

# Determination of Scanning Efficiencies in Experiments Using Nuclear Emulsion Sheets

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## Abstract

During their exposure, nuclear emulsion sheets detect both tracks from experiment-related particles, as well as a considerable amount of background tracks, mainly due to cosmic rays. Unless the exposure has been fairly short, it is therefore fairly likely that a fraction of the tracks that have been identified as belonging to the particles the experiment is interested in, are really due to background. A method, which allows to measure this fraction reliably directly from the data, is described.

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## 1 Introduction

Nuclear emulsion sheets are composed of two thin layers of nuclear emulsion deposited on both sides of a transparent plastic base. They offer track position resolution of about  $1\ \mu\text{m}$  and angular resolution around 1 milliradian.

Various present [1,2] and future neutrino [3,4] experiments have used, or plan to use, the excellent resolution offered by nuclear emulsion sheets to unambiguously detect the production of a tau lepton.

These experiments typically use an electronic detector for calorimetry, particle identification and moderate precision tracking. The tracking detectors are used to reconstruct the points where particles left the emulsions. Tracks compatible with the “prediction” are then searched for with microscopes, in an area proportional in size to the impact point prediction uncertainty. If found, the tracks can be followed from emulsion sheet to emulsion sheet until the interaction vertex is located, or they are lost.

During exposure, which typically lasts for months, these emulsion sheets accumulate significant quantities of background, mainly due to cosmic muons. While most of this background is perpendicular to the beam direction, a small fraction can be mistakenly identified as corresponding to one of the particles the experiment has reconstructed. This generally leads to a wrong estimation of the track finding efficiency in the emulsion sheets. A method has been developed to determine the real track finding efficiency from the effective observed

efficiency directly from the available data. The method does not involve any simulation.

In section 2 the real and effective track finding efficiencies are defined. Then, in section 3, a few assumptions are made which are usually true in neutrino experiments. The method to extract the real track finding efficiency is described in section 4, followed by a summary of the possible sources of uncertainties in section 5. Conclusions are drawn in section 6.

## 2 Definition of Real and Effective Track Finding Efficiencies

The real track finding efficiency is defined by

$$\epsilon_r = \frac{\textit{Number of times the right track is found}}{\textit{Number of tracks searched for}}, \quad (1)$$

and the observed track finding efficiency by

$$\epsilon_o = \frac{\textit{Number of times a matching track is found}}{\textit{Number of tracks searched for}}. \quad (2)$$

It is clear that at first sight the real track finding efficiency is unknown: the observed efficiency results from a convolution of signal and background, so that an unfolding procedure seems to be necessary to extract the real efficiency.

## 3 Assumptions

The following assumptions are made:

- The random background can be assumed to be evenly distributed for all the tracks searched for in the emulsion sheets. This assumption holds for emulsion sheets of uniform quality which have been exposed during the same period.
- The real track finding efficiency can have only two results: found or not found. This is true if the density of events is low enough, and if particles from one event are sufficiently separated in phase space. This condition is satisfied in the experiments considered here.
- For each track, an area of identical size (proportional to the prediction accuracy) is scanned. In other words, when a track candidate is found, the rest of the area must still be scanned for possible additional candidates.
- The maximal number of candidates for a single track exit point prediction is finite. This is an assumption on the emulsion quality and the experiment's ability to see tracks in the emulsion.

An important consequence of the first and third assumptions is that the number of tracks that migrate from 0 candidates to  $n$  candidates due to the background is equal (within statistics) to the number of tracks that migrate from 1 to  $n + 1$  candidates. This relies on the even distribution of background and the scanning of the entire area.

## 4 The Method

The idea is simple: the real result can be only zero (not found) or one (found), while in the data the number of good candidates in a given surface can be much larger due to background.

Consider the distribution of the number of candidate tracks found for tracks that were searched for in an emulsion sheet. In a healthy experiment, this distribution has a few entries at zero, a large peak at 1, and has a small tail extending to larger values.

Call  $N'(i)$  the number of entries in bin  $i$ , corresponding to the number of tracks for which  $i$  candidates were found. And call  $N(i)$  the number of entries that would be observed in each bin for the real track finding efficiency. Under the second assumption  $N(i) = 0$  for  $i > 1$ .

Then let  $X(i \rightarrow j)$  be the number of entries that have migrated from one bin to another due to the background. Here  $i$  is necessarily 0 or 1 due to the second assumption,  $j > 0$  and  $j > i$ .

Since  $X(0 \rightarrow j) = 0$  for some arbitrarily large  $j$  (last assumption),

$$\begin{aligned}
 X(1 \rightarrow j) &= X(0 \rightarrow (j-1)) = N'(j) , \\
 X(1 \rightarrow (j-1)) &= X(0 \rightarrow (j-2)) = N'(j-1) - N'(j) , \\
 &\dots \text{ and} \\
 X(1 \rightarrow 2) &= X(0 \rightarrow 1) = N'(2) - N'(3) + N'(4) - \dots \quad (3)
 \end{aligned}$$

But, by construction,

$$N(0) = N'(0) + \sum_k X(0 \rightarrow k) , \quad (4)$$

which, using (3), is equivalent to

$$N(0) = \sum_{l=0}^{j/2} N'(2l) . \quad (5)$$

Therefore the real track finding efficiency is

$$\epsilon_r = \frac{N_{tot} - N(0)}{N_{tot}} = \frac{N_{tot} - \sum_{l=0}^{j/2} N'(2l)}{N_{tot}} , \quad (6)$$

where  $N_{tot}$  is the total number of tracks searched for.

## 5 Uncertainties

The statistical uncertainty on the contents of each bin quantifies the error on

$$X(1 \rightarrow n) = X(0 \rightarrow (n - 1)) , \quad (7)$$

leading to a statistical uncertainty equal to the quadratic sum of the individual statistical uncertainties of the even bins.

Systematic uncertainties can be induced by the scanning method and individual emulsion sheet properties, so that it is recommended to treat sheets one by one.

## 6 Conclusion

A method to extract the real track finding efficiency from the observed track finding efficiency in emulsion sheets has been described in detail. It relies on assumptions which are not stringent and usually satisfied in any experiment using these types of sheets.

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## References

- [1] Chorus Collaboration, E. Eskut et al., **Nucl. Instrum. Meth. A401**, 7 (1997).
- [2] K. Kodama et al., **FERMILAB-P-0872** (1997).
- [3] A.S. Ayan et al., **CERN-SPSC-97-05** (1997).
- [4] K. Kodama et al., **CERN-SPSC-98-25** (1998).