CERN West Area Neutrino Facility Beam Line Alignment

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Abstract

This papers describes the alignment of the West Area Neutrino Beam Line at CERN to the two neutrino experiments CHORUS and NOMAD. The T9 neutrino (ν) target position and the position of the magnetic horn were optimised using the secondary muon intensity profiles from the muon pits in the shielding. In the experiments the improved geometry provides a better centred beam (< 5 cm) and a measured increase in the ν flux of 8%.

1 INTRODUCTION

The CERN West Area Neutrino Facility (WANF) [1], has been in operation for almost 20 years. A major reconstruction [2] of the line took place in 1992 and 1993 for a new round of $\nu_\mu \rightarrow \nu_\tau$ oscillation experiments CHORUS [3] and NOMAD [4]. Part of the proton beam line and the neutrino 'cave' were completely dismantled and cleared. A new target station with improved cooling and a new small angle collimator with highly improved radiation containment properties were installed. The focusing elements (the magnetic horn and reflector) were displaced downstream by about 8 m in order to provide a harder neutrino beam spectrum [5]. Helium tubes, of total length 80 m, replace wherever possible air in the focusing region before the decay tunnel and a new large area collimator was installed to reduce the $\bar{\nu}$ contamination.

A ν beam monitoring system ('the muon pits') [1], based on the detection of muon yields at several depths in the iron shield, was built in the line from the beginning of its operation. A reduced version of that system is still in use today with new or rejuvenated solid state detectors. The hardware and software of the data acquisition and control system was replaced by a more modern state-of-the-art configuration [6]. The beam line has been now operating for 2 years at record proton intensities, up to ~ $3 \cdot 10^{13}$ protons on target (pot) per 14.4 s accelerator cycle.

In order to make best use of the very high proton intensities necessary for the neutrino oscillation searches, a complete re-tuning of the upgraded neutrino beam line was necessary.

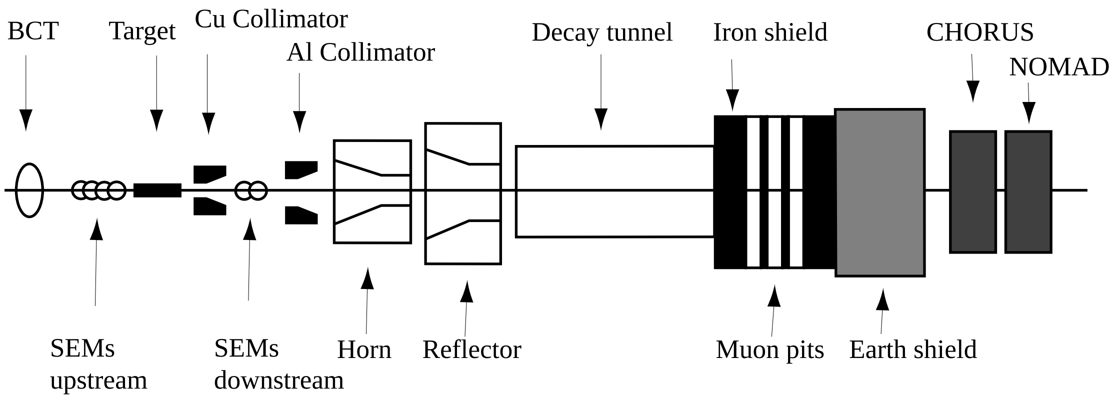

Figure 1. Schematic lay-out of the WANF beam line (not drawn to scale)

2 BEAM LINE, DATA ACQUISITION AND ANALYSIS

2.1 Beam Line

Protons are extracted from the SPS ring on 2 spills during a SPS proton cycle. The extraction is a fast/slow extraction on a combined 2^{nd}-4^{th} order resonance, with a nominal length of 6 ms per spill [7]. The proton beam is taken up to the T9 neutrino production target by the TT66 beam line. The beam is focused on the target such that the beam spot is circular with a 2 mm base-to-base width. The target consists of 11 Be rods of 3 mm diameter and 10 cm length, spaced by 9 cm voids [8]. Total charged particle fluxes and the transfers beam profiles are constantly measured with several types of detectors.

- Beam Current Transformers are used to measure the proton intensity at two places in the proton beam line.
- Secondary Emission Monitors are used to measure the proton intensity in front of the target, the multiplicity of charged particles behind the target and the profile of the proton beam in front of the target.
- Solid state detectors are used to measure the total muon flux and the profile inside voids in the muon

shielding. A schematic lay-out of the beam line can be found in Figure 1.

2.2 Data Acquisition

The data coming from the beam line are acquired by 4 users: proton beam operations, the WANF control system and the experiments CHORUS and NOMAD. The proton beam properties are written on an online ORACLE database. The WANF control system writes all proton data and the data from the solid state muon detectors onto disk. The experiments write summary information of a spill onto their raw data tapes. Displays are available online in the SPS control room and the experiment control rooms.

2.3 Optimisation and Analysis Methods

The parameters to be optimised are:

- The beam direction in horizontal and vertical such that the ν beam is centred on the CHORUS and NOMAD detectors.
- The target position and angle with respect to the incoming proton beam such as to maximise the quantity of protons interacting with the target.
- The horn position such that only a focusing effect is achieved on the positive secondaries.

The sequence of actions is to optimise the beam line is as follows. First, the target position and angle are scanned and the charged particle multiplicity as measured with the SEM detectors is maximised. Second, it is checked that the above optimisation also maximised the peak of the muon flux distribution in the muon pits horizontaly and verticaly. For this, in both planes, a Gaussian fit on readings of the individual muon detectors in a pit is done and the peak value extracted. Third, the position of the horn is scanned and the peak of the muon flux distribution in the muon pits is sought to be maximum. Additionally, these distributions should be centred onto the muon pits. Assuming that the alignment between muon pits and experiments is correct this will also optimise the properties of the ν beam in the experiments. Fourth, it is checked that the ν distributions in the experiments are centred by looking at the spatial distribution of the ν interactions in the CHORUS and NOMAD detectors.

3 ALIGNMENT OF TARGET, BEAM AND FOCUSING ELEMENTS

3.1 Alignment of Target with Beam

The first step was the optimisation of the target position and angle with respect to the beam using the secondary particle multiplicity as measured with the upstream and downstream SEMs. Maximum secondary particle multiplicities of about 18 were found for:

x_{target} = 2.8 mm y_{target} = 0.3 mm
θ_x = 0.0 mrad θ_y = 0.0 mrad.

In Figure 2 the dependence of the SEM multiplicity on the target position is shown.

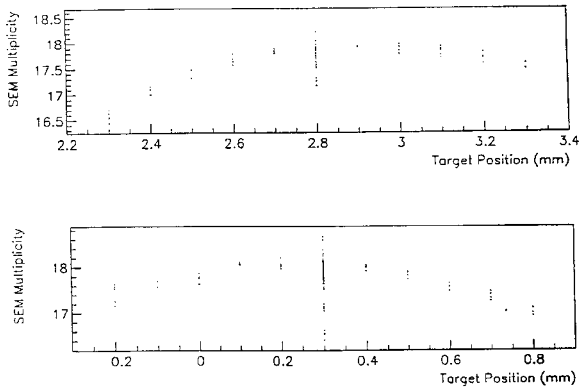

Figure 2. The dependence of the SEM multiplicity on the target position relative to the beam for parallel horizontal (top) and vertical (bottom) displacement.

The second step was to check the muon flux in the muon pits for these scans. The optimum for the muon pits coincide nicely with that found with the SEM multiplicities. In Figure 3 this is illustrated for the horizontal plane.

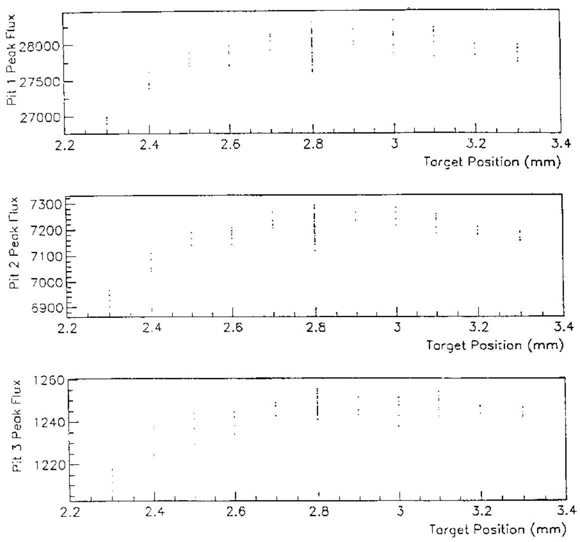

Figure 3. Peak muon flux per pit (μ/cm^2/10^{10} pot) as a function of the target horizontal position relative to the beam.

3.2 Alignment of Horn and Reflector with the Target and Beam

The third step consisted of aligning the horn to the beam, with the target at the optimum position as found in the previous step. A mis-alignment of the horn will reduce the muon flux in the muon pits and displace the distribution there. This is due to the net bending effect of a mis-aligned focusing element. The reflector is not motorised so no scan could be performed on it. During the horn scan it was switched off. The muon profiles shift when the horn is switched on, indicating possible mis-alignment of the horn. The horn can be moved by ±2.5 mm in both directions. The first scan indicated an optimum at:

x_{horn} = -2.5 mm $\quad$ y_{horn} = -2.0 mm.

This could indicate that the optimum might be at larger values. The beam and target were thus moved together in parallel by 3 mm in both planes. After which the scan was repeated. In this new situation the optimum position of the horn was found to be:

x_{horn} = -1.5 mm $\quad$ y_{horn} = -2.0 mm.

At the optimum beam/target/horn positions the peak muon flux in pit 2 was about 3% higher than before with a much better centred profile. Switching on the reflector provides a better centred beam suggesting that this element has the correct alignment. The muon profiles for three situations: before scan, after the scan and with the reflector switched on again, are summarised in the Tables 1,2 and 3.

	<x> cm	<y> cm	peak flux $/cm^2/10^{10}$pot
pit 1	-4.8	9.6	24012
pit 2	-5.0	9.5	7577
pit 3	-1.3	8.7	1596

Table 1. Muon profile parameters with nominal beam/target/horn positions and reflector off.

	<x> cm	<y> cm	peak flux $/cm^2/10^{10}$pot
pit 1	1.7	2.4	25560
pit 2	1.2	2.1	7780
pit 3	3.3	1.5	1600

Table 2. Muon profile parameters with optimum beam/target/horn positions and reflector off.

	<x> cm	<y> cm	peak flux $/cm^2/10^{10}$pot
pit 1	0.9	0.3	46847
pit 2	1.2	0.2	12136
pit 3	3.1	0.6	2289

Table 3. Muon profile parameters with optimum beam/target/horn positions and reflector on.

4 NEUTRINO FLUX IN THE EXPERIMENTS

The result of this alignment operation is an 8% increase in ν flux in the experiments and a better centred ν beam in the detectors. The $<x_\nu>$ improved from -5,5±1.1 cm to 2.6±0.6 cm, the $<y_\nu>$ improved from 14.7±1.2 cm to 3.8±0.5 cm. In Figure 4 this is illustrated for the NOMAD detector.

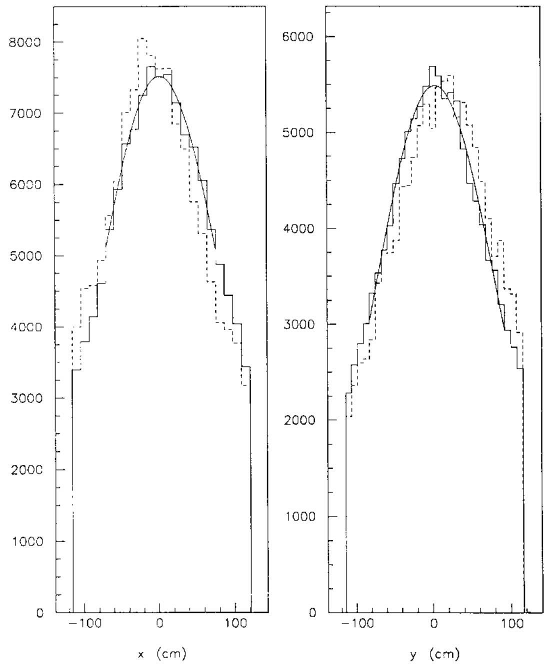

Figure 4. Distribution of the horizontal and vertical ν interaction position in the ECAL of NOMAD. The broken line are the data before, the full line after the beam line optimisation. The Gaussain fit is superimposed on the optimised distribution.

5 CONCLUSIONS

A successful alignment of the CERN ν beam line was performed. A 8% gain in neutrino yield and a better centred ν beam on the detectors were achieved.

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