Charm Identification using Silicon Detectors in a Neutrino Experiment

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Abstract. A target consisting of four passive layers of boron carbide and five layers of silicon microstrip detectors (NOMAD–STAR) with a total surface of 1.14 m^2 was installed inside the NOMAD neutrino oscillation experiment at the CERN SPS. A sample of 45 charm mesons (with 22 background) was obtained from about 11,500 ν_μ charged current interaction in NOMAD–STAR. The efficiencies obtained from this search demonstrate the capabilities of silicon microstrip detectors for charm particle identification at a future neutrino factory.

1. Introduction

A silicon vertex detector (NOMAD–STAR) was installed upstream of the first NOMAD drift chamber [1] to test the capabilities of silicon detectors for $\nu_\mu(\nu_e) \leftrightarrow \nu_\tau$ oscillation searches [2, 3]. The target consisted of four layers of boron carbide (B_4C) with a total mass of 45 kg, interleaved with five layers of single–sided silicon microstrip detectors (see Figures 1 and 2).

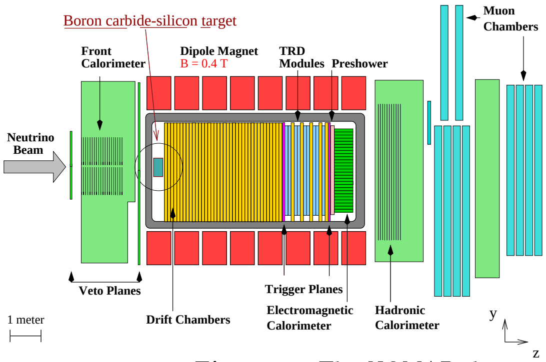

Figure 1. The NOMAD detector with the Silicon TARget (NOMAD–STAR).

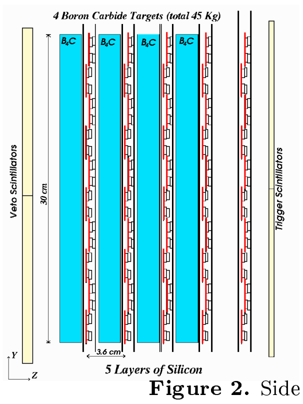

Figure 2. Side view of NOMAD-STAR.

The five layers of silicon detectors had a total active surface of 1.14 m^2, with 10 ladders per layer and 12 silicon microstrip detectors per ladder [4] (at 72 cm, these are the longest working silicon ladders ever built). The detectors were single–sided, 33.5 × 59.9 mm^2 wide, with strip and readout pitches of 25 μm and 50 μm, respectively. The 640 read-out strips per detector, parallel to the NOMAD magnetic field (x axis), measured the y projection of the track with a point resolution of 5 μm [5].

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Charm mesons can mimic the capabilities of NOMAD–STAR for the detection of τ particles. The present paper describes a search for charm inside NOMAD–STAR and consequences for future near detectors at a neutrino factory.

2. NOMAD-STAR performance

The noise performance of most of the long silicon ladders was found to be as expected (a signal-to-noise of 17:1) with average hit-finding efficiencies above 98% [6]). Some ladders exhibited variable noise but always with a signal-to-noise above 12:1 and efficiency above 92%.

A Kalman filter [7] was used for tracking, vertexing and for the alignment of the silicon ladders [8]. The alignment residuals were 9 μm for the three inner planes and 12 μm for the two outer planes. After the alignment, hit residuals in the y projection had a RMS of 8.6 μm, with the y and z vertex resolution 19 μm and 78 μm and the y double vertex resolution (from K_s^0 decays) 18 ± 4 μm [9].

The impact parameter (defined as the projected signed distance of the μ^-, from a ν_μ charged current, CC, interaction to the vertex produced by the remaining hadronic jet) was measured to be 33 μm for all events with three or more tracks in the hadronic vertex (see Figure 3), comparing well with [2].

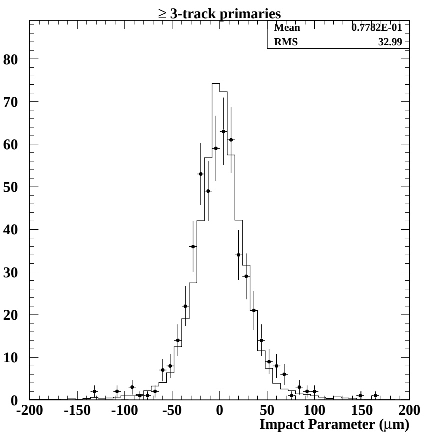

Figure 3. Impact parameter for ν_μ CC events with 3 or more hadronic tracks.

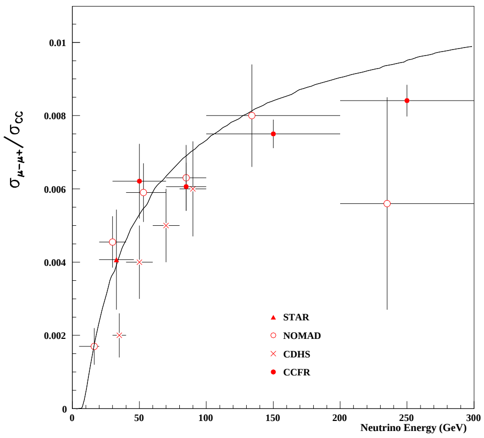

Figure 4. Opposite sign dimuon rate of NOMAD-STAR and other experiments. Overlayed is a charm mass fit of 1.3 GeV/c^2 [14].

3. Charm search

Out of a total of 98,858 triggers, 11,528 were identified as ν_μ CC events in the fiducial volume of NOMAD-STAR. Only 1,545 had a minimum of two tracks and a muon (13.4%), needed to perform an impact parameter measurement. Monte Carlo events were used to determine the reconstruction efficiency and background estimation. The χ^2 of the fit was minimized while constraining the total momentum, the total energy and the yz projected angle of all the decay products for a large fraction of the decay hypotheses of the D^0, D^+ and D_s^+. Further cuts on the invariant mass, the proper decay time, the reconstructed momentum of the D meson, the fraction of momentum carried by the D meson and the consistency of the decay angles allow to pick out the charm candidates [10].

The total number of charm events obtained can be found in Table 1. The efficiency for both D^0 and D^+ identification was 3.5% and for D_s^+ was 12.1%. The total charm meson production rate is $7.2 \pm 2.4\%$ of the ν_μ CC rate, at an average energy of 33 GeV. These rates compare well with the emulsion experiments E531 [11] and CHORUS [12]. Assuming the semi-leptonic branching ratio of charm particles [13], we can also compare the dimuon rate expected in NOMAD-STAR with that observed at other experiments [14] (see Figure 4).

Table 1. Number of charm mesons in ν_μ CC interactions from NOMAD-STAR. The last column shows the resulting production rates of charm mesons as a fraction of ν_μ DIS CC interactions.

Meson	Reconstructed	Background	Production Rate
D^0	24	13.33 ± 0.98	4.2 ± 2.0 %
D^+	10	3.79 ± 0.53	2.4 ± 1.3 %
D_s^+	11	5.17 ± 0.61	0.64 ± 0.36 %
Total Charm	45	22.3 ± 1.3	7.2 ± 2.4 %

4. Discussion

The flux of neutrinos at a near detector (30 metres downstream) of a 50 GeV muon storage ring [15] would produce 200 million ν_μ CC events per year in a detector of the same mass as NOMAD-STAR (45 kg). With the measured efficiencies from the previous analysis, this would correspond to more than 0.6 million charm events reconstructed per year.

With this number of reconstructed charm events, the production cross-sections, the strange quark content of the sea and the CKM parameter V_{cd} (currently known to 5%) could be accurately measured. In addition, a neutrino factory beam could be used to search for CP violation in D^0 - $\overline{D^0}$ mixing. The sign of the lepton produced at the primary vertex can be used to tag the initial charm particle, with the decay products determining whether there was any change in the flavour of the charm meson.

Acknowledgments

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