Subnuclear Physics: Past, Present and Future
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The Proton Beam for the Neutrino Velocity Measurement With OPERA

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1. Introduction

Since the announcement of the measurement of neutrino velocity with the OPERA detector in the CNGS beam [1] much effort has been devoted to searching for possible sources of error in the experiment. This paper concerns the time structure of the primary proton beam striking the neutrino target. With this beam it is not possible to make direct time-of –flight measurement. Instead, the distribution in time of the OPERA neutrino events is fitted to the averaged time structure of the proton beam. Fitting the leading edge of the distribution is crucial to the analysis. Possible sources of error with this procedure are discussed.

A much better beam for the purpose of time-of-flight measurement can be derived from the beam prepared for injection into the LHC. With this beam, all possible sources of error concerning the proton time structure are eliminated. It should make possible a precise and direct time-of-flight measurement with very few neutrino events recorded in the detector.

2. The neutrino beam

The layout of the CNGS beam is shown in Figure 1 [2]. The proton beam is accelerated to 400 GeV in the SPS and extracted with a fast kicker magnet and transported 800m to the production target. Downstream of the target is the standard horn and reflector for focussing the pions and kaons which travel about 100m to the one kilometre long evacuated decay tube. Upstream the production target a fast Beam Current Transformer (BCT) captures the time structure of the proton beam.

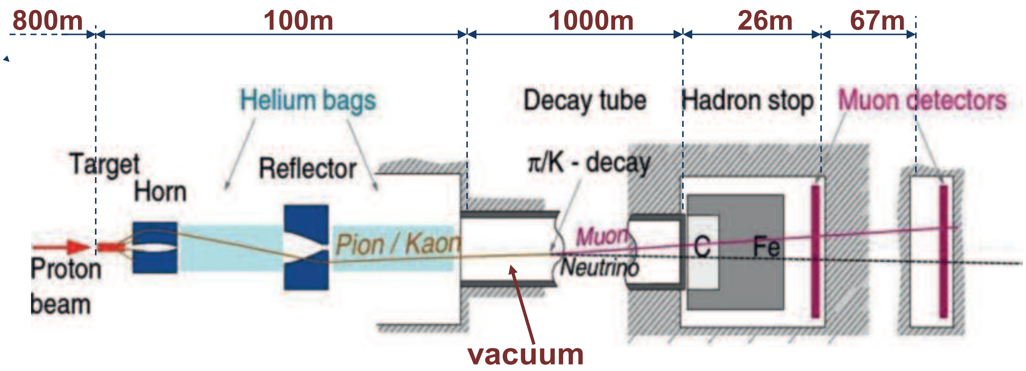

Figure 1
Schematic layout from production target to hadron stop

The proton beam itself is designed to maximise the number of protons on target. The time structure is formed in the CPS where the beam is accelerated to 14 GeV/c and then debunched. Extraction is made by peeling off the beam over 5 turns on an electrostatic septum [3], the so-called continuous transfer, giving a 10 microsecond long pulse. The leasing edge of this pulse is not sharp due to the finite rise time of the closed orbit bump in the CPS and the intensity distribution between the turns is not very uniform. Two successive CPS cycles with 1.2 sec separation are injected into the SPS flat bottom at 14 GeV. Figure 2 shows an SPS super cycle with the long flat-top for the slow spill into the SPS North area is followed by 5 successive cycles for CNGS. The two separate PS injections on each cycle can be clearly seen as well as the losses at the beginning of acceleration. This beam must be taken through "transition" which occurs at around 21 GeV in the SPS. The total intensity per cycle is around 3.10^{13} protons with about 10^{10} protons per bunch.

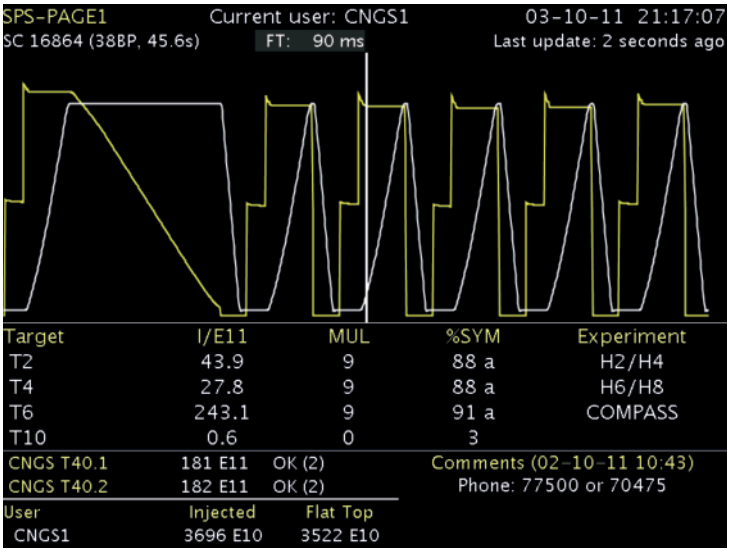

Figure 2
An SPS supercycle with 5 cycles to the neutrino target

Figures 3 and 4 show the intensity distribution of the two CPS "batches" in the SPS. The leading edge can easily be observed as well as the uneven intensity distribution along the batch. It can also be observed that the intensity distribution in the two batches is quite different. The two batches are extracted with a fast kicker separated by 50 ms.

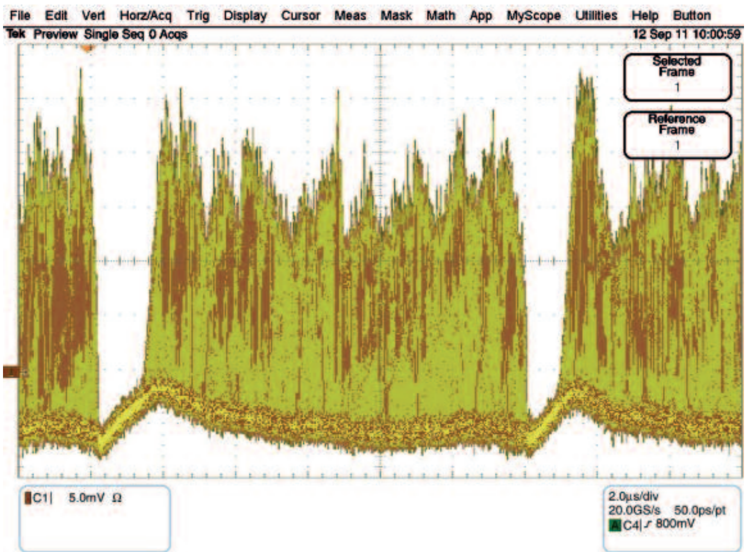

Figure 3
The two batches in the SPS

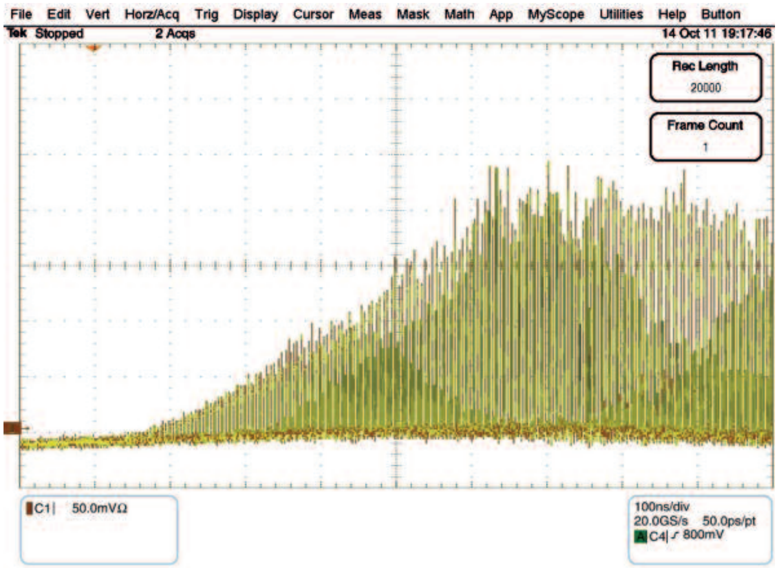

Figure 4
The leading edge of the first batch

At least three possible sources of error concerning the method of neutrino velocity measurement can be identified.

1. Pulse-to pulse variations in intensity distribution in the CPS.
2. The rising edge of the SPS extraction kicker cuts into the leading edge of the beam. Jitter in the kicker timing can cause variations in intensity of the leading edge.
3. The finite frequency response of the fast BCT, in particular the low frequency response due to dispersion in the cables from the BCT to the electronics can distort the leading edge.

All three of these can be removed by using a very different beam, effectively the one injected into the LHC.

3. The LHC beam

The nominal LHC beam has an order of magnitude higher intensity per bunch with a larger bunch spacing than the CNGS beam. The problem of accelerating very high intensity bunches was studied [4] in the late 1970's in the context of the PPBAR Project. It was shown that the passage through transition energy with such intense bunches was impossible due to two instabilities, the transverse "head-tail" instability and the longitudinal "negative mass" instability. The solution adopted was to inject into the SPS above transition at 26 GeV. This is not possible for the continuous transfer process due to hardware limitations and increased cycle time.

For the LHC, the nominal bunch spacing is 25 ns but a very flexible and elegant [5] bunch splitting method has been developed in the CPS to allow many different bunch separations. It consists of a set of harmonic Radiofrequency cavities that allow bunches to be split by varying adiabatically the voltages at the different harmonics. Figure 5 shows such a process producing 25 ns bunch separation.

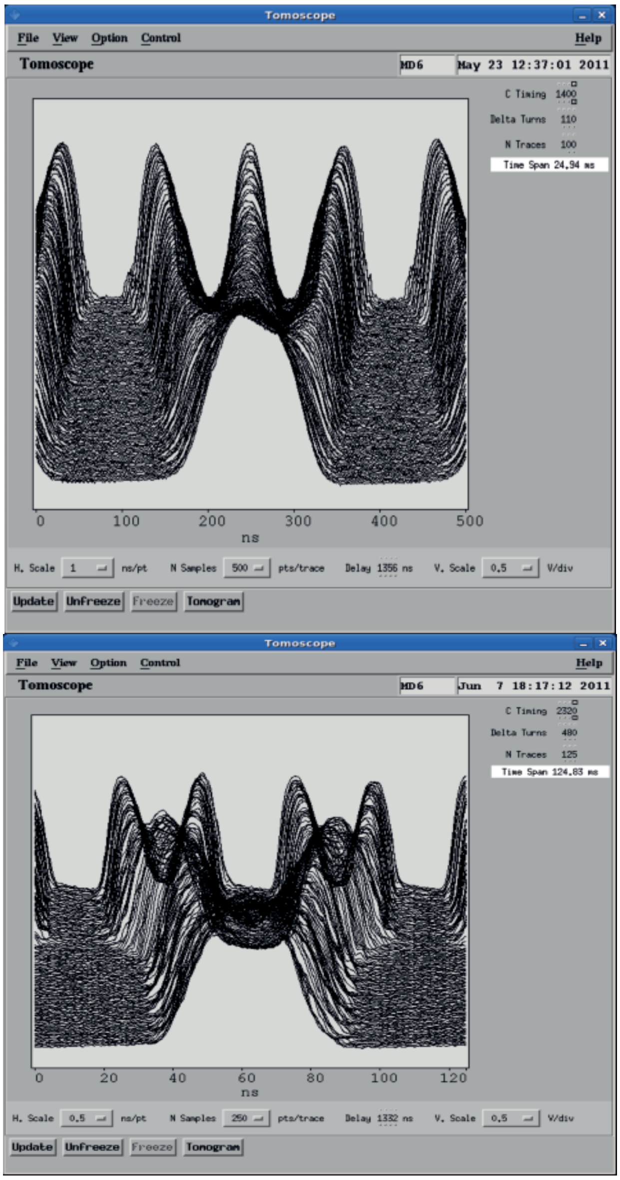

Figure 5

The "mountain range" displays show the bunch shape turn by turn with the time axis moving vertically. Firs (upper) a single booster bunch is split into 3 on the CPS injection plateau followed by a quadruple split on the 26 GeV CPS flat top. This beam can then be cleanly transferred into waiting RF "buckets" in the SPS. Figure 6 shows the bunch distribution using the same monitor as Figures 3 and 4. The leading edge is now perfectly defined.

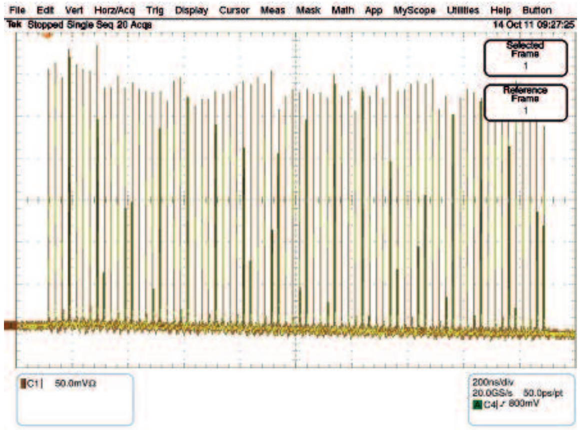

Figure 6

Bunch distribution of the LHC beam in the SPS

Figure 7 shows a single bunch 2 ns duration and with an intensity of 3.10^{11} protons, 30 times the nominal bunch intensity of the CNGS beam.

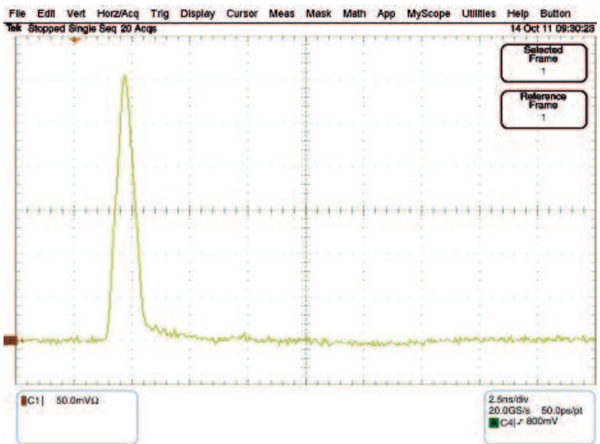

Figure 7

This beam is not suitable for Tau physics at OPERA since the total intensity is about 30 times lower than the normal beam. However, each neutrino event is very precisely defined in time so an accurate time-of-flight measurement can be made with very few events. A number of options have been studied including 25 and 50 ns bunch separation. However in these cases the intensity is limited to about $1.5.10^{11}$ protons per bunch. It is of interest to have the highest possible bunch intensity. A good compromise has been found with 4 bunches each of 3.10^{11} protons per bunch separated by 524 ns per SPS cycle. This beam will give a few neutrino events per day in OPERA.

4. Conclusions

A dedicated “LHC type” beam removes the uncertainties inherent in the normal proton beam to CNGS. It will allow a precise neutrino velocity measurement with very few events.

Acknowledgements

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