly WW$\to \ell\nu q\overline{q}'$ events.

The events are then forced to form two jets with the Durham clustering scheme, without taking the leptons into acount. In Fig. 1, the distributions of the QIPBTAG probability for the event ($\mathcal{P}_{event}$) and of the lepton transverse momentum with respect to the nearest jet are displayed at preselection level for the data and the standard model processes. In both distributions, the excess appears in regions dominated by heavy-flavour di-quark production.

The lepton flavour composition of the samples at this level is the following.

Lepton pair flavour	ee	$\mu\mu$	eμ
Expected background	323.4	110.2	356.4
Data	307	161	387

The excess mostly arises from events with one or two identified muons.

Fig. 2 illustrates the distribution of the QMUIDO muon identification flag for all muons at preselection level. In total, 709 charged particles are identified as muons in the data with only 576.9 expected. The excess mostly concerns charged particle with $\mathrm{ID_{muon}}$=11, *i.e.* those identified only with a good HCAL pattern.

In contrast, the agreement is good for identified electrons: 1001 tracks are identified in the data with 1003 are expected from the simulations. The distributions of the com-

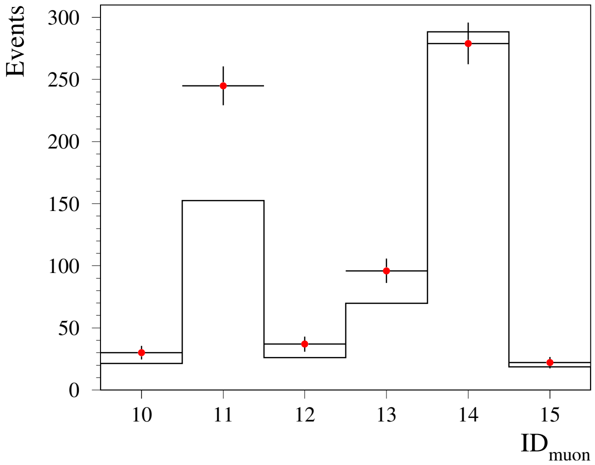

Figure 2: Distribution of the muon identification flag ID_{muon} for all charged particles identified as muons in the data (dots) and in the simulation at the preselection level.

pactness (R_T) and longitudinal profile (R_L) estimators for these tracks are displayed in Fig. 3 . Although the R_L distribution shows a slight shift towards large values, in the simulation, an overall reasonable agreement is observed.

Event selection

The event selection criteria are the same as those used in [1]. The cuts on the thrust value and polar angle are tightened to 0.975 and 45 degrees respectively. To further remove events with a radiative return to the Z resonance, s'/s is required to be larger than 0.5, the event invariant mass must be greater than 110 GeV/c^2 and the visible energy in excess of 55% $\sqrt{\mathrm{s}}$. The energy of the most energetic lepton must be larger than 2%$\sqrt{\mathrm{s}}$ and the azimuthal angles of the two identified leptons (ϕ_{ℓ_1} and ϕ_{ℓ_2}) should fulfil: $|\phi_{\ell_2} - \phi_{\ell_1}| - 180^o \leq 8^o$.

When all the above cuts are applied and the leptons are required to be oppositely charged, 82 events are observed in the data and 72.4 are expected from standard model processes, corresponding to a 1.1 standard deviation excess mainly due to the data taken at $\sqrt{s}$=189 GeV (1.9σ) not confirmed at higher centre-of-mass energies. The $\mathrm{q\overline{q}}$ purity at this level of selection is 99.5% where 33.2% are $\mathrm{e^+e^-} \to \mathrm{b\overline{b}}$, 34.3% are $\mathrm{e^+e^-} \to \mathrm{c\overline{c}}$ and 32.5% are $\mathrm{e^+e^-} \to \mathrm{u\overline{u}, d\overline{d}, s\overline{s}}$. At this level, no compelling evidence for an excess in the data is seen.

When all the selection criteria are applied and the charges of the two leptons are required to be the same, 66 events are selected in the data with 63.6 expected in the simulation with a $\mathrm{q\overline{q}}$ purity similar to that of the oppositely charged leptons events (where 35.0%, 28.8% and 36.2% are respectively b, c and light (uds) quark pairs). The lepton flavour content for both the opposite and same charge samples is the following.

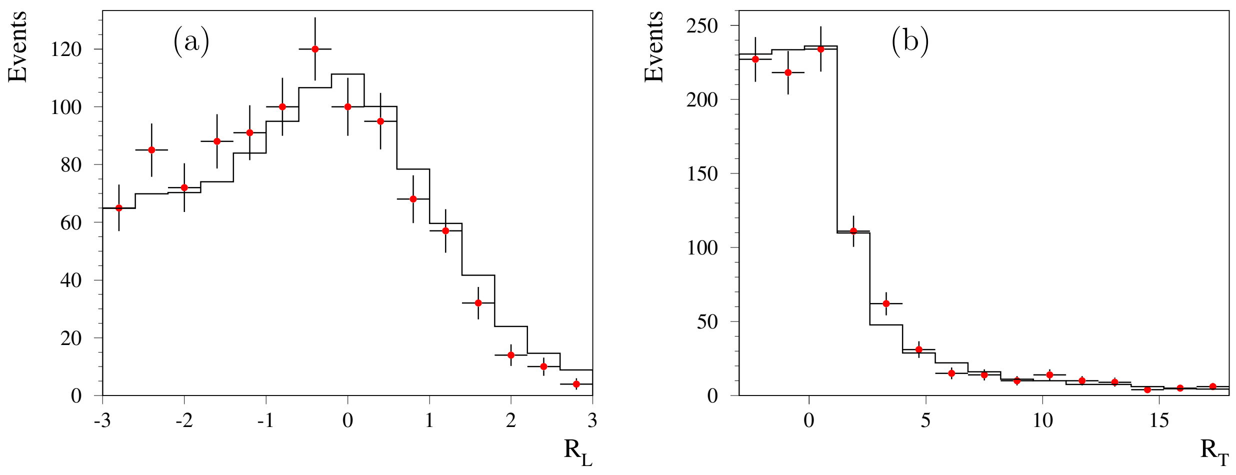

Figure 3: Distributions of (a) the R_L and (b) the R_T estimators for all tracks identified as electrons at the preselection level for data and standard model simulated events.

Lepton charges	opposite			same		
Lepton pair flavour	ee	$\mu\mu$	eμ	ee	$\mu\mu$	eμ
Expected background	32.7	7.7	32.0	30.1	6.1	27.5
Data	37	13	32	24	7	35

At this level, the slight excess observed is not originating only from the events with muons. However the excess in events with muons is still mainly from events with $\mathrm{ID_{muon}}$=11 tags.

To improve the $e^+e^- \rightarrow b\bar{b}$ purity, a cut on $\mathcal{P}_{event}$ is applied. Fig. 4 illustrates the variation of the number of events selected as well as the total number of events expected as a function of the cut performed on $\mathcal{P}_{event}$. To match the total expected number of events from standard model processes at 189 GeV to that expected in [1], $\mathcal{P}_{event}$ must be smaller than 0.001. Overall 24 events are selected when 19.4 are expected (corresponding to an excess of one standard deviation mostly due to an excess at $\sqrt{s}$ =200 GeV where 8 events are observed and 4.6 are expected). In total, 18.8 events with same signs leptons are expected from standard model processes and 18 are observed. The contributions of each lepton flavour is the following.

Lepton charges	opposite			same		
Lepton pair flavour	ee	$\mu\mu$	eμ	ee	$\mu\mu$	eμ
Expected background	6.9	2.8	9.7	7.2	2.8	8.8
Data	9	3	12	7	2	9

The slight excess appears in opposite signs events with electrons. Fig. 5 illustrates the R_T, R_L and $R_{\mathrm{dE/dx}}$ (wires only) estimators for charged particles identified as electrons in

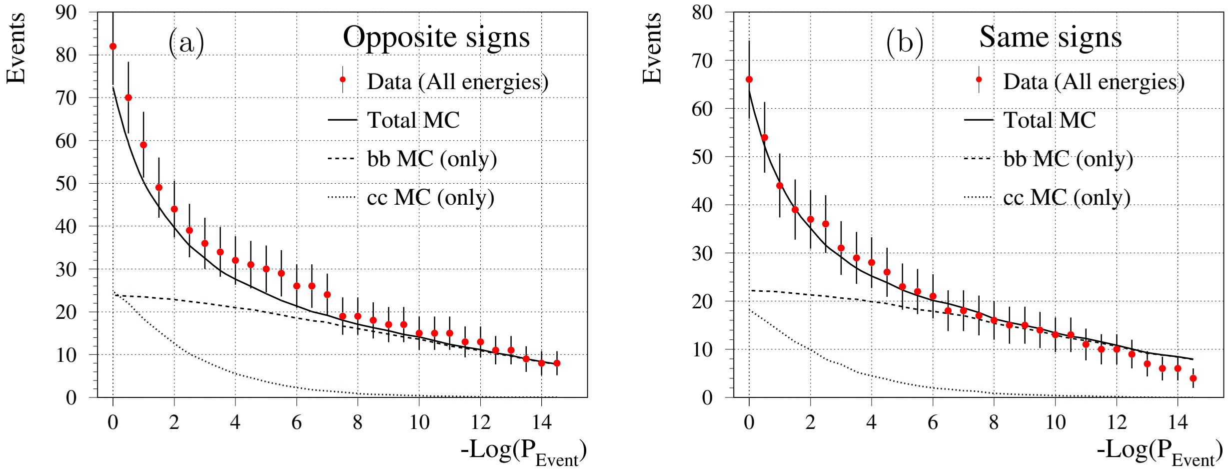

Figure 4: Data *vs.* Monte Carlo simulation comparison varying the cut on $\mathcal{P}_{event}$. The $e^+e^- \to b\overline{b}$ and $e^+e^- \to c\overline{c}$ contributions are also indicated.

opposite signs events passing all cuts except the b-tagging ($\mathcal{P}_{event}$ >0.001). The distribution of these estimators for signal events at $\sqrt{s}$ =200 GeV are also displayed therein. The excess appears for estimator values populated mostly by background events. These distributions also indicate that a tighter cut on the electron identification estimators would be profitable in terms of signal purity.

The selection efficiencies are displayed in Fig. 6a as a function of the cut on $\mathcal{P}_{event}$. The efficiency reached for $\mathcal{P}_{event}$ >0.001 is 26%.

Tightening the electron identification

When a tighter electron identification is used ($R_T > -1.6$, $-1.8 < R_L < 3$ and $R_{\mathrm{dE/dx}} > -2.5$) without changing the selection criteria, except the b-tagging which is not applied, 43 opposite signs events are selected in the data in agreement with 37.3 expected from standard model processes and 37 same signs events are observed with 31.1 expected, corresponding to an excess in the data of one standard deviation. The evolution of the expectation from standard model processes and the number of data events selected as a function of the cut on $\mathcal{P}_{event}$ is illustrated in Fig. 7. As was the case for the loose electron identification the slight excess observed without b-tag cut vanishes at higher $e^+e^- \to b\overline{b}$ purities. It can also be noted that the slight disagreement lies in the region where the $e^+e^- \to c\overline{c}$ is not negligible. The expectation from standard model processes at 189 GeV is matched to that in [1] with a looser cut on $\mathcal{P}_{event}$ (at 0.05), due to the higher purity obtained from the tighter electron identification criteria. When the latter cut is applied, 19.8 opposite signs events are expected from the simulation and 21 are observed. As expected, at roughly equal background levels, with the tighter electron identification a higher signal efficiency of 31.0% is obtained. As shown in Fig. 7b a slight excess of events in the same signs sample is observed, where 21 are selected while 16.7 are expected. The

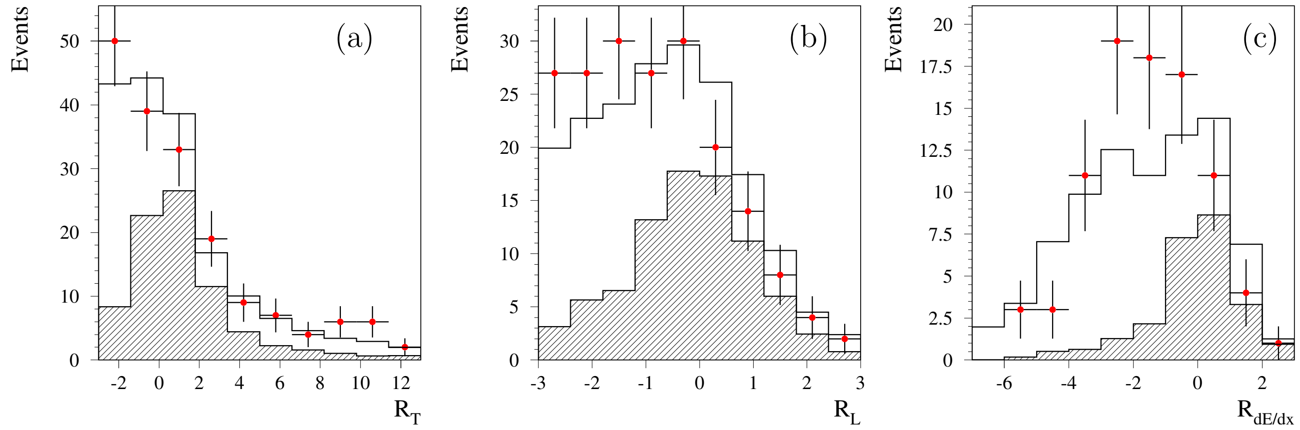

Figure 5: Distributions of R_T (a) R_L (b) and $R_{\mathrm{dE/dx}}$ (c) for the data at all available energies (dots) the standard model expectation (hollow histograms) and signal events at 200 GeV (slantered histograms).

different lepton flavour contributions to these numbers are as follows.

Lepton charges	opposite			same		
Lepton pair flavour	ee	$\mu\mu$	eμ	ee	$\mu\mu$	eμ
Expected background	5.1	4.7	10.0	4.1	3.7	8.9
Data	5	5	11	6	4	11

A good agreement for each flavour combinations is observed, especially for the opposite signs events.

Conclusion

An independent selection aimed at selecting $e^+e^- \to b\bar{b}$ events where the two b-quark decays are semileptonic to opposite charge leptons was carried out to verify the excess observed in the search for a light and long-lived scalar bottom quark [1]. The kinematic cuts of the event selection are the same as those used in the aforementioned analysis. In a first step the same lepton identification criteria as in [1] have been applied. In this first step a fair agreement between data and standard model expectations was seen, in contradiction with the excess reported in [1]. The only difference between the two approaches is the choice of lepton candidates. Then in a second step, using more stringent electron identification criteria, which showed a better performance in selecting signal events, the same conclusion was reached. These results allow to set an upper limit on the signal cross section at $\sqrt{s}$ =200 GeV of 101.6 fb with full background subtraction, without taking the systematic uncertainties into account. Without background subtraction the limit increases to 265.8 fb. Scalar bottom quark pair production, which cross section at $\sqrt{s}$ =200 GeV would be approximately 200 fb is therefore likely to be excluded. However,

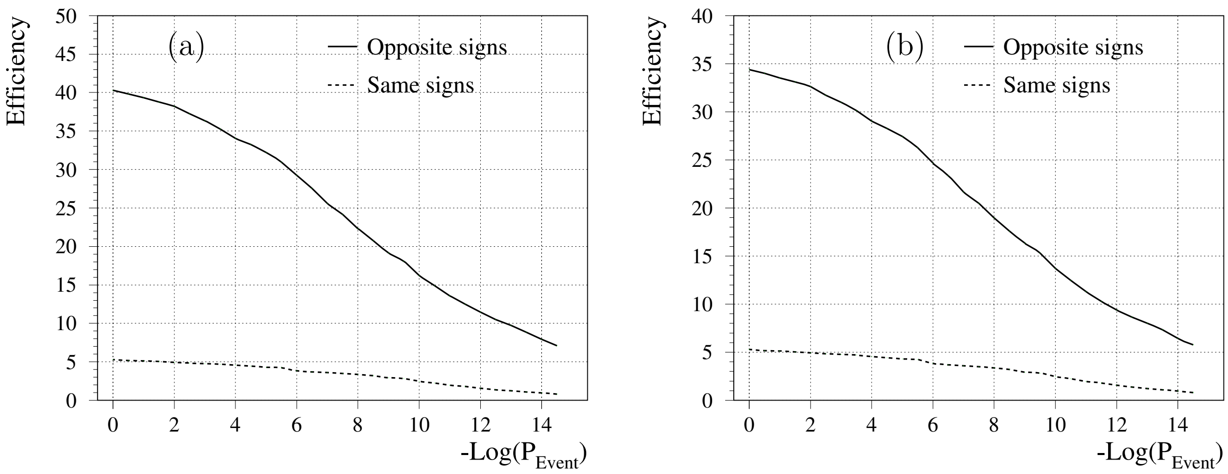

Figure 6: Selection efficiencies as a function of the cut on $\mathcal{P}_{event}$ with the loose (a) and tight (b) electron identification criteria.

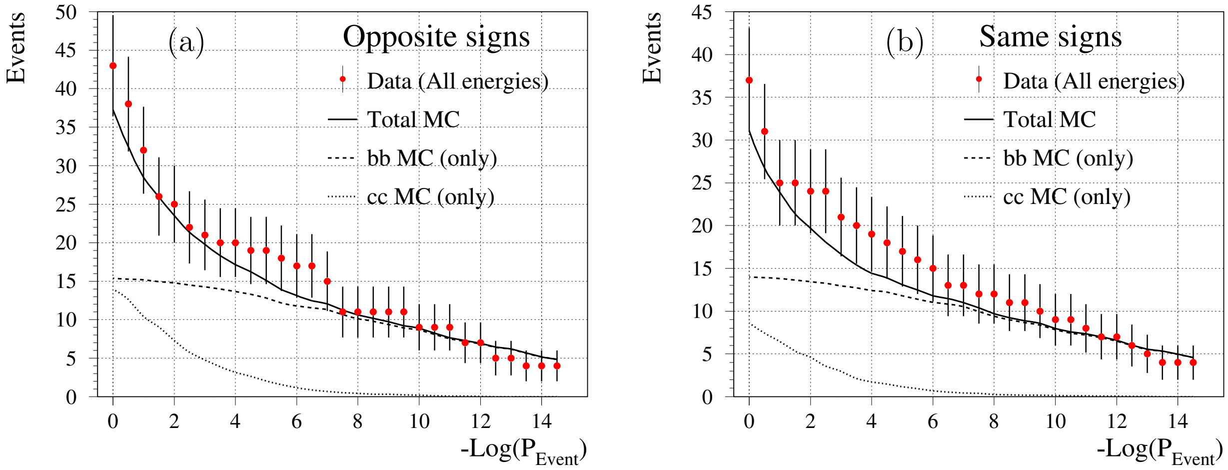

Figure 7: Data *vs.* Monte Carlo simulation comparison varying the cut on $\mathcal{P}_{event}$. The $e^+e^- \to b\bar{b}$ and $e^+e^- \to c\bar{c}$ contributions are also indicated.

a definite answer can only be given with a quantitative evaluation of the systematic uncertainties which, in this case, will mainly arise from lepton identification.

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References

[1] M. Antonelli and M. Maggi, *Thursday meeting presentation*, July 18th 2000.

[2] G. Taylor, *LEPC open session*, July 20th 2000.