NEUTRINOS FROM THE CERN SPS

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The CERN SPS West Area Neutrino Facility (WANF) beam was largely rebuilt in 1992-93, optimized for the goals of CHORUS and NOMAD and equipped with a modern data acquisition and control system. A complete re-alignment of the beam resulted in an 8% higher ν_μ yield per proton.

Operation of the WANF at unprecedented proton intensities was made possible by the record performances of the SPS in 1995 and 1996 and a better insight gained in the behavior of the primary target.

The SPY/NA56 experiment collected data in 1996 and should soon be able to contribute to a better understanding of ν fluxes and energy distributions of the present and of future ν beam configurations. More reliable estimates of the ν_τ content of the beam are also now available.

A few different options for future WANF operation are being proposed. Meanwhile, feasibility studies of a new SPS ν facility, aiming towards very far ν detectors, have been completed. For both options further enhancements are under active study. The CERN SPS remains a competitive tool for future ν physics.

1 The West Area Neutrino Facility

The West Area Neutrino Facility[1] has been now operating at the SPS for almost 20 years. Limited modifications only were introduced for operation of the CHARM II detector (1985-91) after completion of first generation experiments (BEBC, CDHS, CHARM). A major reconstruction[2] of the WANF line took place in 1992 and 1993 for a new round of ν_μ to ν_τ oscillation experiments (CHORUS and NOMAD).

The SPS presently accelerates protons (p) to 450 GeV with a cycle of 14.4 sec. and extracts them onto the WANF primary target (T9) in two 6 ms long spills separated in time by 2.7 s, one at the start and one at the end of the accelerator flat top. Only wide band (WB) ν are used since 1985. Positive (negative) π and K produced in T9 are parallel focused (defocused) in a 120 m long section in front of a 300 meter long decay tunnel, where ν emerge from the decay of a fraction of these parent hadrons. Undecayed hadrons are absorbed very early in a 400 meter shielding of iron and dirt that also stops all muons. Only ν reach the ν detectors, more than 800 m downstream of T9.

The SPS produces an almost pure ν_μ wide band beam with a few percent content of $\bar{\nu}_\mu$ and about 1% content of ν_e.

1.1 The neutrino cave

The neutrino cave, i.e. the 120 m long target and focusing region upstream of the decay tunnel, was completely dismantled and cleared of radioactive waste. A new T9 station[5] and a new small angle collimator were installed with greatly improved radiation containment properties. The geometry of the primary beryllium (Be) target was left unchanged (11 rods of 3 mm diameter and 10 cm length, separated by 9 cm gaps). Helium tubes, of 80 m total length, replaced air wherever possible in the cave to reduce absorption of parent hadrons. A new large angle collimator was installed in front of the second focusing horn (the reflector) to absorb defocused hadrons and thus reduce the $\bar{\nu}_\mu$ contamination.

The ν_μ spectrum was optimized[3] for the search of ν_μ to ν_τ oscillation. The cross section for ν_τ charged current interactions is zero below a ν energy threshold of about 3.5 GeV and grows slowly with energy. τ detection efficiency is also small at low energy and increases with energy. Low energy ν are effectively 'sterile' for the oscillation search. A harder ν beam spectrum increases the sensitivity to small ν mixing angles. This was achieved by displacing both focusing elements (horn and reflector) downstream by about 8 m, so that parent hadrons of higher momentum are focused.

1.2 The new beam control system

A Neutrino Flux Monitoring (NFM) system in the muon 'pits'[1], based on the detection of muon yields at several depths in the iron shield, was built into the beam line from the beginning of its operation. It constitutes the vital real time 'luminosity' monitor of the beam; any reduction of the detected muon yield inequivocally and immediately identifies the presence of a fault in the operation of the line.

A reduced version of this system is still in use today with new or rejuvenated solid-state detectors. The NFM system also collects data concerning the primary p beam and the secondary hadron beam from Beam Current Transformers (BCTs) upstream of the T9 and from Secondary Emission Monitors (SEMs) upstream and downstream of the T9. The hardware and software of the NFM data acquisition and control system was replaced with a state-of-the-art configuration[4], supervised by an object-oriented industrial control package (FactoryLink). It has proven extremely versatile and effective for the needs of maintenance, troubleshooting and tuning.

1.3 Tuning the neutrino beam

In order to make the best use of the very high p intensities necessary for the ν oscillation searches, a complete alignement[6] of the upgraded ν beam line was necessary. It was carried out during its first year of operation.

T9 and the magnetic horn were aligned with respect to the p beam using the intensity of the secondary particles produced in the target, measured by the SEMs downstream of the T9, and the detected intensity and profiles of the muons in the pits. The improved alignement provided a better centred ν beam (within 5 cm of its nominal center) and a significant increase (8%) of the ν_μ flux reaching the ν detectors.

1.4 Measuring the absolute ν flux

The absolute flux of ν reaching the ν detectors can be deduced from the measured rate of ν interactions, relying of the knowledge of ν interaction cross sections. An independent and complementary approach is an accurate absolute measurement of the muon yields in the pits. A procedure of absolute calibration of the response of the muon detectors in the NFM was established many years ago[1]. Small emulsion plates are exposed to the muon beam and the number of tracks passing through them is measured. These exposures, that had not been performed for quite a number of years, have been jointly resumed by CHORUS and NOMAD. Their analysis is in progress[13].

1.5 Operation at higher intensities

The mechanical and thermic stress induced in T9 by an intense burst of very high energy p's limits the intensity per spill. The two-spill operation began during the CHARM II datataking, to achieve the flux needed to study ν-e scattering after first generation ν-N scattering experiments. The total intensity per cycle to T9 was kept however always below 1.8 10^{13} protons.

Higher and higher p intensities have been delivered onto T9 during 1995 and 1996, reaching frequently values close or above 2.6 or 2.7 10^{13} protons in 2 spills, hitting occasionally the current safety limit 3.0 10^{13} and making the WANF a much more intense ν 'factory'.

This has been made possible by two concurring factors:

a) a better understanding[5] of the behavior of the primary target, resulting in a much improved cooling system. It was proven at the end of 1994 that the new T9 station would stand intensities well above the 1.8 10^{13} p/cycle mark,

b) the unprecedented peformance of the CERN p acceleration complex from 1995 on. This required a careful tuning of the quality of the high intensity beam provided from the CERN PS to the SPS and a remarkable improvement of the capability of the SPS to capture and accelerate higher intensities. Record cycles with more than 4.5 10^{13} accelerated p's have been recorded in 1996. Record intensities became thus possible on T9, while all other SPS experimental targets were still adequately served.

1.6 Present understanding of neutrino yields

In experiments using ν beams, the knowledge of the beam characteristics is an important and difficult problem. One has to set up an accurate simulation of the beam, correct and refine it until it reproduces well the quantities measurable in the ν detectors; one can then trust its predictions for the non-measurable quantities with reasonable confidence. Such accurate simulations are also needed as a tool for the design of modified or completely new beamline configurations.

A MonteCarlo program (GBEAM), based on the GEANT library, was developed[7] inside the CHARM II Collaboration and is now used by CHORUS to predict the WANF ν fluxes. π and K produced in the hadronic shower induced by a

450 GeV/c p, in the primary interactions in the thin Be target as well as in the secondary interactions, are tracked through the passive material and the active focusing elements of the beam line until they escape, are absorbed or decay. ν fluxes at the detectors can thus be predicted.

A similar independent program (NUBEAM) was later developed by NOMAD[8] and a modified version[18] of the simulation was used in the design of the new long baseline facility.

The choice of the generator of hadronic interactions has proven very critical. Analysis of data from ν interactions in CHARM II in the recent past and now in CHORUS and NOMAD shows that the average ν_μ energy is lower and the $\bar{\nu}_\mu$ contamination higher than those predicted by calculations based on existing data[10] for production in p-Be collisions of secondaries with momenta above 60 GeV/c and on extrapolations of these data to the region below 60 GeV/c where no data is available. Both discrepancies suggest the presence of an additional component of low energy positive and negative π.

1.7 The SPY measurement

These discrepancies, as well as new ideas[9,18] of more systematic exploitation of lower energy ν parents have prompted a new measurement of the yield of low energy π and K produced in the primary target. The SPY/NA56 experiment[11] used the existing NA52 524 m long double bend double focusing one particle spectrometer, equipped with excellent particle identification detectors and housed in the H6 beam originating from the T4 target of the SPS North Area. It collected, in the spring of 1996, data on forward production of positive and negative π and K in the 7-40 GeV/c secondary momentum range and at two momenta (67.5 and 135 GeV/c) where comparison with the existing higher momentum data is possible. At 15 and 40 GeV/c data were collected at several production angles.

An old absolute normalization procedure[12] of the monitors of p intensity on T4 was resurrected for the goals of SPY and was extended also to the other North Area target stations T2 and T6.

The SPY data sample should soon contribute to a better understanding of ν fluxes and energy distributions in present and future ν beam configurations. The more precise determination of the K/π ratio will also improve our predictions of the ν_e content of the beam.

1.8 The ν_τ content of the beam

Two new estimates of the prompt ν_τ content of the WANF, irreducible background for CHORUS, NOMAD and any similar experiment, have been published[14,15].

ν_τ come from the decay of D_s^+ mesons (into τ^+ and ν_τ) and of $\bar{D}_s^-$ mesons (into $\bar{\nu}_\tau$ and τ^- that decays in turn into ν_τ) produced by p interactions in T9 and in the shielding. The new estimates include the contribution from $\bar{D}_s^-$ (neglected so far, but infact dominant), a more reliable linear A dependence of D_s^+ and $\bar{D}_s^-$ production cross section and the twice higher value of the D_s^+ and $\bar{D}_s^-$ tauonic branching ratio that is now currently accepted.

The two estimates suggest values of the ratio R of the number of ν_τ over the number of ν_μ induced charged current interactions much larger than the one (of order 10^{-7}) quoted in the CHORUS and NOMAD proposals several years ago. The estimate of R based on a semi-empirical parametrization[14] of D_s production is 3.3 10^{-6}, while the one obtained from non-perturbative QCD inspired calculation[15] is some 20% larger. They agree reasonably well, within the uncertainties of both approaches.

This level of irreducible background, still well below one event in the lifetime of CHORUS and NOMAD, suggests a reduction of the primary p energy for future searches sensitive to smaller ν mixing.

2 Future possibilities

2.1 Options for the West Area Facility

The West Area facility, in its present configuration, provides a rate of ν interactions/ton/year only 3 times smaller than the one envisaged for the NuMI[16] facility proposed at Fermilab. Several enhancements, actively being studied, are trying to make it even more competitive.

An increase of the SPS repetition rate will be possible after LEP and promises significant gains. Improvements in the yield of ν per p are also possible. Sizeable factors could come from shorter target to detector distances (cfr. the suggested[17] replacement of the present passive shielding with a much shorter active magnetic shielding).

The choice among the different options currently being presented will be driven by the physics results expected in the near future from CHORUS, NOMAD and other experiments. Higher ν fluxes and higher detector mass and efficiency are in any case the key to further progress. If an oscillation signal is detected by CHORUS and NOMAD, however, the ν beam should be modified so that a determination of the ν_τ mass can be pursued. This may come [17] from a reduction of the length of the decay tunnel, ie of the uncertainty in the ν flight path.

2.2 A future Neutrino Facility

Feasibility studies [18,19] of a new SPS ν facility, aiming towards far ν detectors at Gran Sasso and possibly in the Greek sea, have been completed. A number of possible configurations have been studied covering a range of ν energy bands. Viable event rates (about 1/ton/year) and backgrounds levels are reported. This long baseline approach would allow to explore small ν masses unaccessible to current experiments.

Available p intensities in the SPS cannot adequately support two ν lines simultaneously. This line should thus also serve short baseline ν detectors housed in a 100 m deep pit that would have to be excavated. This may require some adjustement of the current design. Most of the enhancements presently being studied for the WANF may apply infact also to the new facility.

3 Conclusions

The SPS WANF is presently the most copious and reliable source of high energy ν, thanks to the long effort of a large number of people from different CERN Divisions and from Collaborating Institutions. It will continue to be competitive for future ν physics.

The option of a new SPS ν facility is also being vigorously pursued. It may one day replace (or complement) the WANF, inheriting its strength and thriving on its experience.

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