OPERA note 88

Rock muons identification using the TT and the VETO detectors

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Abstract

An algorithm for the automatic recognition of rock muon events using the VETO and the TT OPERA sub–detectors is described. The algorithm has been applied to the Fall 07 neutrino beam data, to a rock muon MC simulation and to charged current MC events contained in the OPERA target. Finally, preliminary estimates of the expected performances are presented.

Contents

1 Hardware setup

In order to tag rock muons, muons generated from the interactions of the CNGS neutrino beam with the material surrounding the OPERA detector, the VETO and the Target Tracker, TT in the following, data are used. The developed algorithm has been applied to the Fall 07 neutrino beam data.
The VETO hardware setup and performances during the Fall 07 data taking period are summarized in [1].
A complete description of the TT can be found in [2]. What is relevant here is that the TT has 31 sensitive planes equipped with orthogonal scintillator bars. The gaps between the planes are filled with the OPERA “bricks”, alternate layers of lead and emulsion.
During the Fall 07 neutrino beam data taking period only the first TT SM was almost completely filled with “bricks”. In particular there were “bricks” only after the second TT wall. Hence any interaction occurring in the first two TT planes is most likely due to rock muons. Backscattering from a neutrino interaction occurring in the lead of the third wall, or deeper, could also generate some observable activity in the first two TT planes. Hence the first two TT planes can be used in conjunction with the VETO to tag with the highest possible efficiency rock muons.

2 Method

The event display of a typical rock muon event is shown in fig. 1. The hits recorded by the VETO detector are shown by the red bullets at a z of about -1000. cm. The hits associated to the rock muon track in the first TT SM and in the first harm of the first RPC SM are shown by the other red bullets of fig. 1.
As the bullets associated to the track are of the same color in the x, upper plot, and y, lower plot, projections this track has been reconstructed in 3 dimensions, 3D track in the following. In this particular event the tracks reconstruction package, OpRec, fails to associate all the TT hits of the rock muon to the track, as shown by the black bullets in the first walls on the first TT SM.
Keeping this is mind, as a first step, the algorithm is extrapolating the 3D track to the following planes:

- first wall of the first TT SM, TT1;
- second wall of the first TT SM, TT2;
- VETO external plane, VETO1;
- VETO internal plane, VETO2;

and looking for “nearby hits” in each of the above planes. So even if the 3D track ends before TT1 (TT2) the algorithm will anyway search for “nearby hits” in TT1 (TT2). Hence the algorithm will not be affected by the failures of the OpRec shown in fig. 1.
A straight line extrapolation is performed because in the region between the VETO and the end of the first TT SM the magnetic field strength is negligible.
“Nearby hits” are defined by computing the distance between the track extrapolation

and the TT or VETO measured position in the relevant plane. In case more that one hit is present the minimal distance is retained. Fig. 2 shows the distribution of the minimal distance for the x projection of TT1 or TT2, upper left plot, the y projection of TT1 or TT2, upper right plot, the x projection of VETO1 or VETO2, lower left plot, and the y projection of VETO1 or VETO2, lower right plot. All the hits with distance below 10 cm for the TT or 30 cm for the VETO, as shown by the red lines in fig. 2, are counted as "nearby hits". Fig. 2 is obtained with the "ontime with CNGS" neutrino beam data recorded in Fall 07. Due to the hardware setup for both TT1, TT2, VETO1 and VETO2 the number of "nearby hits" can be 0, 1 or 2. The distribution of the x and y distances, also referred to as residuals, for the VETO planes is quite broad. This observation triggered some work on the understanding of the VETO position summarized in the next section.

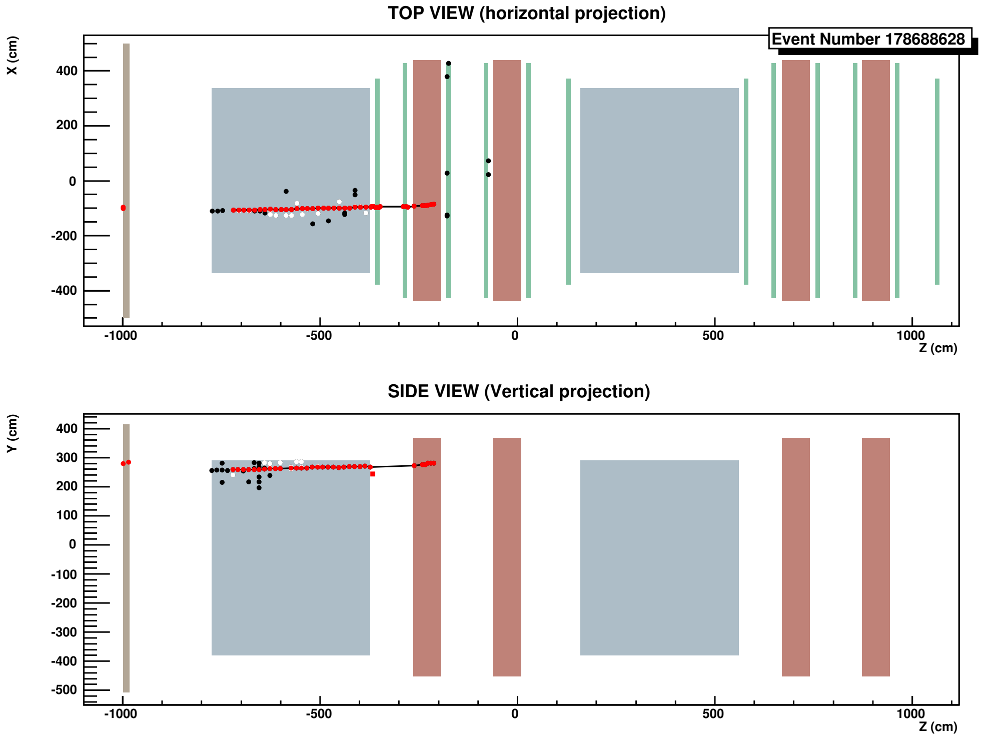

Figure 1: Event display of a typical rock muon event.

Some more events are shown in fig. 3. The two upper plots show rock muon events. The lower left is very likely a contained event with two "nearby hits" in TT2, likely due to backscattering, but no hits in TT1 and VETO. The lower right event has no hits in VETO and one nearby hit in both TT1 and TT2. In this case a reliable response from the VETO is mandatory to firmly assess if this event is contained or not.

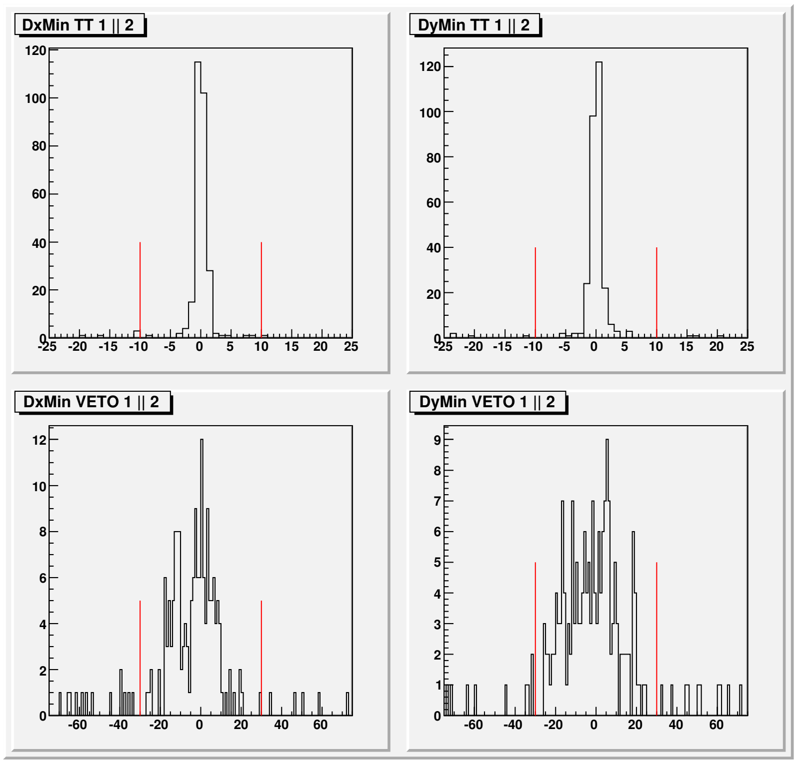

Figure 2: Distance between the track extrapolation and the TT or VETO measured position in the relevant plane. The two upper plots are for the x and y projections of TT1 and TT2. The two lower plots are for the x and y projections of VETO1 and VETO2.

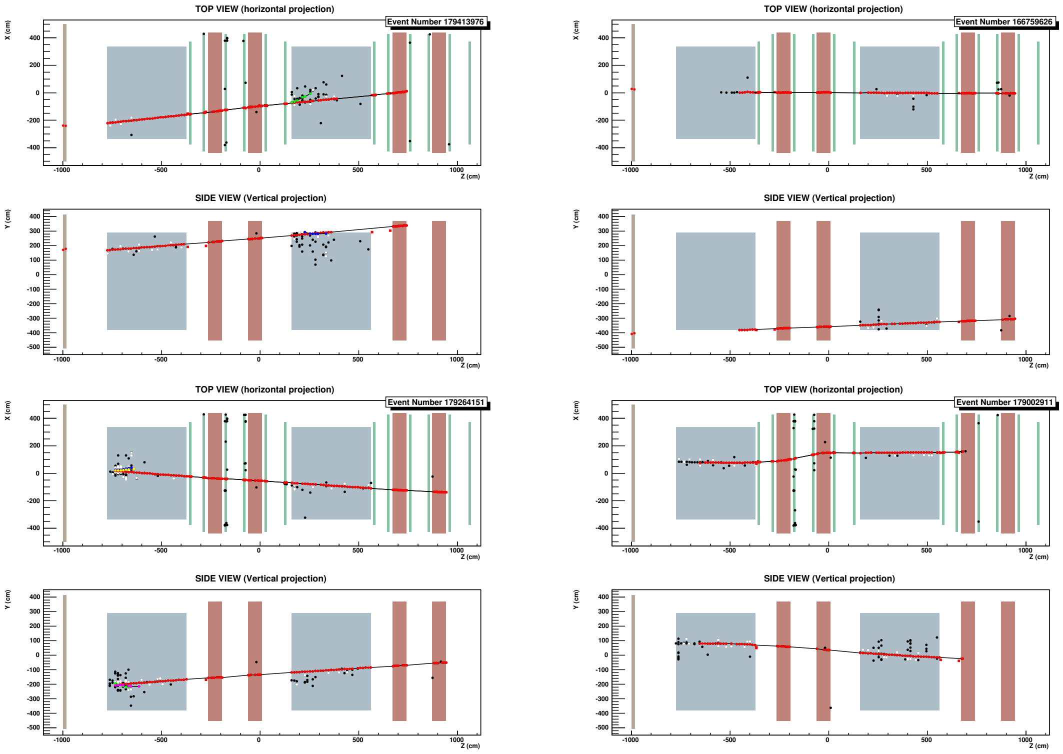

Figure 3: The two upper plots show rock muon events. The lower left is very likely a contained event with two "nearby hits" in TT2, likely due to backscattering, but no hits in TT1 and VETO. The lower right event has no hits in VETO and one nearby hit in both TT1 and TT2: this is a particularly ambiguous event.

3 Improvements in the understanding of the VETO residuals

After the results of fig. 2 were obtained for the VETO residuals the following corrections were taken into account:

- the pitch of the VETO strips implemented in the OPERA geometry files was set to 2.4 cm, fixing a previous bug;
- the position of the VETO planes was shifted by + 20 cm along the z direction with respect to the position implemented in the OPERA geometry files.

The "ontime with CNGS" Fall 07 neutrino beam data were then reprocessed taking the two above points into account. The new residual distributions for the x and y projection of VETO1 and VETO2 are shown in fig. 4. The improvement with respect to fig. 2 is striking.

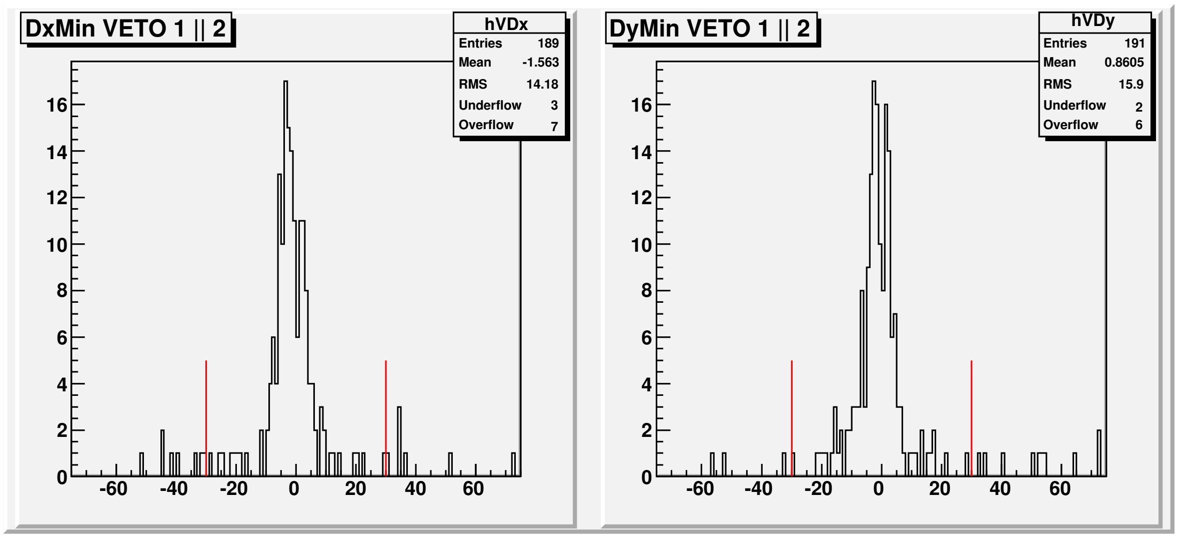

Figure 4: Residuals for the x and y projections of VETO1 and VETO2 after the strip pitch and z position corrections.

4 Results on Fall 07 beam data

As seen in sec. 2 for each 3D track the algorithm provides the number of "nearby hits" seen in TT1, TT2, VETO1 and VETO2. We can then plot along the x axis the sum of the number of hits in TT1 and TT2, TT(wall 1&2) in the following, and along the y axis the sum of the number of hits in VETO1 and VETO2, VETO in the following. Both the x and y coordinates span the range between 0 and 4. The result obtained using the "ontime with CNGS" Fall 07 neutrino beam data is shown in fig. 5.

There are 30 tracks with $x = y = 4$, this is the maximum possible number of hits and almost certainly the events containing these tracks are rock muons. The upper left event of fig. 3 has $x = y = 4$. There are also 7 tracks with $x = 0$ and $y = 4$, one

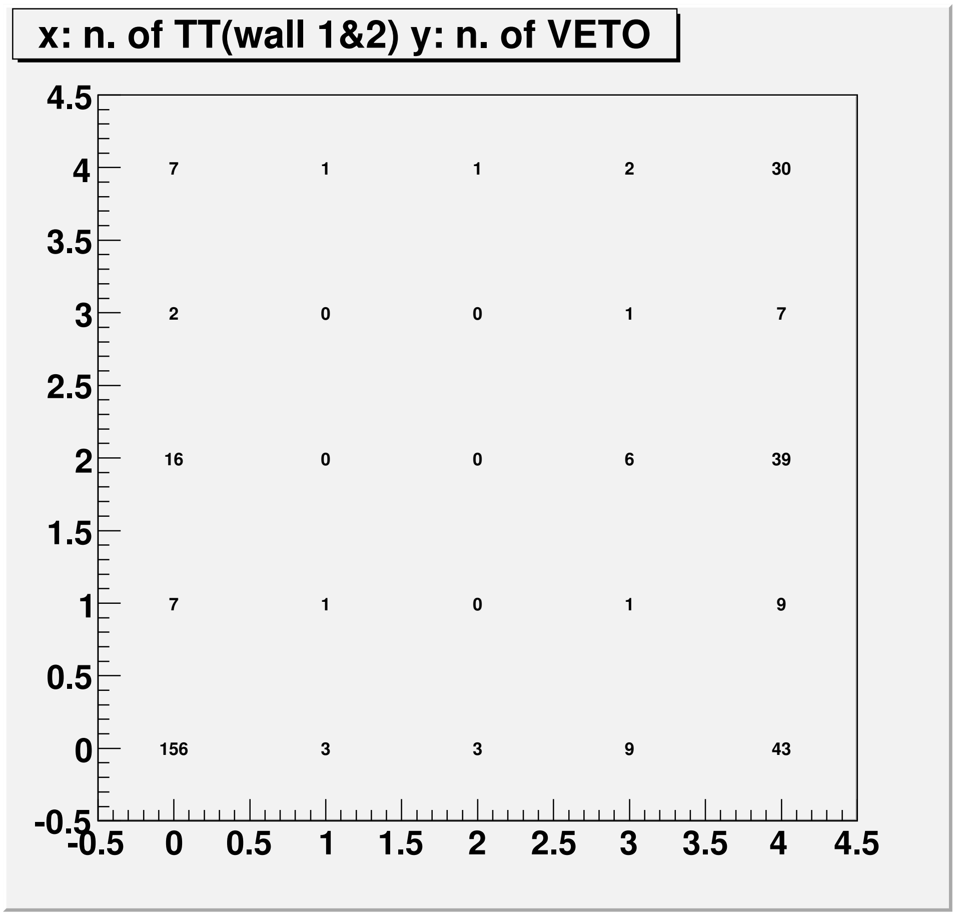

Figure 5: Number of “nearby hits” in TT(wall 1&2) vs number of “nearby hits” in VETO. The “ontime with CNGS” Fall 07 neutrino beam data sample was used.

event with such a track is shown in the upper right part of fig. 3. These “off axis” rock muons can only be tagged by the VETO. The events with $x = 4$ and $y = 0$ are rock muons crossing the first two TT planes not seen by the VETO, these events are a symptom of the not so good performances of the VETO system during the Fall 07 neutrino run [1]. When the total number of hits decreases the events become more ambiguous: the lower left and lower right events in fig. 3 have $x = 2$ and $y = 0$.
Finally there is a rather large cluster of events at $x = y = 0$ i.e. no hits in the first two TT walls and in the VETO system. Neutrino interaction events occurring inside the OPERA target are expected to populate this bin. So in order to safely isolate unambiguous rock muons events we can require $x + y \geq 3$.

5 Results on rock muons MC events

The algorithm was also tested on a sample of neutrino interactions generated everywhere outside the OPERA target. The following processes have been taken into account: charged current, neutral current, quasi–elastic and resonant. The distribution in the x y plane obtained from this sample is shown in fig. 6.

The fraction of events that have too few hits to be detected, mostly in the bin $x = y = 0$, is about 36 %. As a consequence about 64 % of the MC rock muon events are correctly tagged by this algorithm.
As explained before, the $x = 0$ and $y = 4$ events, but also $x = 0$ and $y = 2$, can only be tagged by the VETO. MC events with $x = 0$ and $y = 2$ occur because the two VETO planes are shifted along the y direction so at large (in absolute value) y only one layer can be crossed. The result of this MC simulation suggests that about 20 % of the rock muon events, bins $x = 0$ $y = 4$ and $x = 0$ $y = 2$, can be tagged only by the VETO.

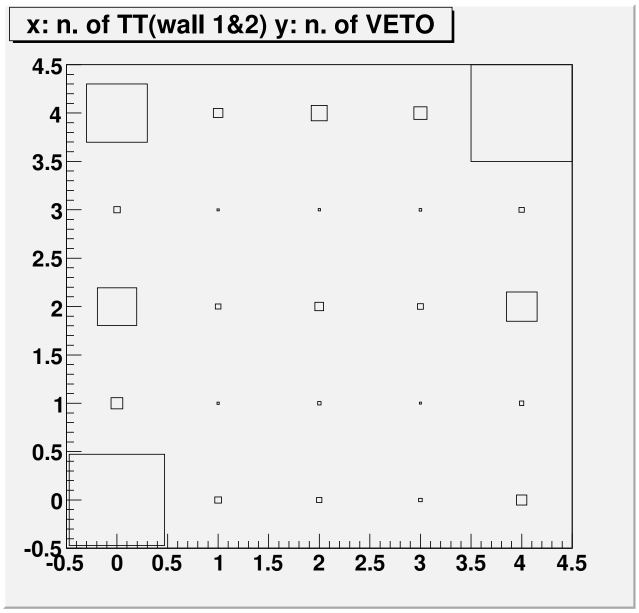

Figure 6: Distribution of the number of hits in TT(wall 1&2) vs VETO for a MC sample of rock muon events.

The x vs y distribution obtained from the rock muon MC sample shows a strong dependence on the volume in which the primary interaction occurred. The upper plot in fig. 7 shows the x vs y scatter plot for interactions in the rock in front of the OPERA experiment. As expected the relative population of the $x = y = 0$ bin is small i.e. most of the rock muons generated in front of OPERA are properly tagged. The lower plot in fig. 7 is for interactions occurring in the "basement" of the experiment. In this case a large fraction of the rock muons are not leaving hits in the first two TT planes nor in the VETO. The event display of such a MC event is shown in fig. 8.

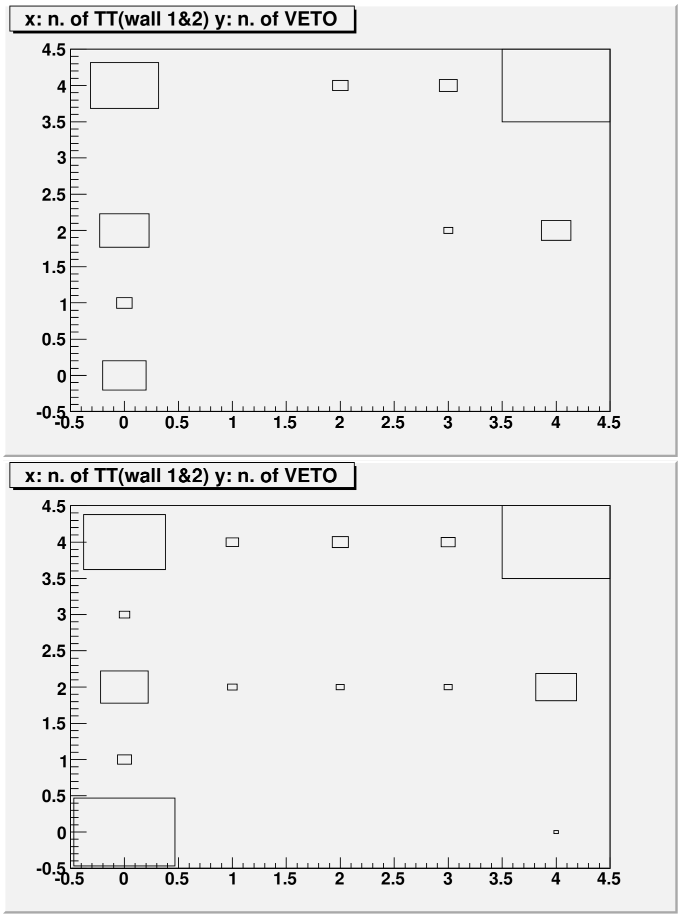

Figure 7: x vs y distribution for MC rock muon events in which the primary interaction occurred in the rock in front of the OPERA experiment, upper plot, and in the "basement" of the experiment, lower plot.

The distances used for the "nearby hits" definition obtained from a subsample of the rock muons MC events are shown in fig. 9. The two lower plots are for the VETO residuals. The same distributions obtained from the "ontime with CNGS" Fall 07 neutrino beam data have already been shown in fig. 4. The RMS measured on data and MC are in good agreement.

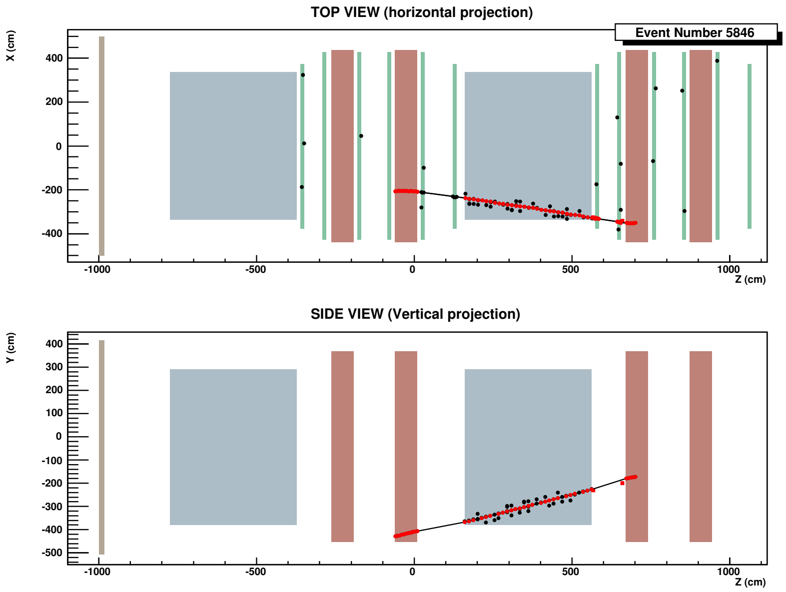

Figure 8: Event display of a rock muon MC event generated in the "basement" of the detector leaving no hits in the VETO nor in the first two wall of the first SM TT.

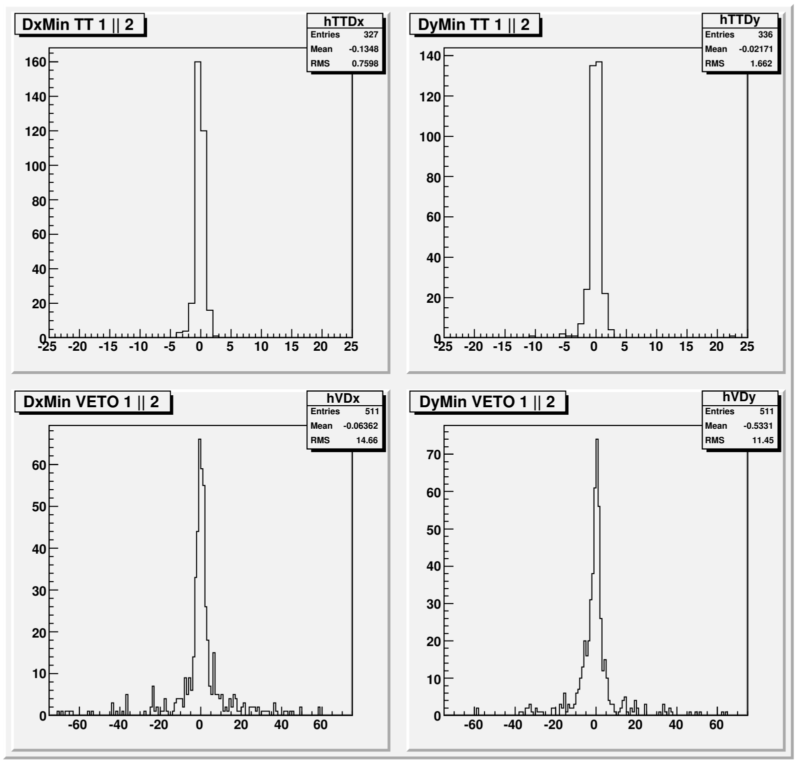

Figure 9: Distances used for the "nearby hits" definition obtained from a subsample of the rock muons MC events. The upper plots are for the first and second TT walls, the lower ones are for the VETO, respectively.

6 Results on CC contained events

As a last step, the algorithm was applied to a sample of MC charged current events, CC in the following, occurring in the lead inside the OPERA target.
In the MC simulation the first two walls were completely empty but all the following walls were completely full of "bricks". This is is not true because, due to mechanical problems, not all the raws are completely full of "bricks", some raws are even completely empty. At the time this document is being written it is not yet possible to have a fully realistic simulation of the "brick" filling pattern in the MC. Future studies will be needed to evaluate the impact of raws not fully filled on the developed algorithm.
The available MC sample contained 3200 events. The resulting x vs y distribution is shown in fig. 10. As expected the largest fraction of the events occurs in the $x = y = 0$ bin.
If we consider again the cut $x + y \geq 3$ only 6+1+1+1 events have some activity in the VETO (bins 1–2, 2–1, 4–1 and 4–2); this is about 0.3 % of the initial MC sample.
If we take into account also the activity in the TT two new bins have to be considered (bins 4–0 and 3–0) and the overall number of discarded events is 6+1+1+1+19+19; this is about 1.5 % of the initial MC sample. These events are mis–tagged as rock muons.
In this case the activity seen in the VETO or in the first two TT walls is likely due to backscattering. Fig. 11 shows 4 event display pictures of mis–tagged events.

For completeness fig. 12 shows the "nearby hits" distances obtained with the MC CC contained event sample. In the TT case a clear peak at zero is still visible and hence reducing further the minimal distance would only partially help in reducing the number of mis–tagged events.

7 Conclusions and future prospects

An algorithm for the automatic recognition of rock muon events using the VETO and the TT OPERA sub–detectors has been setup. The algorithm has been applied to the Fall 07 neutrino beam data. The analysis has shown that it is possible to split the events in tree samples: unambiguous rock muon events, ambiguous rock muon events and events with no hits in VETO nor in the first two wall of the first SM TT.
The analysis of a sample of rock muon MC events has shown that about 64 % of the rock muons can be unambigously recognised. About 36 % of the remaining rock muons are not leaving hits in the VETO nor in the first two wall of the first SM TT. Most of the MC rock muons generated in the "basement" of the experiment are of this type. Further studies are in progress to tag automatically these events taking into account informations from other detectors.
Furthermore the algorithm has been applied to a sample of MC CC events generated in the lead of the OPERA target. Due to backscattering, about 1–2 % of these events are mis–identified as rock muons. This result was obtained simply by counting the number of "nearby hits" but with a more refined usage on the TT granularity it should be possible to reduce further the fraction of mis–identified events.

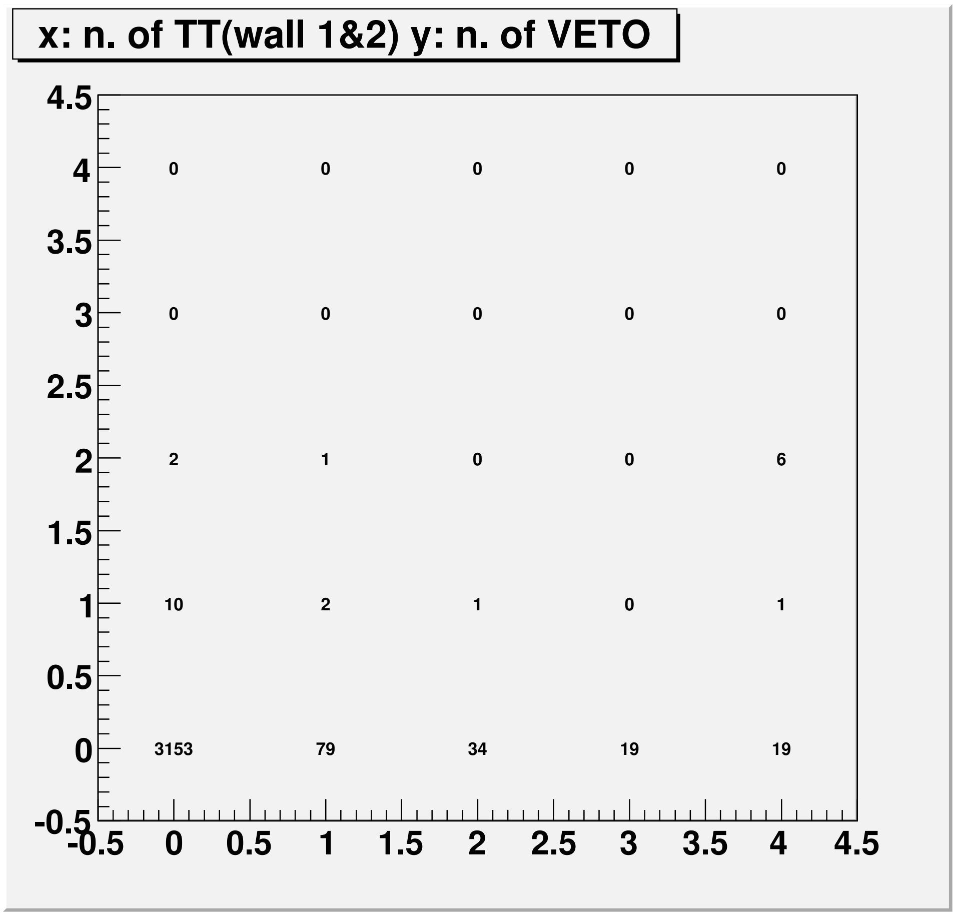

Figure 10: x vs y distribution for a sample of MC CC events occurring in the lead inside the OPERA target.

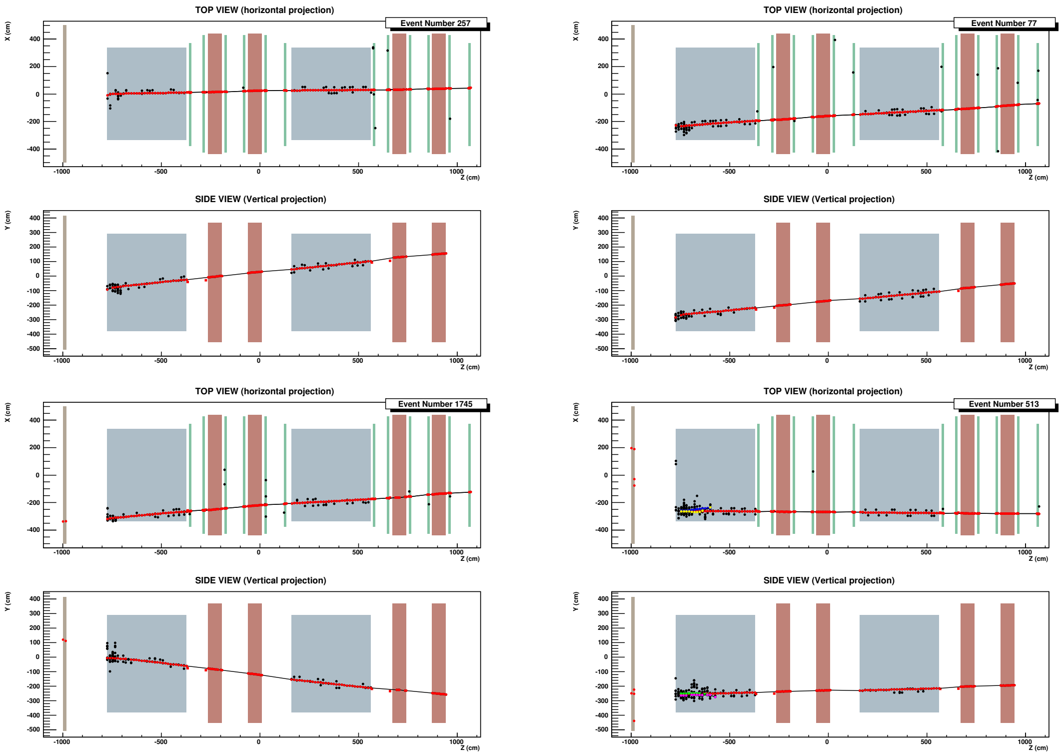

Figure 11: Event display pictures of MC CC contained events showing activity in the first two TT planes or in the VETO.

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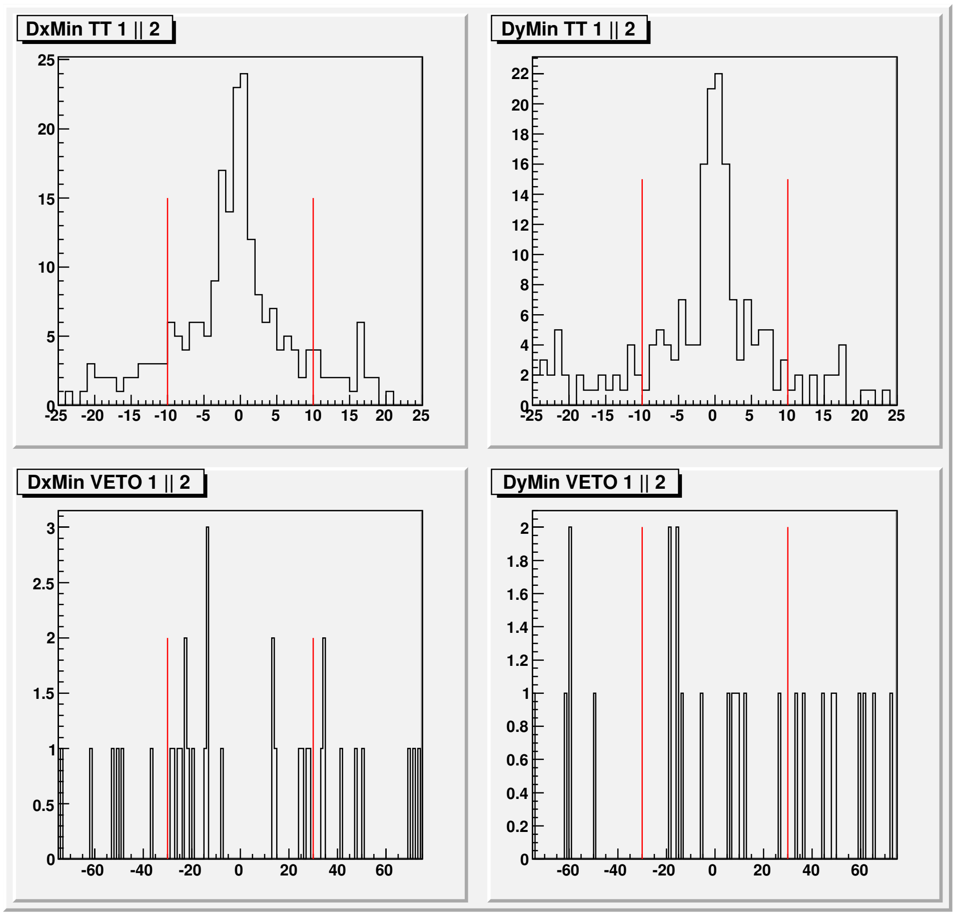

Figure 12: "Nearby hits" distances obtained with the MC CC contained event sample.

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[2] The OPERA experiment Target Tracker, T. Adam et al., Nuclear Instruments and Methods in Physics Research, A 577 (2007) 523–539;
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