

## Status of MIND

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The Magnetised Iron Neutrino Detector (MIND) has been identified as the ideal candidate for the detection of the golden “wrong sign muon” channel at a Neutrino Factory. However, previous analyses of the channel relied on a parameterisation of the detector performance which assumed perfect muon pattern recognition. For the first time, a study of the muon reconstruction efficiency involving full pattern recognition has been carried out.

*10th International Workshop on Neutrino Factories, Super beams and Beta beams*

*June 30 - July 5 2008*

*Valencia, Spain*

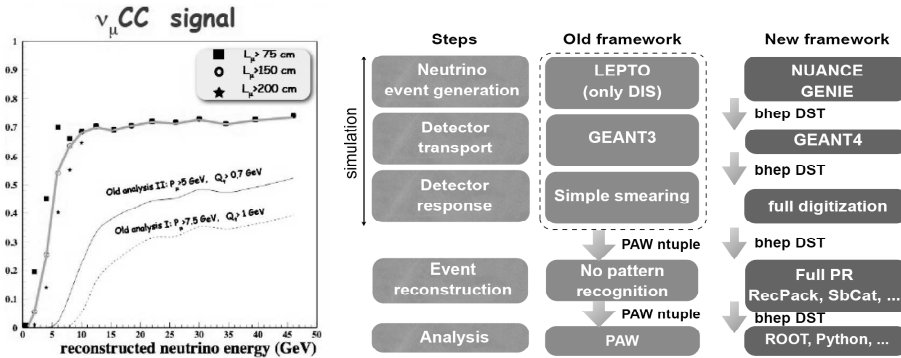
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## 1. Introduction

The Magnetised Iron Neutrino Detector (MIND) – a large sampling calorimeter made of a sandwich of iron and active layers (scintillators or RPCs) with fiducial mass of 50kTon – has the power to isolate a muon resulting from a  $\nu_\mu(\bar{\nu}_\mu)$  CC interaction from the accompanying hadronic shower. While this technology does not have the ability to identify electron or tau events, with proper optimisation, MIND is the ideal candidate as the detector for the golden channel ( $(\bar{\nu}_e \rightarrow \bar{\nu}_\mu)$  oscillation) at a neutrino factory [1], where the signal is identified by the presence of muons of the opposite sign to those stored in the decay ring (*wrong sign muons*) [2].

Past analyses have shown that with simple kinematical cuts it is possible to achieve an efficiency plateau at about 5 GeV [3] (*shown in Fig. 1*). However, to optimise the sensitivity to, in particular, the CP violating phase,  $\delta_{CP}$ , one ideally requires an efficiency plateau as low as 3 GeV [4] and indeed one must demonstrate that, within this energy region, the muon track can be efficiently and purely isolated on an event by event basis.

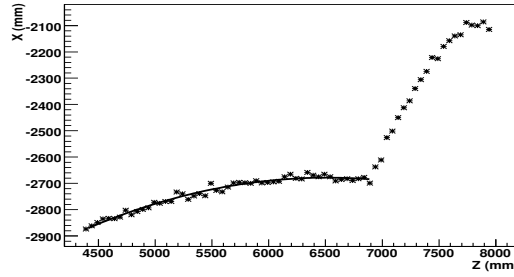


**Figure 1:** Efficiency curves for previous analyses (left) and a diagram showing major steps in the old and new simulation framework (right).

Demonstration of the abilities of MIND in the baseline setup (with cells including 3 cm of iron and two slabs of scintillator of thickness 1 cm each), optimisation of the geometry and an improved analysis will be approached using more sophisticated simulations. A more modern software framework (*see Fig. 1*) is being developed, including more powerful neutrino event generation using NUANCE [5], a GEANT4 [6] simulation, full digitization and full event pattern recognition and reconstruction with a Kalman filter provided by the RecPack package [7]. The GEANT4 representation of MIND is currently being tested. Development of the new analysis is well underway and has been applied to event data generated using the same GEANT3 simulation – 4 cm iron with 1 cm scintillator considering deep inelastic scattering (DIS) events only – used in past studies [3] with a Gaussian smearing on the 3D hit positions (perfect view matching is assumed); it is this work which will be the focus of the remainder of this discussion.

## 2. Muon reconstruction and charge identification

Optimisation of the reconstruction algorithms is approached in three ways: fitting of isolated muon tracks, pattern recognition on isolated tracks and full event pattern recognition.



**Figure 2:** High angle scatter track hits in XZ view demonstrating the detection of high local  $\chi^2$ .

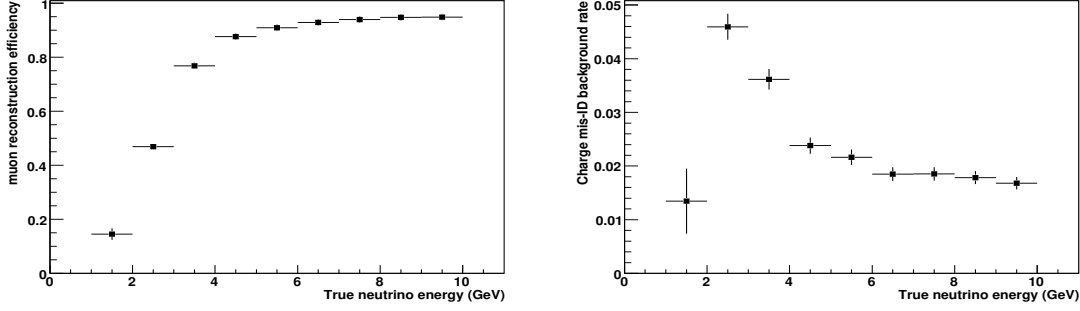
## 2.1 Isolated muon fits

A naive polynomial fit to the track left in MIND by a muon would rarely result in an accurate reconstruction of the muon charge and momentum, due mainly to the effects of energy loss and high angle scatters. RecPack allows the user to model the detector, including multiple scattering and energy loss, as well as making ‘kink’ identification possible through the definition of a maximum local  $\chi^2$  above which a hit can be ignored or the filtering process of the Kalman filter stopped. In this way even tracks with large angle scatters can be positively identified (*see Fig. 2*).

When considering  $\bar{\nu}_\mu$  CC events in the energy range 1-10 GeV and assuming perfect pattern recognition, the Kalman filter is able to reconstruct the momentum of the muons and positively identify the polarity with efficiency that plateaus at around 5 GeV as in the previous analysis. Currently many low energy tracks are rejected as having too few hits; this cut can perhaps be relaxed when resonance and quasielastic scattering events are included. However, charge mis-identification before any cuts is at the 4% level (*Fig. 3*). While this level of charge mis-identification background is too high for the application, this first attempt shows that much can be gained by improving the quality of the seed given to the fitter. The Kalman filter is very sensitive to its seed value. While the seed must try to represent the initial conditions, should there be a badly reconstructed point or high multiple scattering initially, the seed can be too local and cause the filter to fail. Using a less sophisticated fitting algorithm applied sequentially to an increasing number of the hits one can check for charge agreement along the sequence and hence select the seed using the largest number of hits possible for the Kalman filter. Indeed, in the case of a highly penetrating track where the charge agrees across all fits in the sequence a non-oscillation event can be rejected without the use of the Kalman filter fit.

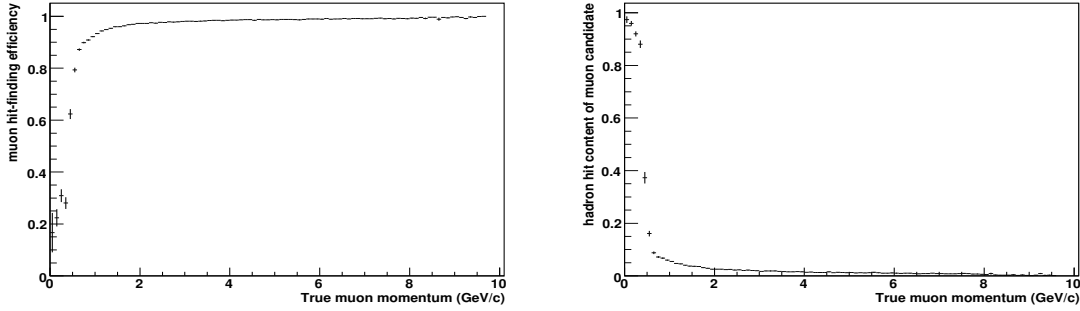
## 2.2 Pattern recognition

A simple pattern recognition algorithm based on the identification of the most penetrating track in the event has been developed. Again using RecPack with similar model parameters as in the fits and an additional requirement that no more than two consecutive active layers can be omitted one can move backwards through the deposited hits casting them into our ‘candidate muon’ where hits are alone in a plane. Should there be more than one hit deposited in an active layer, the one with the lowest  $\chi^2$  is taken. These candidates are then passed to the fitting algorithm. Application to isolated muon tracks yields high hit finding efficiency and similar background and identification efficiency as above.



**Figure 3:** Fits to free muons: Signal reconstruction efficiency (left) and charge mis-id background (right) for fitting of free muons.

In applying the algorithm to the full event topology it is required not only to achieve high efficiency in finding the true muon hits but also limit the number of hadronic hits entering our candidate. High purity not only allows for a better reconstruction of the muon identity and momentum but will also improve the reconstruction of the hadronic vector from the remaining hits. As can be seen in Fig. 4 high muon hit finding efficiency above 1 GeV/c has already been achieved with a low hadron hit content in the candidate in the same region.

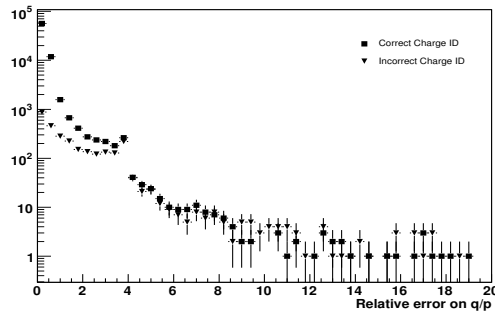


**Figure 4:** Pattern recognition statistics: Muon hit finding efficiency (left) and hadron hit content of candidate muon (right) as a function of true muon momentum for full  $\nu_\mu$  CC DIS events.

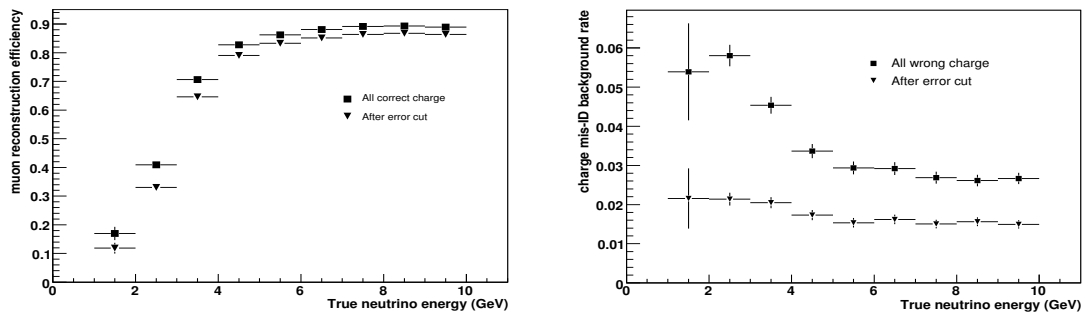
It is interesting here to consider a basic cut on the reconstructed parameters. The momentum parameter used by the Kalman filter is the ratio of reconstructed charge to momentum ( $\frac{q}{p}$ ). Those tracks which have their charge incorrectly reconstructed tend to have a greater relative error on  $q/p$  (shown in Fig. 5). Thus by only allowing tracks where this value is less than one it is possible to reduce the background significantly (Fig. 6).

### 3. Conclusions

Although improvements are needed in both pattern recognition and fitting algorithms in order to fully exploit the potential of MIND, these initial studies have demonstrated muon pattern recognition and identified areas where improvement is needed. Integration of all aspects of the new software framework will allow full optimization of MIND in all respects.



**Figure 5:** Comparison of relative error on reconstructed momentum parameter for correct and mis-ID tracks



**Figure 6:** Muon reconstruction efficiency (left) and charge mis-identification background (right). Shown for all successful fits (squares) and after the cut in  $q/p$  relative error (triangles).

## Acknowledgments

We are indebted to Pau Novella, Justo Martín-Albo, J.J. Gómez-Cadenas and Paul Soler for all their help and advice.

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