How to extract Neutrino Factory flux from IMD and neutrino elastic scattering?

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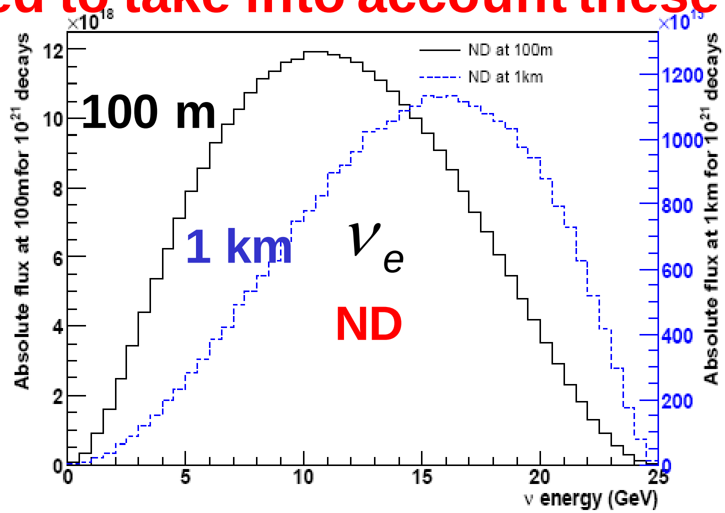
Outline

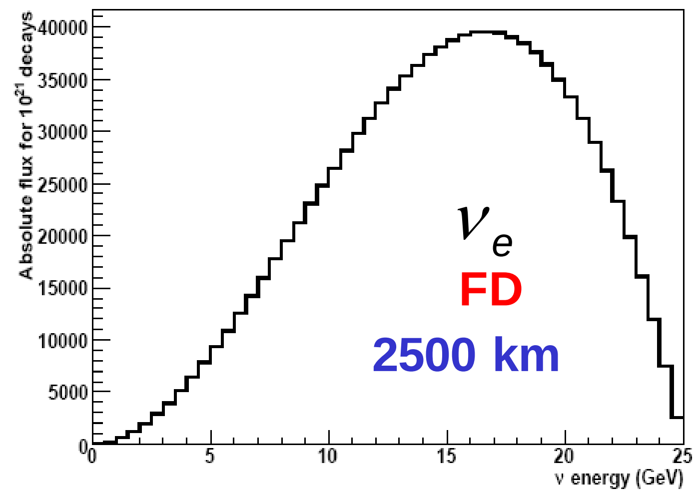
- Spectra at near detector of a neutrino factory
- Outline method to extract fluxes at ND
- Inverse Muon Decay
- Muon-neutrino electron elastic scattering
- Electron-neutrino electron elastic scattering
- Combination of channels to extract fluxes

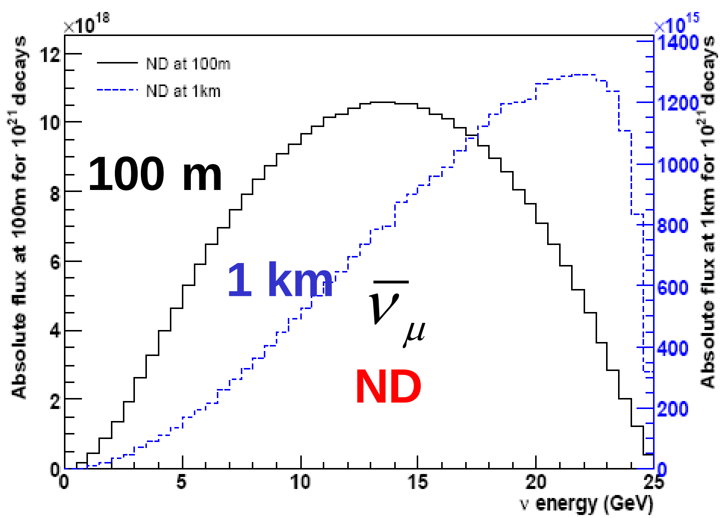
Spectra at Near Detector

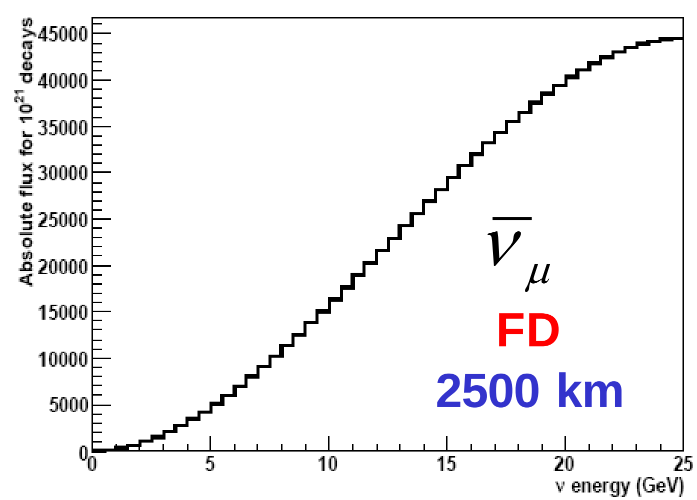
- Near Detector sees a line source (600 m long decay straight)
- Far Detector sees a point source

Need to take into account these differences for flux measurement









Method

- How to extract the neutrino factory flux from the measurements of IMD and nue elastic scattering?
- Use channels with very small theoretical error in the cross-sections and measure them at near detector:
  - Inverse muon decay (Charged Current):

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

  - Elastic neutrino scattering:
    - Neutral Current:

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

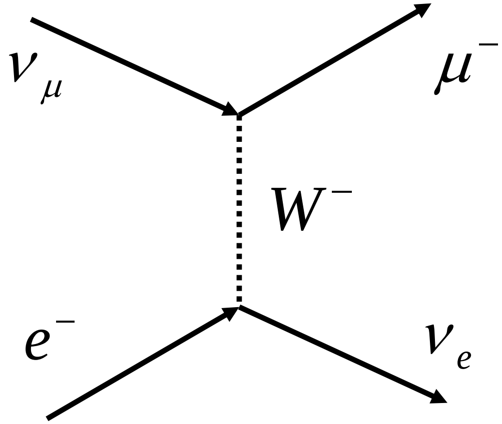
    - Interference Charged Current/Neutral Current:

$$\nu_e + e^- \rightarrow \nu_e + e^- \qquad \bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$

- These processes have cross-sections about 10^{-3} of total CC cross-section but can still expect $\sim 10^6$ events in a near detector at a neutrino factory

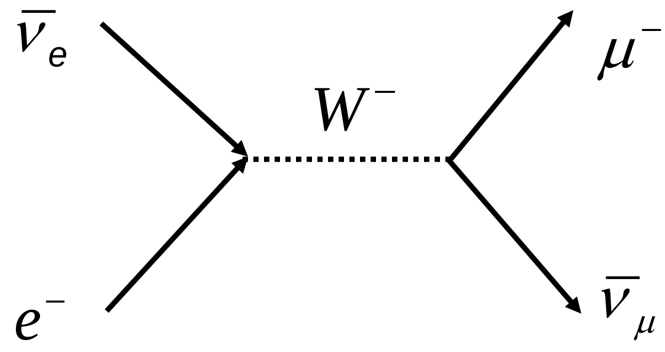
Inverse Muon Decay

- Charged current processes:



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

$$\sigma^{CC}_{\nu_\mu e^-}(E) = \frac{G_F{}^2}{\pi}\frac{(s-m_\mu^2)^2}{s}$$



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

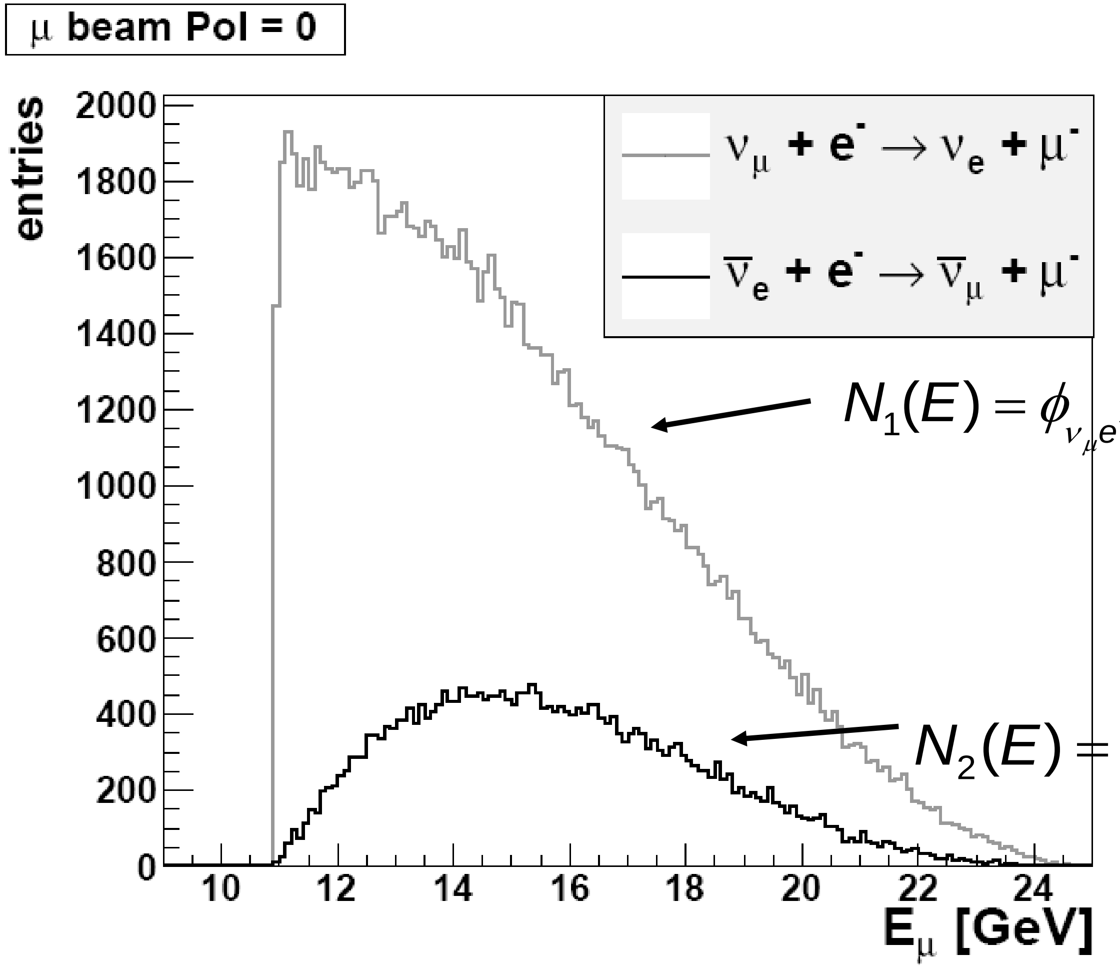
$$\sigma^{CC}_{\bar{\nu}_e e^-}(E) = \frac{G_F{}^2}{\pi}\frac{(s-m_\mu^2)^2}{s}\left(E_e E_\mu + \frac{1}{3}E_{\nu_1}E_{\nu_2}\right)$$

- Cross-section ~1.7x10^{-41} E(GeV) cm^2, threshold = 11 GeV
- We cannot distinguish between the two channels so we measure $N_1(E) + N_2(E)$:

$$N_1(E) = \phi_{\nu_\mu e^-}(E)\sigma^{CC}_{\nu_\mu e^-}(E) \qquad N_2(E) = \phi_{\bar{\nu}_e e^-}(E)\sigma^{CC}_{\bar{\nu}_e e^-}(E)$$

Inverse Muon Decay

- Charged current processes:

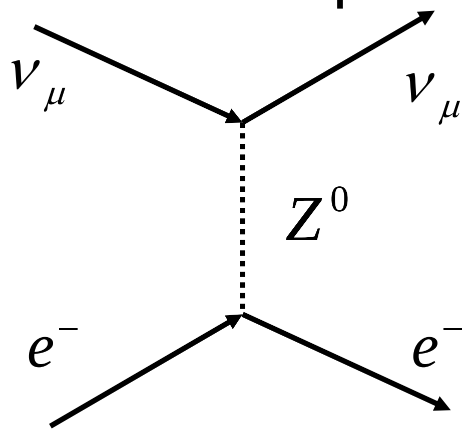


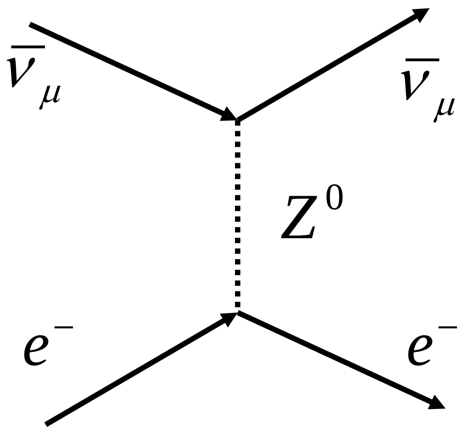
$$N_1(E) = \phi_{\nu_\mu e^-}(E)\sigma^{CC}_{\nu_\mu e^-}(E)$$

$$N_2(E) = \phi_{\bar{\nu}_e e^-}(E)\sigma^{CC}_{\bar{\nu}_e e^-}(E)$$

Muon-neutrino electron scattering

- Neutral current processes:





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

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

$$\sigma^{NC}_{\nu_\mu e^-}(E) = \frac{G_F{}^2 s}{\pi}\left[\left(-\frac{1}{2}+\sin^2\theta_W\right)^2 + \frac{1}{3}\sin^4\theta_W\right]$$

$$\sigma^{NC}_{\bar{\nu}_\mu e^-}(E) = \frac{G_F{}^2 s}{\pi}\left[\frac{1}{3}\left(-\frac{1}{2}+\sin^2\theta_W\right)^2 + \sin^4\theta_W\right]$$

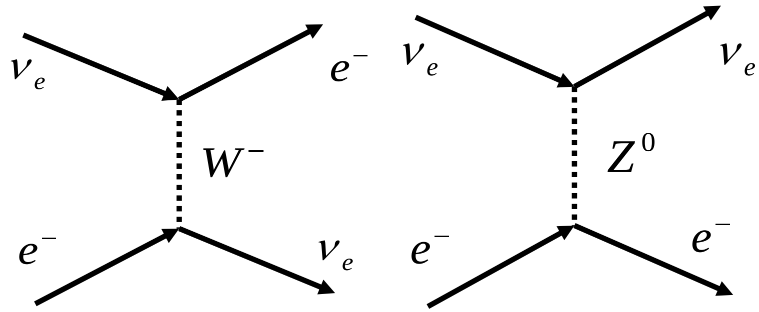
- Cross-section $0.16\text{x}10^{-41}$ E(GeV) and $0.13\text{x}10^{-41}$ E(GeV) cm^2
- We can only distinguish between the two channels since each come from a different muon decay:

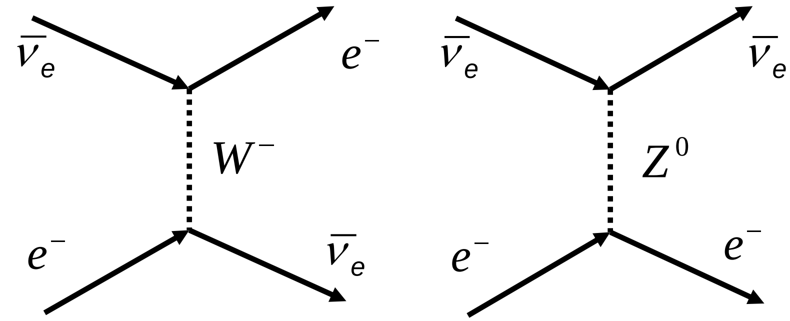
$$N_3(E) = \phi_{\nu_\mu e^-}(E)\sigma^{NC}_{\nu_\mu e^-}(E) \qquad N_4(E) = \phi_{\bar{\nu}_\mu e^-}(E)\sigma^{NC}_{\bar{\nu}_\mu e^-}(E)$$

- Accuracy of cross-section depends on $\sin^2\theta_W$

Electron-neutrino electron scattering

- Interference neutral and charged current processes:





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

$$\sigma^{CC+NC}_{\nu_e e^-}(E) = \frac{G_F^{\;2} s}{\pi}\left[\left(\frac{1}{2} + \sin^2\theta_W\right)^2 + \frac{1}{3}\sin^4\theta_W\right]$$

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

$$\sigma^{CC+NC}_{\bar{\nu}_e e^-}(E) = \frac{G_F^{\;2} s}{\pi}\left[\frac{1}{3}\left(\frac{1}{2} + \sin^2\theta_W\right)^2 + \sin^4\theta_W\right]$$

- Cross-section 0.96×10^{-41} E(GeV) and 0.40×10^{-41} E(GeV) cm^2
- We can only distinguish between the two channels since each come from a different muon decay:

$$N_5(E) = \phi_{\nu_e e^-}(E)\sigma^{CC+NC}_{\nu_e e^-}(E) \qquad N_6(E) = \phi_{\bar{\nu}_e e^-}(E)\sigma^{CC+NC}_{\bar{\nu}_e e^-}(E)$$

- Accuracy of cross-section depends on $\sin^2\theta_W$

Combination of all channels

- So, if we consider the IMD and neutrino elastic scattering channels together we obtain:
  - For the NF decay: $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

$$N_1(E) + N_2(E) = \phi_{\nu_\mu e^-}(E)\sigma^{CC}_{\nu_\mu e^-}(E) + \phi_{\bar{\nu}_e e^-}(E)\sigma^{CC}_{\bar{\nu}_e e^-}(E)$$

$$N_3(E) + N_6(E) = \phi_{\nu_\mu e^-}(E)\sigma^{NC}_{\nu_\mu e^-}(E) + \phi_{\bar{\nu}_e e^-}(E)\sigma^{CC+NC}_{\bar{\nu}_e e^-}(E)$$

  - We can extract the fluxes when we have IMD and elastic scattering:

$$\phi_{\nu_\mu e^-}(E) = \frac{\sigma^{CC+NC}_{\bar{\nu}_e e^-}(N_1 + N_2) - \sigma^{CC}_{\bar{\nu}_e e^-}(N_3 + N_6)}{\sigma^{CC+NC}_{\bar{\nu}_e e^-}\sigma^{CC}_{\nu_\mu e^-} - \sigma^{CC}_{\bar{\nu}_e e^-}\sigma^{NC}_{\nu_\mu e^-}}$$

$$\phi_{\bar{\nu}_e e^-}(E) = \frac{\sigma^{NC}_{\nu_\mu e^-}(N_1 + N_2) - \sigma^{CC}_{\nu_\mu e^-}(N_3 + N_6)}{\sigma^{CC+NC}_{\bar{\nu}_e e^-}\sigma^{CC}_{\nu_\mu e^-} - \sigma^{CC}_{\bar{\nu}_e e^-}\sigma^{NC}_{\nu_\mu e^-}}$$

  - Below 11 GeV we cannot resolve since we only have N_3+N_6

Combination of all channels

- So, if we consider the IMD and neutrino elastic scattering channels together we obtain:
  - For the NF decay: $\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$
  - We cannot resolve the two fluxes because they are together:

$$N_5(E) + N_4(E) = \phi_{\nu_e e^-}(E)\sigma^{CC+NC}_{\nu_e e^-}(E) + \phi_{\bar{\nu}_\mu e^-}(E)\sigma^{NC}_{\bar{\nu}_\mu e^-}(E)$$

- So, we can only resolve the fluxes when we are in an energy bin in which we have both IMD and elastic scattering for μ^- decay. For μ^+ decay, we cannot resolve fluxes with this method – maybe we can do ratio of μ^+/μ^- or fit shapes
- Are there any other neutrino processes that we can use?
- We need to look at these possibilities to extract final fluxes

Conclusions

- Method for extracting neutrino fluxes at NF relies on using channels in which cross-sections are known very well theoretically
- Channels identified include:
  - Inverse Muon Decay
  - Muon-neutrino electron elastic scattering
  - Electron-neutrino electron elastic scattering
- Combination of IMD+neutrino elastic scattering works very well for μ^- decay above IMD threshold (11 GeV)
- For μ^+ decay cannot resolve two fluxes
- Might have to rely on fitting shapes or other processes (quasi-elastic scattering?)