Calculation of the Expected Number & Type of Neutrino Interactions

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1 Prompt neutrino beam

The number of muon and electron neutrinos produced per proton on target (beam dump) is simply given by the following formula :

$$\frac{N_{\nu}}{POT} = \frac{\sigma(c\bar{c})A^{\alpha(c\bar{c})}}{\sigma(pp)A^{\alpha(pp)}} BR(c \ or \ \bar{c} \to l\nu X) \tag{1}$$

where POT are the protons on target, $\sigma(c\bar{c})$ is the charm production cross section (D^+, D^-, D^o), $\sigma(pp)$ is total proton-proton cross section, A is the atomic mass of the beam dump, α is the nuclear dependence of the production cross section and $BR(c \ or \ \bar{c} \to l\nu X)$ is the leptonic branching ratio of the charmed particles produced. Tau neutrinos are produced mainly via the production and subsequent semileptonic decay of the charmed meson $D_s \to \tau\nu_\tau$, accompanied by the decay of the produced tau lepton which gives rise to another tau neutrino.Therefore the number of tau neutrinos produced per incident proton in the beam dump can be calculated using the relation:

$$\frac{N_{\nu_\tau}}{POT} = 2 \cdot \frac{\sigma(D_s)A^{\alpha(c\bar{c})}}{\sigma(pp)A^{\alpha(pp)}} BR(D_s \to \tau\nu_\tau) \tag{2}$$

where $\sigma(D_s)$ is the D_s production cross section and a factor of 2 is added, since two tau neutrinos are generated from each D_s decay.

1.1 Open charm hadroproduction

Many fixed target experiments have measured the D production cross section using proton, pion and kaon beams of various energies, but only three so far have performed the calculation using an 800 GeV proton beam. In Table 1 we see the measured $D^{+(-)}$ and D^o production cross sections from these three experiments.

For the extraction of these results, old values of branching ratios have been used, which later changed[4]. Therefore, a correction is performed (wherever possible) to these results [5]. The weighted average extracted from these measurements is :

$$\begin{aligned} \sigma(D^{\pm}) &= 25.0 \pm 4.0 \mu b \\ \sigma(D^{o}) &= 18.6 \pm 3.2 \mu b \end{aligned}$$

Experiment	Number of events	Published value	Corrected value
$\sigma(D^o) \mu barn/nucleon$			
E789[1]	4000	17.7±3.5	16.9±3.5
E743[2]	10	22±11	22±12
E653[3]	128	38±13	38±13
$\sigma(D^{+(-)}) \mu barn/nucleon$			
E743[2]	46	26±4	25±4
E653[3]	18	38±17	33±17

Table 1: *Charm production cross sections measured by 800 GeV proton beams. For the published results old branching ratios have been used and are therefore updated wherever possible.*

However, the expected ratio of charged-to-neutral D cross section does not agree with the previous result. If one assumes isospin invariance in the $c \to D$ and $c \to D^*$ transition, and furthermore the D cross section to be one third of the D^* cross section (due to counting of polarization states), then the ratio R of charged-to-neutral D cross section is roughly [30]:

$$R = \frac{\sigma(D^+)}{\sigma(D^0)} \simeq 0.32 \tag{3}$$

For pion-nucleon collisions, nearly all experimental data agree with each other[30], and furthermore, the average ratio R is:

$$R = \frac{\sigma(D^+)}{\sigma(D^0)} = 0.41 \pm 0.03 \tag{4}$$

This experimental value is very close to the theoretical expectation, and therefore the proton-nucleon collision data either overestimate the $D^{\pm}$, or underestimate the D^0 production cross sections. For that reason, we are going to use the most precise experimental measurement of the charm production cross section from an 800 GeV proton beam, which is the D^o production cross section obtained from the E789[1] collaboration using a relatively large data sample of 4000 events, and the R value, in order to estimate the $D^{\pm}$ production cross section. Finally

$$\begin{aligned} \sigma(D^{\pm}) &= 8.04 \pm 1.4 \mu b \\ \sigma(D^o) &= 16.9 \pm 3.5 \mu b \end{aligned}$$

These are the values we are going to use in order to perform the beam composition calculations.

1.2 D_s production cross section

So far there has been no direct measurement of the D_s production cross section from 800 GeV proton interactions. However the ratio of the inclusive cross sections for $D_s/D^{+(-)}$ has been measured by various experiments for various types of beams and beam energies (Table 2). Thus the D_s production cross section for 800 GeV protons can be indirectly extracted through:

$$\sigma_{D_s} = \langle \frac{\sigma_{D_s}}{\sigma_{D^\pm}} \rangle \cdot \sigma_{D^\pm}^{800\ p\ interactions} \tag{5}$$

Experiment	Beam type	Beam Energy (GeV)	$\sigma_{D_s}/\sigma_{D^\pm}$
CLEO[9]	e^+e^-	10(CM)	0.77±0.31
E691[6]	γ	80 - 230	0.44±0.16
NA32[7]	π	250	0.47±0.19
E653[8]	π	600	0.56±0.18†
E769[10]	π	250	0.62±0.14†
	K	250	1.00±0.30†
	p	250	0.47±0.32†
WA92[11]	π	350	0.40±0.13
Average			0.48±0.07

Table 2: *Ratios of $\sigma_{D_s}/\sigma_{D^\pm}$ from various experiments with various beams and beam energies. Wherever possible the ratios have been corrected for the new D and D_s branching ratios.The E769 measurement for the Kaon beam has been excluded.*

All measurements[1] , as seen from Table2 are consistent with each other except for the E769 kaon beam ratio which is, therefore, not used in the average.

1.3 Nuclear α Dependence for Charm Hadroproduction

The cross sections on a heavy nucleus are usually expressed by a power-law dependence[13] :

$$\sigma = \sigma_o \cdot A^\alpha \tag{6}$$

where A is the atomic mass of the target and α a parameter determined by experiments. The total inelastic cross section for proton-nucleon collisions has an $\alpha = 0.69$[12]. The α dependence of charm production cross section has been measured by several experiments and the obtained values are shown in Table 3

Experiment	Beam type	Beam Energy (GeV)	α
WA82 [14]	π	340	0.92±0.06
E769 [15]	π	250	1.0±0.05
E789 [16]	p	800	1.02±0.04
WA92 [11]	π	350	0.95±0.07
Average			0.987±0.026

Table 3: *α dependence measurements from various experiments for the charm production cross section*

The results are consistent with an α of 1. Hence we will adopt the 1.02±0.04 measurement obtained by 800 GeV protons and this is the value we are going to use in the calculations throughout this section.

[1] † These values are not corrected with new D,D_s branching ratios

1.4 Leptonic decays of D mesons

The overall D branching ratio to electron and muon neutrinos [5] is :

$$\begin{aligned} D^{\pm} \to e^{\pm} + anything &= 17.2 \pm 1.9(\%) \\ D^{\pm} \to \mu^{\pm} + anything &= 16.7 \pm 1.8(\%) \end{aligned}$$

Assuming lepton number conservation, each electron or muon in the previous decays, will be accompanied by its corresponding neutrino. The decay rate to muons has been extracted from the one to electrons taking into account that former is 3% less than the later[17] due to reduction of the available phase space by the larger muon mass. The corresponding branching ratios of D^o decays involving muon and electron neutrinos are [5] :

$$\begin{aligned} D^{o} \to e^{+} + anything &= 6.75 \pm 0.29(\%) \\ D^{o} \to \mu^{+} + anything &= 6.6 \pm 0.8(\%) \end{aligned}$$

These are the values we are going to use later on the calculation of the expected composition of the prompt neutrino beam for the DONUT experiment.

1.5 Leptonic decay of D_s

As we have previously discussed the tau neutrinos are mostly produced by the leptonic decay of $D_s^{\pm} \to \tau^{\pm} + \nu_\tau(\overline{\nu}_\tau)$: The decay rate for that process is given by the relation :

$$\Gamma(D_s^{+} \to l^{+} + \nu_l) = \frac{G_F^2 |V_{cs}|^2}{8\pi} f_{D_s}^2 m_l^2 m_{D_s}^2 (1 - \frac{m_l^2}{m_{D_s}^2})^2 \qquad (7)$$

where l is electron. muon or tau, m_l is the lepton mass, m_{D_s} is the D_s mass, G_F is the Fermi coupling constant, f_{D_s} the decay constant and V_{cs} the CKM matrix element. The decay constant f_{D_s} has been measured by six experiments and the values are presented in Table4. All these values have been corrected according to the new [5] D_s branching fractions and lifetime. The first CLEO measurement [19] has been additionally corrected by the CLEO Collaboration with the use of a new analysis method [23]†.[2]

Using the average value of f_{D_s} from the experimental measurements in Eq.7 we obtain the following result for the $D_s \to \tau + \nu_\tau$ branching ratio :

$$B(D_s \to \tau + \nu_\tau) = 5.2 \pm 1.0(\%)$$

This value is in agreement with the experimental measurement of the branching ratio[22] of:

$$B(D_s \to \tau + \nu_\tau) = 7 \pm 4(\%)$$

and this is the value we are going to use for the calculations.

[2]† The corrections for the new D_s branching ratios are presented in this paper, and the corrections for the D_s lifetime are performed by us.

Experiment	Decay channel	$f_{D_s}(MeV)$
WA75 [18]	$D_s \to \mu + \nu_\mu$	228±68
CLEO [19]	$D_s \to \mu + \nu_\mu$	271±60
BES [20]	$D_s \to \mu + \nu_\mu$ and $D_s \to \tau + \nu_\tau$	413±141
E653 [21]	$D_s \to \phi + l + \nu$	182±46
L3 [22]	$D_s \to \tau + \nu_\tau$	296±75
CLEO [23]	$D_s \to \mu + \nu_\mu$	269±47
DELPHI [28]	$D_s \to \tau + \nu_\tau$	317±92
Average		251±24

Table 4: *Decay constant f_{D_s} as measured by six experiments.*

1.6 Composition of Prompt Neutrino beam

Gathering together the experimental results for the D mesons production cross sections, as well as their branching ratios to modes including neutrinos, we can calculate the expected composition of the prompt neutrino beam for the DONUT experiment, using Eq.1 and Eq.2. The atomic weight of the tungsten beam dump for the DONUT experiment is 181, and the inelastic total 800 GeV proton cross section is 34 mb per nucleon[4]. Using Eq.1 we can calculate the number of muon, electron and tau neutrinos produced per Protons On Target. The electron and muon neutrinos are mainly produced from the leptonic decays of D mesons, thus we have :

$$\begin{aligned}\frac{N_{\nu_{\mu(e)}}}{POT} &= \frac{\sigma(D^+)A^1}{\sigma(pp)A^{0.69}} BR(D^+ \to \mu^+(e^+) + \ anything) \\ &+ \frac{\sigma(D^-)A^1}{\sigma(pp)A^{0.69}} BR(D^- \to \mu^-(e^+) + \ anything) \\ &+ \frac{\sigma(D^o)A^1}{\sigma(pp)A^{0.69}} BR(D^o \to \mu^+(e^+) + \ anything)\end{aligned} \tag{8}$$

and the tau neutrinos are mainly produced from the leptonic decays of D_s using the formula:

$$\begin{aligned}\frac{N_{\nu_\tau}}{POT} &= 2 \cdot \frac{\sigma(D_s)A^1}{\sigma(pp)A^{0.69}} BR(D_s \to \tau\nu_\tau) \\ &= 2 \cdot \langle \frac{\sigma_{D_s}}{\sigma_{D^\pm}} \rangle \cdot \frac{\sigma_{D^\pm}^{800\ p\ interactions} \cdot A^1}{\sigma(pp)A^{0.69}} \cdot BR(D_s \to \tau\nu_\tau)\end{aligned} \tag{9}$$

For the muon neutrinos, there is an additional contribution from pion and kaon decays, the so called "no prompt ν_μ component, which is estimated to be $44 \pm 17\%$.[29]. Substituting the various experimental values, presented in the previous section, for the charm production cross sections, the branching ratios and the nuclear A dependence we finally have:

$$\begin{aligned} \frac{N_{\nu_\mu} prompt}{POT} &= (5.6 \pm 0.9) \times 10^{-4} \\ \frac{N_{\nu_\mu} nonprompt}{POT} &= (4.4 \pm 2.3) \times 10^{-4} \\ \frac{N_{\nu_e}}{POT} &= (5.76 \pm 0.91) \times 10^{-4} \\ \frac{N_{\nu_\tau}}{POT} &= (0.80 \pm 0.50) \times 10^{-4} \end{aligned} \tag{10}$$

2 Protons on target

In order to calculate the number of neutrinos produced from the beam dump we need to know the number of Protons On Target. Therefore we have to take into consideration the live time of the experiment, as well as efficiency of Protons On Tapes. Some data tapes have been damaged, and therefore a small fraction of data is inaccessible. On the following Table 5 we present the initial number of Protons On Target, as well as the corrections taking into account live time and the efficiency of protons on tape, for the four periods of the experiment.

Period	POT	Live Time	Protons On Tape efficiency	Effective POT
1	0.65×10^{17}	0.93	0.90	5.40×10^{16}
2	0.53×10^{17}	0.93	0.90	4.40×10^{16}
3	1.30×10^{17}	0.88	0.90	1.03×10^{17}
4	1.99×10^{17}	0.87	0.90	1.55×10^{17}

Table 5: *Effective Protons On Tape for the four different periods of the experiment. Total Live Time and Protons On Tape efficiency have been taken into consideration.*

3 Neutrino Interaction Probability

The interaction probability of neutrinos of all flavors in the emulsion target of the DONUT experiment can be calculated using the following simple formula:

$$P_{int.} = (\frac{\sigma_{\nu N}^{CC \ or \ NC}}{E_\nu}) \cdot \langle E_\nu \rangle \cdot \beta \cdot N_A \cdot \rho \cdot L \tag{11}$$

where $\sigma_{\nu N}^{CC \ or \ NC}$ is the charged current(CC) or neutral-current(NC) deep inelastic neutrino-nucleon scattering cross section, E_ν is the neutrino energy, $\langle E_\nu \rangle$ is the mean neutrino energy, β is the emulsion target (angular) acceptance, ρ is the emulsion target density, and L is the emulsion target length. In the following sections we present the values used for each one of these parameters.

3.1 Deep Inelastic Neutrino-Nucleon cross sections

In this section we present the experimental values of charged current deep inelastic neutrino-nucleon cross section per neutrino energy $\frac{\sigma^{CC}_{\nu(\overline{\nu})N}}{E_\nu}$, for both neutrinos and antineutrinos of all three flavors. For the charged current deep inelastic electron and muon neutrino interactions, we can neglect the muon and electron masses, since there are negligible in comparison to the neutrino energy. In Fig.1 we see the various experimental measurements of the $\frac{\sigma^{CC}_{\nu(\overline{\nu})N}}{E_\nu}$ ratio. These can be summarized in the following averages [5]:

$$\frac{\sigma^{CC}_{\nu N}}{E_\nu} = 0.677 \pm 0.014 \times 10^{-38}\ cm^2/GeV$$
$$\frac{\sigma^{CC}_{\overline{\nu} N}}{E_\nu} = 0.334 \pm 0.008 \times 10^{-38}\ cm^2/GeV$$

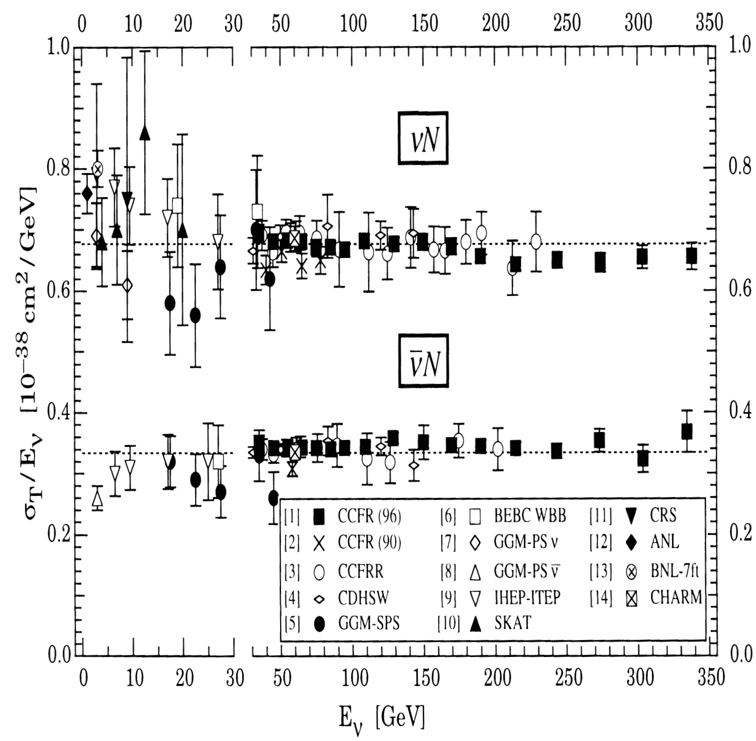

Figure 1: $\frac{\sigma^{CC}_{\nu(\overline{\nu})N}}{E_\nu}$ *for the muon neutrino and muon antineutrino as a function of the neutrino energy as measured from various experiments. The straight lines are averaged values over all energies.*

The fact that the electron and muon masses are considered negligible in comparison to the neutrino energy, cannot hold for the tau neutrino, due to the finite tau mass. Thus the tau neutrino (and antineutrino) charged current deep inelastic scattering cross section does not show a linear dependence to the neutrino energy. The large tau lepton mass gives rise to a kinematic factor K_F and the cross section reads :

$$\begin{aligned}\sigma^{CC}_{\nu_\tau} &= K_F(E_{\nu_\tau}) \cdot \sigma^{CC}_{\nu_\mu} \\ &= K_F(E_{\nu_\tau}) \cdot \alpha \cdot E_{\nu_\tau} \qquad (12)\end{aligned}$$

where α is the numerical constant that has been determined from the fit of Fig1 to be 0.677 ± 0.014 and 0.334 ± 0.008 for muon neutrinos and antineutrinos respectively and E_{ν_τ} is the tau neutrino energy. The numerical calculation of the kinematic factor K_F can be performed according to the method described by Albright and Jarlskog [24] and the result is shown on Fig.2 which has been created by B.Lundberg[25].

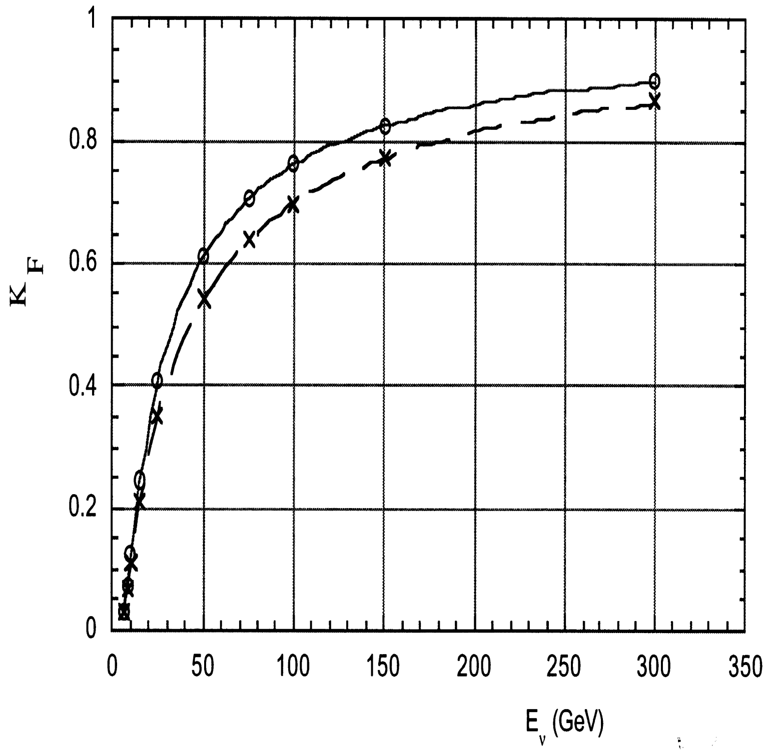

Figure 2: *The kinematic factor K_F as a function of the tau neutrino energy. The solid line corresponds to neutrinos and the dashed to antineutrinos.*

The kinematic factor K_F is, as expected, zero for neutrino energies below the tau lepton mass, since these cannot interact via a charged current interaction. The average factor K_F is found to be [25] :

$$K_F = 0.666 \pm 0.005$$

Using this result in Eq.12 we obtain:

$$\begin{aligned}\frac{\sigma^{CC}_{\nu_\tau N}}{E_{\nu_\tau}} &= 0.451 \pm 0.010 \times 10^{-38}\ cm^2/GeV \\ \frac{\sigma^{CC}_{\overline{\nu_\tau} N}}{E_{\nu_\tau}} &= 0.222 \pm 0.005 \times 10^{-38}\ cm^2/GeV\end{aligned}$$

The Neutral Current (NC) neutrino - nucleon scattering cross sections can be determined from the ratio $R(\overline{R}) = \frac{\sigma_{NC}^{\nu(\overline{\nu})N}}{\sigma_{CC}^{\nu(\overline{\nu})N}}$. These ratios, for an isoscalar target, are expressed through the following relations [26]:

$$
\begin{aligned}
R &= \frac{\sigma_{NC}^{\nu N}}{\sigma_{CC}^{\nu N}} = \frac{1}{2} - sin^2\theta_W + \frac{20}{27} sin^4\theta_W + corrections \\
\overline{R} &= \frac{\sigma_{NC}^{\overline{\nu} N}}{\sigma_{CC}^{\overline{\nu} N}} = \frac{1}{2} - sin^2\theta_W + \frac{20}{9} sin^4\theta_W + corrections \qquad (13)
\end{aligned}
$$

Various experiments have measured the weak mixing angle $sin^2\theta_W$ and the value corresponding to a global fit to all data is[5] :

$$sin^2\theta_W = 0.23117 \pm 0.00016$$

Using this value and substituting to Eq.13 we obtain the following values for $R(\overline{R})$:

$$
\begin{aligned}
R &= 0.3084 \pm 0.0001 \\
\overline{R} &= 0.387584 \pm 0.000004 \qquad (14)
\end{aligned}
$$

Using the values of the ratios R and $\overline{R}$ and the Charged Current cross sections we can determine the Neutral Current cross sections of all neutrino flavors. Thus we have :

$$
\begin{aligned}
\frac{\sigma_{\nu N}^{NC}}{E_\nu} &= 0.21 \pm 0.04 \times 10^{-38} \; cm^2/GeV \\
\frac{\sigma_{\overline{\nu} N}^{NC}}{E_\nu} &= 0.13 \pm 0.02 \times 10^{-38} \; cm^2/GeV \\
\frac{\sigma_{\nu_\tau N}^{NC}}{E_{\nu_\tau}} &= 0.14 \pm 0.032 \times 10^{-38} \; cm^2/GeV \\
\frac{\sigma_{\overline{\nu_\tau} N}^{NC}}{E_{\nu_\tau}} &= 0.086 \pm 0.013 \times 10^{-38} \; cm^2/GeV
\end{aligned}
$$

The first two cross sections are for the electron and muon neutrinos if we consider the electron and muon masses to be negligible in comparison to the neutrino energies.

3.2 Average Neutrino Energy

The average neutrino energies for this experiment are determined[3] from the Monte Carlo to be 89 GeV for the electron neutrinos, 83 GeV for the prompt muon neutrinos, 40 GeV for the muon non prompt neutrinos and 111 GeV for the tau neutrinos.

3.3 Target acceptance

The size of the each emulsion target is $50cm \times 50cm$ in the plane perpendicular to the beam directions, and the length is ~6 cm. The beam dump is located 36.5 m upstream of the most upstream emulsion module. Therefore the targets effective angle from the beam dump is $\pm 6.9mr$. the fraction of neutrinos that reach the target has been calculated from Monte Carlo[27], and the resulting acceptances, for the three neutrino flavors, are :

$$\begin{aligned} \beta_e &= 0.064 \\ \beta_\mu &= 0.064 \\ \beta_\tau &= 0.064 \end{aligned}$$

The acceptance for the tau neutrinos is the average for the two neutrinos produced in each D_s decay (the daughter tau lepton decays giving rise to a second tau neutrino).

3.4 Target Composition & Configuration

In the experiment there are three different types of emulsion: Bulk, ECC-800 (Emulsion Cloud Chamber), and ECC-200. Combinations of these types finally form six different types of emulsion modules, as far as their composition is concerned. There are modules constructed entirely from Bulk-type emulsion, modules constructed entirely from ECC-type emulsion and modules where the upstream part is Bulk-type and the downstream part ECC-type. In Table 6 we see the characteristics of the various emulsion modules.

Module	Composition	$\rho(gr/cm^3)$
BULK	100% Emulsion	3.8
ECC	95% Steel + 5% Emulsion	7.6
E/B4	57% ECC + 43% BULK	6.0
E/B3	68% ECC + 32% BULK	6.5
E/B2	61% ECC + 39% BULK	6.2
E/B1	72% ECC + 28% BULK	6.6

Table 6: *The composition and density of the six different target modules of the DONUT experiment.*

Four different combinations of these target modules where used throughout the data taking period that correspond to the four different periods of the experiment. In Table 7 we see the target configuration for the four different periods of the experiment.

PERIOD	MODULE1	MODULE2	MODULE3	MOCUDLE4
1	ECC	-	ECC	-
2	ECC	-	ECC	E/B4
3	ECC	E/B2	E/B3	E/B4
4	E/B1	E/B2	E/B3	B4

Table 7: *The four different target configurations corresponding to the four different periods of the DONUT experiment*

4 Event Selection Efficiency

The various steps we have followed in the analysis of experimental data, are accompanied with a characteristic efficiency, which has to be taken under consideration for the final determination of the expected number of neutrino interactions. The first step of the event selection procedure, is the hardware trigger of the experiment. The trigger logic accepts a great fraction of the interesting neutrino interactions, while on the same time rejecting a large fraction of background interactions. It is mainly based on event topology. The stripping procedure is also accompanied by an efficiency for selecting the interesting neutrino interactions. All these different efficiencies have been calculated, either by Monte Carlo simulations, or by Artificial Neural Network techniques. Their values for the various neutrino flavors and interactions are summarized in Table 8

Interaction type	Trigger efficiency	Stripping efficiency	Overall efficiency
ν_μ CC prompt	0.96	0.75	0.72
ν_μ CC non prompt	0.89	0.75	0.67
ν_e CC	0.97	0.75	0.73
ν_τ CC	0.95	0.75	0.71
NC	0.86	0.75	0.65

Table 8: *Trigger, stripping and overall efficiency for selecting neutrino interactions.*

5 Expected number of neutrino interactions

Now we have calculated all parts of Eq.1 and therefore we are ready to proceed with the final estimation of the expected number of neutrino interaction, for all four periods of the experiment. We present the calculations for each period and each neutrino interaction type separately, in Table 9. Gathering all these results together we estimate the expected overall number of neutrino interactions for the DONUT experiment to be :

Expected Number	1073±24
Observed Number	1008

We clearly see that the observed (selected) number of neutrino interactions (1008) is in good agreement with the theoretical expectation (1073±24), which implies that all the steps of the event selection procedure were quite successful. From this calculation, we are also able to estimate the expected number (and ratio) of the ν_μ CC, ν_e CC, ν_τ CC and NC neutrino interactions. Since we have classified the experimentally observed 1008 neutrino interactions into the previous categories, with the use of Artificial Neural Network techniques, we are able to perform the comparison with the theoretical expectation. In order to perform the comparison we "process" the expected number of ν_μ CC, ν_e CC, ν_τ CC and NC interactions, (scaled to the 1008 events) in an identical way as the ANN filters. Namely we used the ANNs efficiency, purity and contamination, so as to estimate what we would expect to "see" from the overall ANN analysis.

PERIOD 1	TARGET TYPE				
	ECC	–	ECC	–	
Int. Type	# of Int.	# of Int.	# of Int.	# of Int.	Total #
ν_μ CC prompt	17±2		17±2		34±3
ν_μ CC non prompt	5±2		5±2		10±3
ν_μ CC all	22±3		22±3		44±4
ν_e CC	18±2		18±2		36±3
ν_τ CC	2±1		2±1		4±1
NC	13±1		13±1		26±1
Total #	55±4		55±4		110±6
PERIOD 2	TARGET TYPE				
	ECC	–	ECC	E/B4	
Int. Type	# of Int.	# of Int.	# of Int.	# of Int.	Total #
ν_μ CC prompt	14±2		14±2	11±1	39±3
ν_μ CC non prompt	4±2		4±2	3±1	11±3
ν_μ CC all	18±3		18±3	14±1	50±4
ν_e CC	15±2		15±2	12±1	42±3
ν_τ CC prompt	2±1		2±1	1±1	5±2
NC	10±1		10±1	8±1	28±2
Total #	45±4		45±4	35±2	125±6
PERIOD 3	TARGET TYPE				
	ECC	E/B2	E/B3	E/B4	
Int. Type	# of Int.	# of Int.	# of Int.	# of Int.	Total #
ν_μ CC prompt	32±4	26±3	28±3	25±3	111±7
ν_μ CC non prompt	10±4	8±3	9±3	8±3	35±7
ν_μ CC all	42±6	34±4	37±4	33±4	146±10
ν_e CC	34±4	28±3	29±3	27±3	118±7
ν_τ CC prompt	4±2	3±1	3±2	3±1	13±3
NC	24±3	20±2	21±2	19±2	84±5
Total #	104±8	85±5	90±6	82±5	361±14
PERIOD 4	TARGET TYPE				
	E/B1	E/B2	E/B3	E/B4	
Int. Type	# of Int.	# of Int.	# of Int.	# of Int.	Total #
ν_μ CC prompt	42±5	40±5	41±5	24±3	147±9
ν_μ CC non prompt	13±5	12±5	13±5	8±3	46±9
ν_μ CC all	55±7	52±7	54±7	32±4	193±13
ν_e CC	45±5	42±5	44±5	26±3	157±9
ν_τ CC prompt	5±2	5±2	5±2	3±1	18±4
NC	31±4	29±3	31±4	18±2	109±7
Total #	136±10	128±9	134±9	79±5	477±18

Table 9: *Expected number & type of neutrino interactions for each emulsion module and period*

Ratios	ν_μ CC	ν_e CC	ν_τ CC	NC
Expected	40.3±1.8%	32.9±1.3%	3.7±0.5%	23.0±0.9%
ANN "Expected"	32.0±1.4 %	36.±1.3 %	—	31.6±1.0 %
ANN "Observed"	34.1±1.5%	35.9±1.5%	—	30.0±1.4%
Numbers	ν_μ CC	ν_e CC	ν_τ CC	NC
Expected	407±16	332±11	38±5	232±8
ANN "Expected"	322±12	368±9	—	318±7
ANN "Observed"	344±15	362±15	—	302±15

Table 10: *Expected and observed, through the ANN analysis, ratio (and number), of the various types of neutrino interactions.*

In Table 10 we present: a) the theoretically expected ratios of ν_μ CC, ν_e CC, ν_τ CC and NC interactions, obtained from this analysis, b) the theoretically expected ratios after processing the events through the ANN filters, and c) the actual experimentally observed rations, with the use of the ANN filters. As we see, the experimental results are in very good agreement (within errors) with the theoretical expectations. This gives us confidence on both the neutrino event selection procedure, as well as the neutrino event characterization.

References

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