# Brick finding efficiency in muonic decay tau neutrino events

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# Brick Finding Efficiency in Muonic Decay Tau Neutrino Events

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**Abstract**

In this paper a new algorithm is used for the brick finding of muonic decay tau neutrino events. The new algorithm uses Hough Transform to select the most significant strips. The events are then classified in few categories depending on the nature of the neutrino interaction. A neural network based on kinematics and geometric configurations of each category is then used to select the right wall. Once the right wall is found the strips selected by the Hough Transform are used to find the X-Y position of the neutrino interaction vertex. The brick finding efficiency of this new algorithm is 72.3%. This represents a tangible improvement with respect to the performance of the previous algorithm used in OPERA [1]

# 1 Introduction

An essential issue in OPERA is the finding of the right brick in which the neutrino interaction takes place. This is a crucial point when looking for evidence of tau neutrino appearance through the detection of a tau. The tau decays in many channels but the muonic decay mode is by far the most relevant channel for a detector like OPERA since the presence of the muon in the final state could be detected thanks to the spectrometer. Finding the right brick will then allow to search for a tau-muon kink inside the nuclear emulsions.

The neutrino charged current interactions through which the tau is produced, are of two kinds, either quasi-elastic (QE) or deep inelastic scattering (DIS). In the first case, only a tau is produced while an additional hadronic shower is present in the second. An important issue related to the wall finding is the presence in part of the neutrino interaction events of back-scattered particles. This may fake the information concerning the position of the brick in which the interaction vertex is present. Back-scattering is more present in DIS events (50%) than in QE ones (10%) which explains why the wall finding efficiency will depend on the nature of the neutrino interaction. The back-scattered particles are usually low-energy ones and deviated from the event axis. The plane containing the strips touched by those particles is easily distinguished. However in some events the back-scattered particles are either energetic or located on the event axis or even both. In this case it is difficult to separate the back scattered particles from those produced in the forward direction of the event determined by the neutrino beam. This last scenario may happen for events for which the reaction takes place at the begining of the brick.

In order to get rid of those touched strips due to back-scattered particles as well as those due to electronic noise, Hough Transform (HT) is used. This helps at least to clean the events from isolated and disconnected strips. The next step is to select the first scintillator planes of each event in order to determine which of those planes is the one located after the vertex in the downstream direction with respect to the neutrino beam. The touched strips in the following planes are then used to determine the visible energy event axis in both (z,x) and (z,y) planes. The intersection of those two axes with the first plane determines the brick in which the interaction vertex is located.

In this paper the first section will be devoted to explain how the Hough Transform is used for cleaning each event. In the second section, the selection of the first planes and events classification will be detailed and the variables used in the different neural networks will be explained. The results of wall finding efficiency are then quoted in the third section. In the last section the method used to find the (x,y) interaction position is shown with the total efficiency of the brick finding.

# 2 Hough Transform for event cleaning

The Hough Transform method was proposed in 1962 by P.V.C Hough [2] to get rid of noises in the images obtained from the bubble chambers. It is based on the fact that hits located on geometric lines like straight lines or even curved ones can be distinguished from isolated hits. The success of this method went beyond high energy physics to become one of the powerful methods used in the signal treatment field. In this method, each hit is determined by two coordinates say (x,y). An infinity of directions passing by (x,y) and covering the $2\pi$ angular orientations are associated to each hit. Each direction can be expressed using polar coordinates $(\rho, \theta)$:

$$\rho = x \cos\theta + y \sin\theta$$

It is clear that each hit gives birth to a sinusoidal curve. The hits located on the same straight line will have their curves intersecting in the $(\rho, \theta)$ related to that very line as shown in figure 1. In practice the number of orientations should be limited and chosen according to the experimental angular resolution in order to obtain the different curves intersection. This can be achieved by constructing a bi-dimensional histogram of $(\rho, \theta)$ where each hit contributes to fill a number of bins located on its sinusoidal curve. The different straight lines of the events can then be determined by picking up the most filled bins of the histogram.

In OPERA the bricks walls are perpendicular to the beam axis and each wall is followed by a scintillators wall made of two planes. The first one is y-coordinate scintillators plane whereas the second is x-coordinate one. Seen from the scintillators, each event is a sum of strips in (y,z) and (x,z) planes. An important part of the back-scattered particles are low energy ones and deviated from the principal geometric event axis (which often coincides with the outgoing muon). Electronic noises as well as neutral particles interactions are disconnected strips for the former or showers of strips for the latter. In all these configurations the HT method can be used to eliminate or at least reduce the associated strips making the vertex location much more easier.

In our case, two histograms, one for x and the other for y-oriented strips, of 50 bins, covering a $2\pi$ range for the $(\theta)$ axis, and 50 bins, covering $\rho$ up to its maximum possible value, are filled by all the touched strips in each event. In each histogram the most populated bin was singled out and its value used as a reference. Bins with values more than 95% of the reference are kept. Hits belonging to straight lines associated with the previous bins are tagged as HT-strips. In figure 2 the selected HT strips are shown with respect to all touched strips for one of the muonic decay tau events in both (y,z) and (x,z) orientations.

For events in which all the hit strips are located in one scintillators wall, all the strips are considered as HT-strips since the Hough transform is useless in this case.

# 3 Scintillators walls selection

An important step in finding the right wall in the new algorithm is a preliminary selection of some scintillators walls (up to four) which are likely to be candidates for being the first downstream wall after the vertex. The choice of the first of these walls is of the utmost importance since in the absence of back-scattered particles the first touched scintillators wall is the one of interest while in the presence of back-scattered particles the first touched wall and even one or two successive walls are to be eliminated.

The strategy adopted here is to reject all touched walls if any of the four following walls is not touched at all or touched but with collected energy less than 6 photo-electrons in each scintillators wall. This strategy is also applied for those events where the first wall is near the end of the target detector. In this case the number of four walls is replaced by the available number of walls behind the first one. The aim of the previous step is to eliminate the touched planes due to neutral back-scattered particles like neutrons reinteracting far behind the vertex.

Starting from the first wall fulfilling the previous condition, only scintillators walls containing at least one HT strip for each orientation (x and y) are kept.

For events with low number of strips (less than 2.5 strips/plane) the first scintillators wall is selected even if it does not fulfill the previous condition and walls with at least two strips are selected even if they are not HT selected ones. This is intented to limit the loss of efficiency for QE for which back scattering is low.

For each selected scintillators wall the following variables are then estimated:

- Number of photo-electrons detected in each selected scintillators wall
- Number of hit strips in each selected scintillators wall
- The geometric dispersion of the strips in each selected wall calculated as:

$$\sigma = \sqrt{\sigma_x^2 + \sigma_y^2}$$

  where $\sigma_x(\sigma_y)$ is the dispersion in the x(y) oriented plane defined as the maximum distance of any two strips in this plane
- The mean distance of the strips of each plane with respect to the event principal axis defined by the HT strips of the first scintillators planes of each event (except the very first one). The determination of the event principal axis will be presented in th x-y vertex position determination section.

# 4 Wall finding efficiency

The muonic decay tau events are separated in three categories depending on the number of the selected walls and on the mean number of strips per wall of scintillators. This separation is motivated by the fact that the neural network performance used to locate the right wall is improved by separataing QE-like from DIS-like events and also by separating events with small shower development from those of important one. The three categories of events are defined as follows:

- Events with less than two touched walls of planes of scintillators
- Events with more than two touches walls of planes and a mean number of strips/wall less than 2.5
- Events with more than two touched walls of planes and a mean number of strips/wall more than 2.5

Three neural networks are used, one for each category. In the first category, only 6 variables are considered. The collected energy, the number of strips and the geometric dispersion in each of the two walls of scintillator planes are the variables used to train the neural network. For the next two categories the mean distance of the strips in each wall with respect to the event principal axis is also used. In addition to those variables estimated for the three first touched walls, the total collected energy as well as the mean number of strips per wall are also introduced to train the neural network.

The neural network used is the Stuttgart Neural Network Simulator (SNNS) [3] with feed forward, standard back propagation option. The number of hidden layers used in this NN is one with as many nodes as the number of used variables.

The number of the outputs is one for the first category and 3 for the others. The outputs give the probability of each of the considered walls to be the first plane after the vertex. In figure 3 the weight of each variable used in the neural network is shown for one of the three neural networks. Figure 3 shows that the collected energy of the scintillators walls is by far the most important one. The training and the validation of these NN use as many as 24000 events. 6000 events are then used to determine the efficiency of finding the right wall of brick. 30% of these events are QE events.

The events used in this study are tau neutrino events with the same energy spectrum as the LNGS muon neutrino beam one [4]. Taking into account the oscillation effect on the energy spectrum will not affect the result of the present analysis. This can be seen in figure 4 which shows that the wall finding efficiency does not depend on the neutrino energy.

In table 1 the efficiency and the proportion for each of the three categories of tau-muon events are shown.

| Category | Composition(%) | Efficiency(%) |
|---|---|---|
| first | 5.6 | 93.4±1.4 |
| second | 41.5 | 91.7±0.6 |
| third | 52.9 | 85.6 ±0.6 |

Table 1

Taking into account the proportion of each category the total wall brick finding efficiency is found to be:

| Wall Brick Finding Efficiency = 88.6±0.4% |
|---|

# 5 X-Y vertex position determination

Once the right wall is found, the event principal axis is used to determine the x-y position of the vertex. The determination of this axis is identical to the one used to estimate the strips distance variable mentioned before, except that here we include the first touched plane when it is the first plane after the vertex. In the following we give a short description of this determination.

The event direction in both (x,z) and (y,z) planes, is determined using selected hit strips. These strips are chosen according to the event topology:

Only HT-selected strips are used when they satisfy the followoing requirements:

- The distance of the strip to the geometric centre of the hit strips is less than D. The initial value of D is 30 cm. It is then decreased step by step ( 3 cm each) until the fit of the straight line passing by all the chosen strips is good enough ($\chi^2 \leq 5$). In any case the value of D could not go under 5 cm.

- Strips should belong to the first N planes when possible. N is determined as following

N=10 for events with number of strips per wall of scintillators planes less than 2.5

N=7 for events with number of strips per wall of scintillators planes more than 2.5

N=2 when only two walls are selected

These numbers take account of the different topologies encountered in the muonic tau's decay events.

The selected strips are then used to fit two lines, one in the (x,z) plane and one in the (y,z) plane. The intersections of the two fitted straight lines with the first scintillator wall after the right brick wall, are considered as the predicted (x,y) coordinates of the vertex. The brick located in the right wall and containing the predicted (x,y) coordinates is then considered as the right brick.

Comparison between the predicted brick and the one within which the neutrino interaction takes place shows that in events where the right wall was correctly predicted, the brick prediction is correct for 81.7% of the events.

| Vertex Brick Finding Efficiency = 81.7 ±0.5% |
|---|

# 6 Conclusion

The total efficiency of finding the brick in which the neutrino interaction takes place in the muonic tau decay events is improved using a new algorithm. The new algorithm uses the Hough Transform technique as a preselection of the significant strips. The neural network technique is then used after separating the events in three categories according to their topolgy. Once the wall is found, a fit of the event thrust in both (x,z) and (y,z) is done to determine the right brick. The total efficiency of finding the right brick in the muonic decay of tau neutrino events is then estimated to be 72.3%.

| Brick Finding Efficiency = 72.3±0.6% |
|---|

Optimisation of the previous algorithm will certainly allow to improve this efficiency especially in the vertex coordinates determination where more sophisticated tracking algorithm using topoplogies of one, two and many branches can be used. The improvement on the wall finding efficiency can also be possible by studying thoroughly the HT criterion selection and by improving the separation between QE-like and DIS-like events.

The next step to this work is to extend the improvement to the brick finding efficiency for tau neutrino events with the tau decaying through hadronic and electronic channels.

# References


[1] M. G. Moret et al. OPERA internal note 23 May 2001, 'Brick finding efficiency: comparisons between several scintillator tracker options'.

[2] HOUGH P.V.C Methods and means for recognizing complex patterns. United States Patents, n.3, 069, 654, 18 December 1962.

[3] A.Zell et al. SNNS User manual, Version 4.1, Report N 6/95. SNNS is(c) (Copyright) 1990-95 SNNS Group, Institue of Parellel and Distributed High-Performance Systems(IPVR),University of Stuttgart, Breitwiesentrasse 20-22, 70565 Stuttgart, Germany.

[4] G.Acquistapace et al., CERN 08-02, INFN/AE-98/05, 19 May 1998.

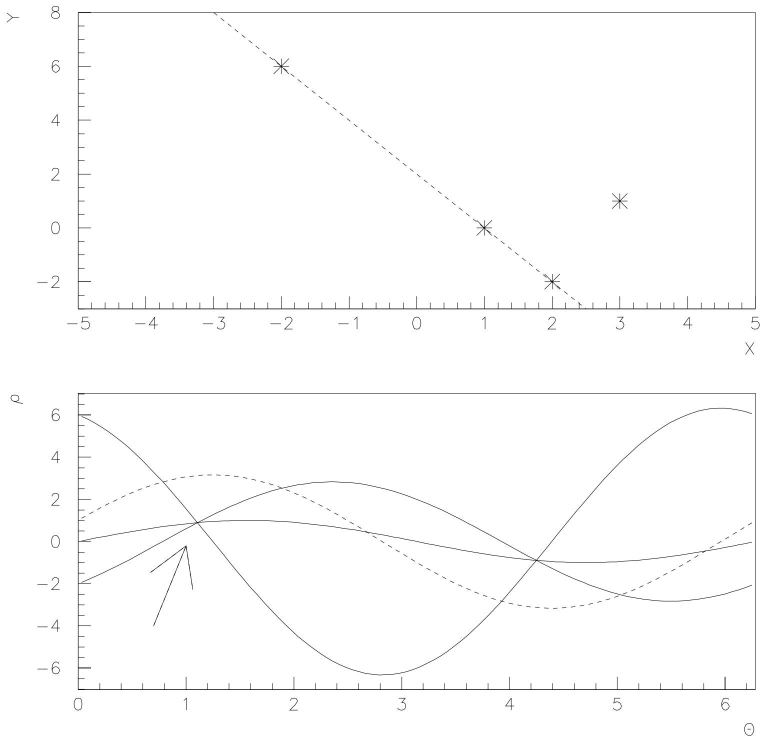


Figure 1: Illustration of the Hough Transform method with a)four points three of them on the line defined by y=-2X+2 and one outside b)the associated curves of the four points in the $(\theta, \rho)$ plane.

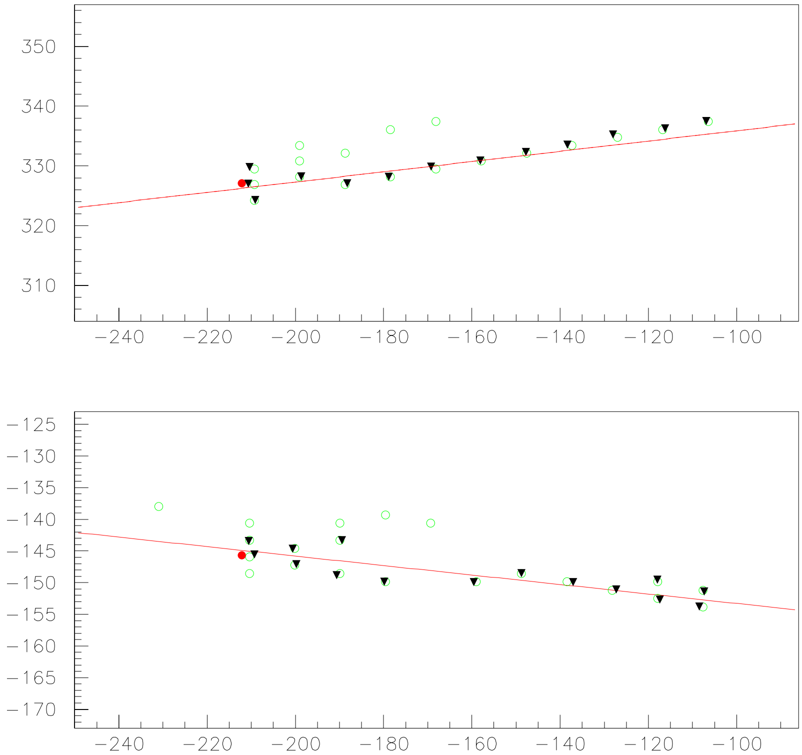


Figure 2: An exemple of HT selected strips. The HT selected ones are tagged with triangle markers and the black circle represents the vertex position. a) in the (x,z) plane, b) in the (y,z) plane. Distances are in cm.

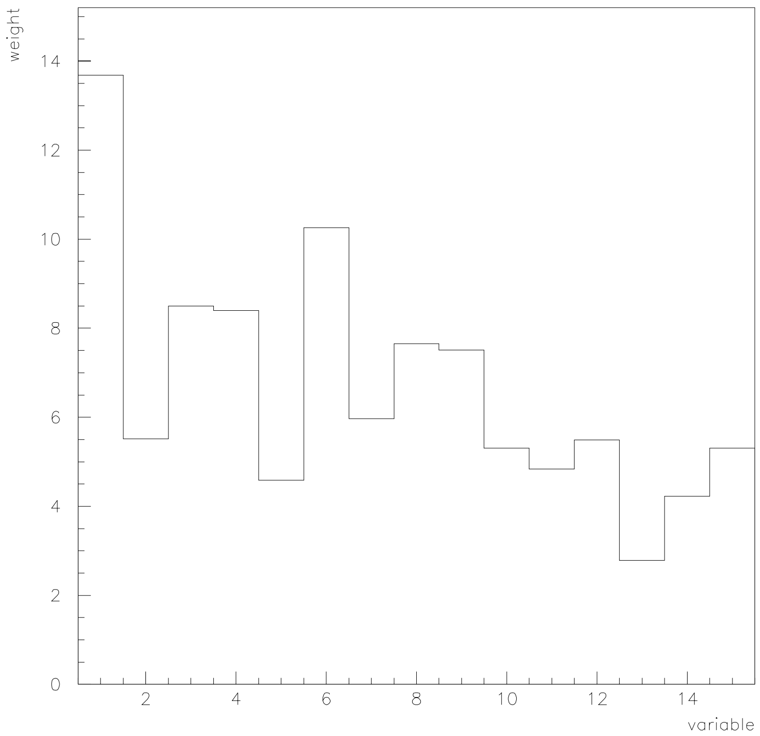


Figure 3: Weight of the different variables of the second category of events:
var1: number of photo-electrons in the first plane
var2: dispersion in the first plane
var3: nb of strips in the first plane
var4: distance with respect to the event axis in the first plane
var5: ratio of the number of photo-electrons in the first plane with respect to the second one
var6: number of photo-electrons in the second plane
var7: dispersion in the second plane
var8: nb of strips in the second plane
var9: distance with respect to the event axis in the second plane
var10: number of photo-electrons in the third plane
var11: dispersion in the third plane
var12: nb of strips in the third plane
var13: distance with respect to the event axis in the third plane
var14: total number of photo-electrons in the event
var15: number of strips/wall of scintillators

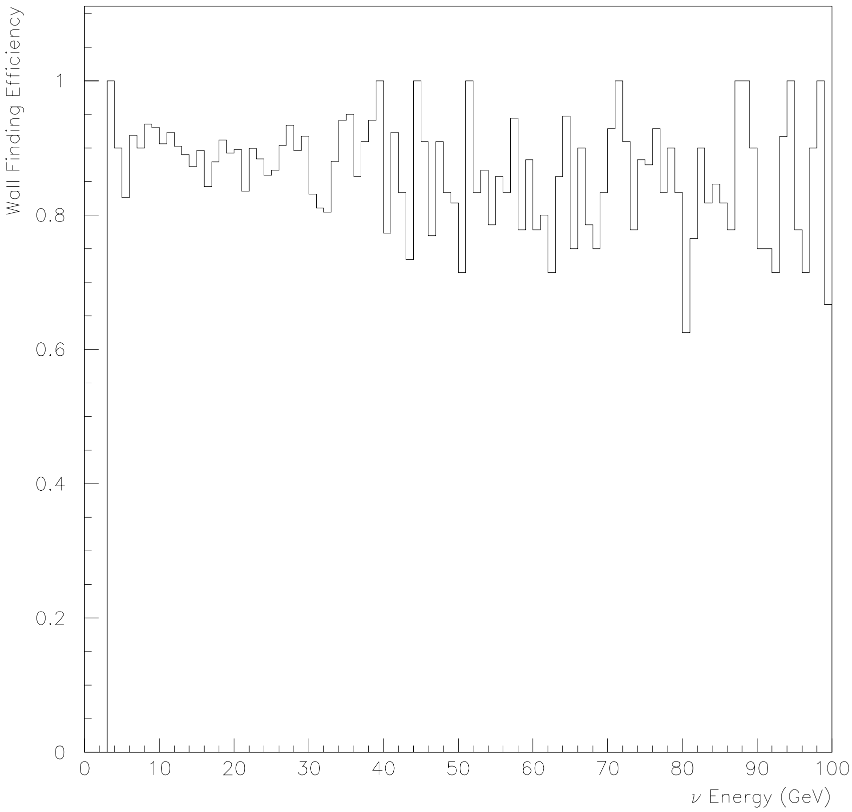


Figure 4: Wall brick finding efficiency as a function of the neutrino beam energy.