Neutrino Factory Near Detector Simulation

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Neutrino Factory Near Detector

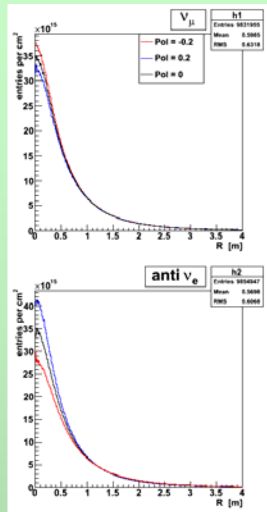
The aim of the Near detector of the Neutrino factory is to measure the absolute flux normalization. It will be used also for precise measurements of the neutrino cross sections and to estimate the background to the far detector.

Muon decay matrix element

For ν_μ $\qquad \dfrac{d^2N_\nu}{dx\,d\Omega} \sim \left((3-2x)+\cos\theta P_\mu(1-2x)\right)x^2$

For antiν_e $\qquad \dfrac{d^2N_\nu}{dx\,d\Omega} \sim \left((1-x)+\cos\theta P_\mu(1-x)\right)x^2$

where $x = 2E_\nu/m_\mu$, P_μ is the polarization of the muon and θ is the angle between polarization vector and the neutrino direction.



Simulation of the neutrino flux in the Near detector

The neutrino flux depends on the polarization of the beam. The figure shows the neutrino flux at 100 m after the end of the straight section of the muon storage ring for 10^{21} muon decays (1 year) for three different polarizations of the muon beam.

The input parameters of the simulation are:

- Length of the straight section of the muon storage ring : 400 m.
- beam energy : 25 GeV.
- muon energy distribution : Gaussian (σ = 80 MeV)
- muon angular distribution : Gaussian (σ = 0.5 mrad)

Measurement of the neutrino flux in the Near detector

The quasielastic scattering off electrons can be used to measure the flux, because its absolute cross-section can be calculated theoretically with great confidence. The two processes of interest for neutrinos from μ^- decays are:

$$\nu_\mu + e^- \rightarrow \nu_e + \mu^-$$

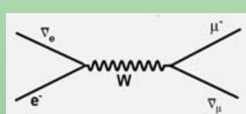
and

$$\overline{\nu}_e + e^- \rightarrow \overline{\nu}_\mu + \mu^-$$

In addition, it is possible to measure the polarization of the beam.

Quasielastic scattering off electrons in the near detector

$\overline{\nu}_e + e^- \rightarrow \overline{\nu}_\mu + \mu^-$

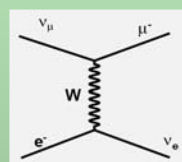


Differential cross section in c.m. system is:

$$\frac{d\sigma}{d\cos\theta} = \frac{2G_F^2}{\pi}\frac{(s-m_\mu^2)^2 E_e E_\mu}{s^2}\left(1+\frac{s-m_e^2}{s+m_e^2}\cos\theta\right)\left(1+\frac{s-m_\mu^2}{s+m_\mu^2}\cos\theta\right)$$

And total cross section is:

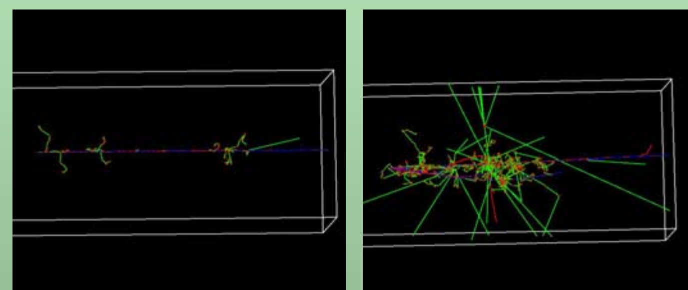
$$\sigma = \frac{2G_F^2}{\pi}\frac{(s-m_\mu^2)^2(E_eE_\mu + 1/3\,E_{\nu 1}E_{\nu 2})}{s^2}$$



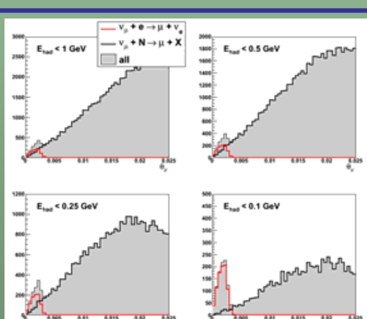
$\nu_\mu + e^- \rightarrow \nu_e + \mu^-$

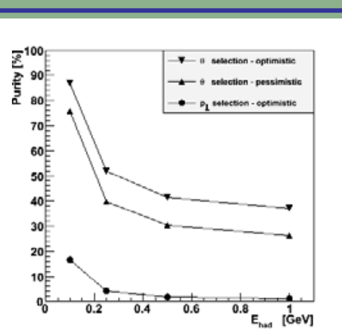
Cross section is isotropic in c.m. system

$$\sigma = \frac{G_F^2}{\pi}\frac{(s-m_\mu^2)^2}{s}$$



If we want to measure the neutrino flux by using the quasielastic scattering off electrons,the detector has to be able to distinguish between these two events.





$$\frac{\sigma(E_{had})}{E_{had}} = a.E_{had}$$

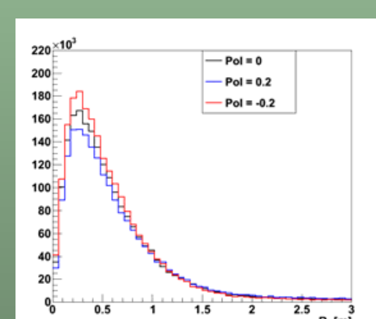
$$\frac{\sigma(p_T)}{p_T} = b.p$$

$$\sigma(\theta) = c$$

Simulation of the neutrino interactions in the Near detector

The neutrino event generator GENIE is used to simulate the interactions of the neutrinos with the material of the detector (polystyrene). Different criteria for suppression of the background from inclusive CC reactions $\nu_\mu N$ are tested. It is considered that the detector will be able to measure the angle between the beam axis and the direction of the outgoing muon θ, the transverse momentum of the outgoing muon p_T, and the total hadronic energy E_{had} with resolution described by the formulae above. Two scenarios are tested. In the so called ***optimistic*** scenario a = 0.01GeV^{-1}, b = 0.0001GeV^{-1} and c = 0.1 mrad. In the so called ***pessimistic*** scenario a = 0.1GeV^{-1}, b = 0.0001GeV^{-1} and c = 1 mrad. The four plots on the top-left above show the angular distributions of the outgoing muons for events with E_{had} < 1 GeV, 0.5 GeV, 0.25 GeV and 0.1GeV, respectively. The leptonic events are in red, the hadronoc events are in black and the total spectrum is filled with grey. The plot on top-right shows the purity (in %) of the selection of the leptonic events as a function of the cut energy where the angle θ and the transverse momentum p_T are used to distinguish between the leptonic and the hadronic events.

Conclusion : For the given resolutions of the measurement of θ, p_T and E_{had} the angle θ has better selective power than the transverse momentum p_T. The confidence of the measurement of E_{had} in the range between 1 GeV and 100 MeV is critical for the selection.



Monitoring of the muon beam polarization

The leptonoc interactions of the neutrinos can be used to monitor the polarization of the muon beam in the storage ring. The plot shows the number of leptonic events as a function of the distance from the neutrino beam axis for three different polarizations of the muon beam in the storage ring and for 10^{21} muon decays (1 year). It is clear that the variation of the distribution of the events because of the different polarization of the muon beam is much bigger than the statistical errors.