



# Neutrino Factory Near Detector Simulation

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## Neutrino Factory Near Detector

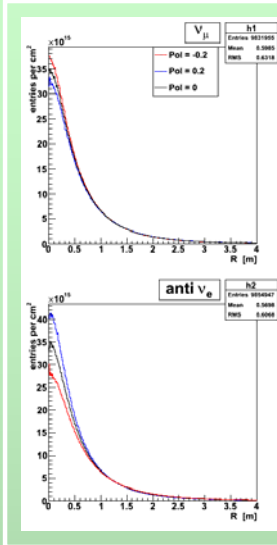
The aim of the Near detector of the Neutrino factory is to measure the absolute flux normalization. It will be used also for precise measurements of the neutrino cross sections and to estimate the background to the far detector.

## Muon decay matrix element

$$\text{For } \nu_\mu \quad \frac{d^2 N_\nu}{dx d\Omega} \sim ((3-2x) + \cos\theta P_\mu (1-2x))x^2$$

$$\text{For } \bar{\nu}_e \quad \frac{d^2 N_\nu}{dx d\Omega} \sim ((1-x) + \cos\theta P_\mu (1-x))x^2$$

where  $x = 2E_\nu/m_\mu$ ,  $P_\mu$  is the polarization of the muon and  $\theta$  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 ( $\sigma = 80$  MeV)
  - muon angular distribution : Gaussian ( $\sigma = 0.5$  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  $\mu^-$  decays are:

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

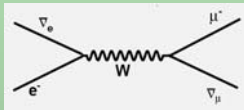
and

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

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

## Quasielastic scattering off electrons in the near detector

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

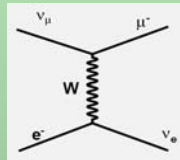


Differential cross section in c.m. system is:

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

And total cross section is:

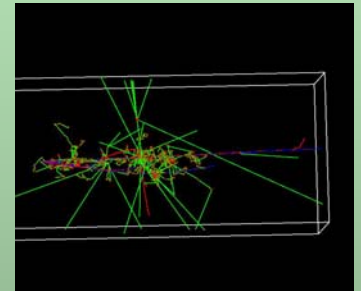
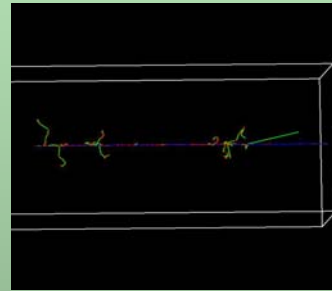
$$\sigma = \frac{2G_F^2}{\pi} \frac{(s-m_\mu^2)^2}{s^2} (E_e E_\mu + 1/3 E_{\nu_l} E_{\nu_2})$$



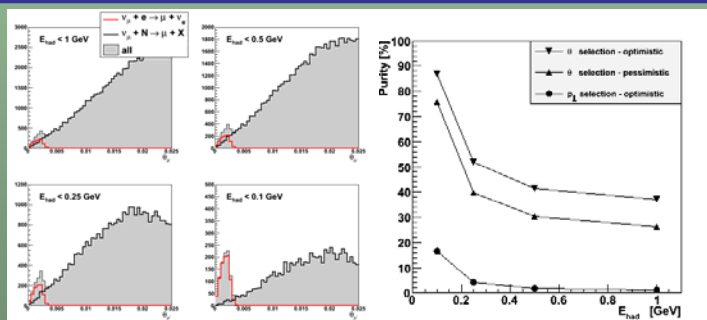
$$\nu_\mu + e^- \rightarrow \nu_e + \mu^-$$

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.



## Simulation of the neutrino interactions in the Near detector

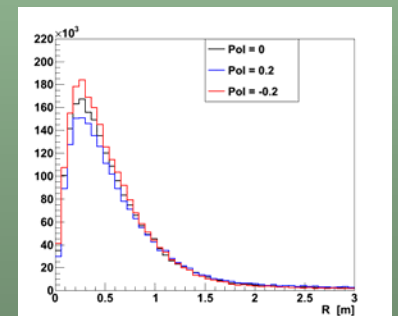
The neutrino event generator GENIE is used to simulate the interactions of the neutrinos with the material of the detector (polystyrene). Different criteria for suppression of the background from inclusive CC reactions  $\nu_\mu N$  are tested. It is considered that the detector will be able to measure the angle between the beam axis and the direction of the outgoing muon  $\theta$ , 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  $a = 0.01 \text{ GeV}^{-1}$ ,  $b = 0.0001 \text{ GeV}^{-1}$  and  $c = 0.1$  mrad. In the so called *pessimistic* scenario  $a = 0.1 \text{ GeV}^{-1}$ ,  $b = 0.0001 \text{ GeV}^{-1}$  and  $c = 1$  mrad. The four plots on the top-left above show the angular distributions of the outgoing muons for events with  $E_{had} < 1 \text{ GeV}$ ,  $0.5 \text{ GeV}$ ,  $0.25 \text{ GeV}$  and  $0.1 \text{ GeV}$ , respectively. The leptonic events are in red, the hadronic 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  $\theta$  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  $\theta$ ,  $p_T$  and  $E_{had}$  the angle  $\theta$  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.

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

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

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



## Monitoring of the muon beam polarization

The leptonic 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.