A Background Study for $\nu_\mu \rightarrow \nu_e$

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Introduction

- Where we stand:
  - $\nu_\mu \rightarrow \nu_\tau$ **established**
    - ν_μ disappearance experiments: SK,K2K,Soudan2,MACRO
    - $\sin^2 2\theta_{23}$ and $\Delta m^2_{atm} \sim \Delta m^2_{23}$ measured
  - $\nu_e \rightarrow \nu_x$ **established**
    - ν_e disappearance experiments: Cl,SK,Ga,SNO,KamLAND
    - $\Delta m^2_{12} << \Delta m^2_{23} \sim \Delta m^2_{13}$
  - If $\Delta m^2_{12} << \Delta m^2_{23} \sim \Delta m^2_{13} = \Delta m^2_{atm}$, then

    $P(\nu_\mu \rightarrow \nu_e) \sim \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2(1.27\Delta m^2_{atm}/E_\nu)$
  - Observation of $\nu_\mu \rightarrow \nu_e$ will give us info on $\sin^2\theta_{13}$

- How we do that?
  - $\nu_\mu \rightarrow \nu_e$ **and** ν_e**+N-> e + N' + (invisible** π**s)**
  - **Look for single electron events**
  - **Major background**
    - $\nu_\mu + N \rightarrow \nu_\mu + N' + \pi^0 +$ (invisible πs)
    - ν_e contamination in beam (typically 0.7%)
  - **With a large water Cherenkov detector such as UNO**
    - Cheaper for a large volume than other technologies
    - Potentially quite capable of removing background

Monte Carlo Event Generation

- Atmospheric neutrino events in SK-> BNL superbeam
  - **All ν interactions available but only QE and single π^0 NC used**
  - **SK- I geometry/configuration/PMT coverage**
  - **Standard SK-I analysis package** + Special π^0 finder
  - **Neutrino spectrum reweighted for BNL superbeam using all events**
  - **Total number of events normalized with BNL proposal using QE events**
  - **$\Delta m^2_{21} = 7.3 \times 10^{-5}\ eV^2$, $\Delta m^2_{31} = 2.5 \times 10^{-3} eV^2$**
  - **$\sin^2 2\theta_{ij}(12,23,13) = 0.86/1.0/0.04$, $\delta_{CP} = +45^o$**

From Brett Viren

- Interactions included
  - **Mode 1 : QE (CC)** * signal
  - **Mode 11-13 : Single π from Δ (CC)**
  - **Mode 16 : Coherent π^0 (CC)**
  - **Mode 21 : Multi π (1.3<W<2.0 GeV) (CC)**
  - **Mode 22 : Single η (CC)**
  - **Mode 23 : Single K (CC)**
  - **Mode 26 : Deep inelastic (2.0 GeV <W) (CC)**
  - **Mode 31-34 : Single π from Δ (NC)** * background (π^0 only)
  - **Mode 36 : Coherent π^0 (NC)** * background
  - **Mode 41 : Multi π (1.3<W<2.0 GeV) (NC)**
  - **Mode 42-43: Single η (NC)**
  - **Mode 44-45: Single K (NC)**
  - **Mode 46 : Deep inelastic (2.0 GeV <W) (NC)**
  - **Mode 51-52: Elastic (NC)**

Selection Criteria

- Cut 0:
  - **Fiducial volume cut (200 m inside from PMTs)**
- Cut 1:
  - **1 ring and e- like**

2 γ s, E_γ > 150 MeV, $\theta_{\gamma\gamma}$ > 9° –> 2 rings

BNL proposal requirements

- Cut 2:
  - **E_{ring} > 100 MeV and no decay electrons**

To remove invisible π/μ (for this study not needed)

- Cut 3:
  - **80 < $m_{\gamma\gamma}$ < 160 MeV/c^2**
  - **E_{vis} > 500 MeV**
  - **$\cos\theta_{ring}$ > 0.5**

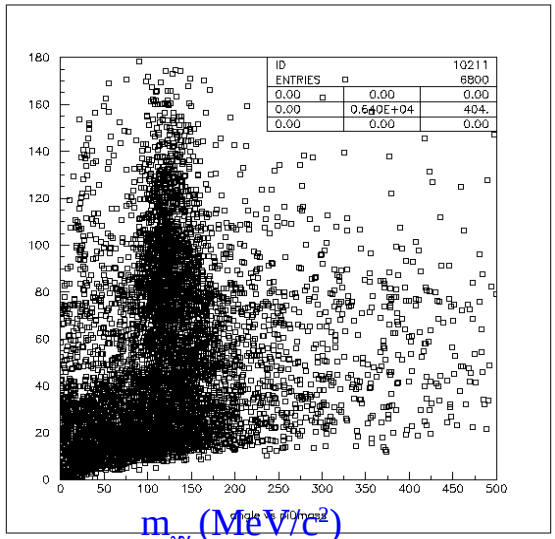
invariant mass btwn primary ring and an extra ring found by π^0 finder

BNL proposal requirements

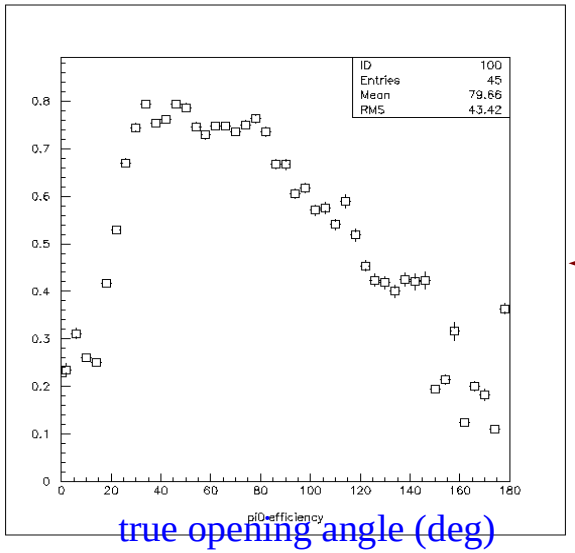
- π^0 finder
  - **π^0 detection efficiency with standard SK software**
  - **π^0 detection efficiency with π^0 finder**

Always finds an extra ring in a single ring event

Single e-like events from single π^0 int.



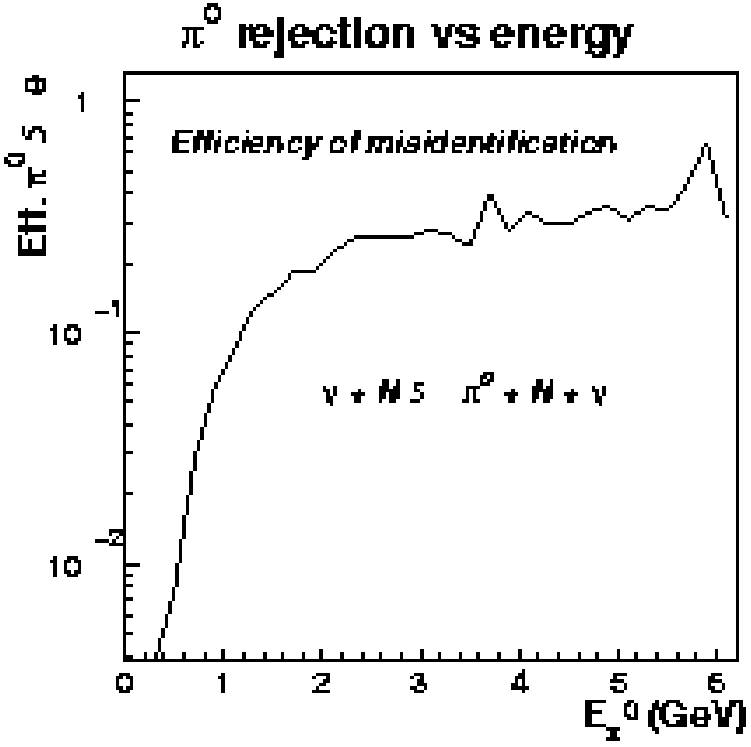
All the single π^0 int.



Detection Efficiencies and Background Rejection

- π^0 –> e probability

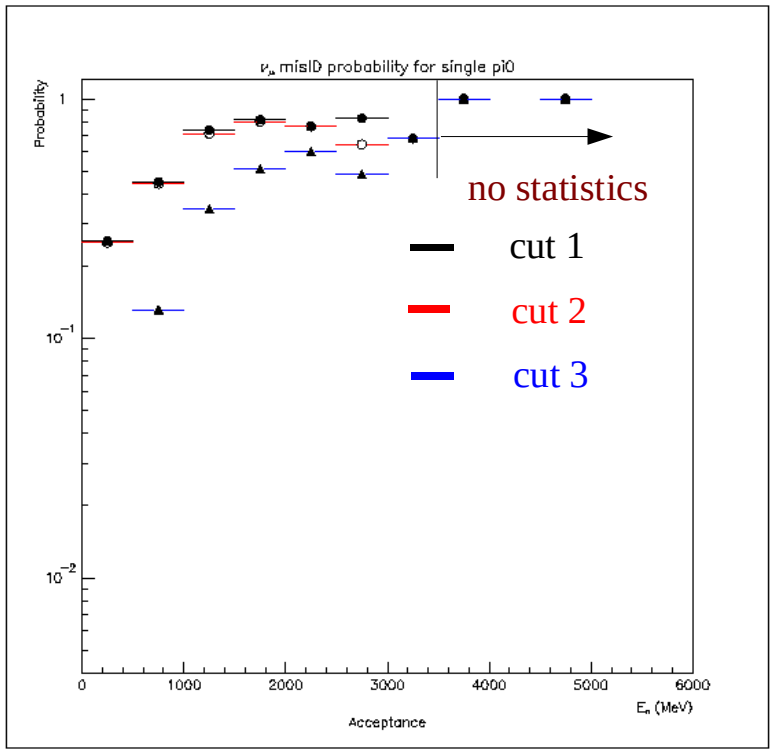
- BNL proposal



E_π(GeV)

~7.5% at 1 GeV
~20% at 2 GeV

- This study



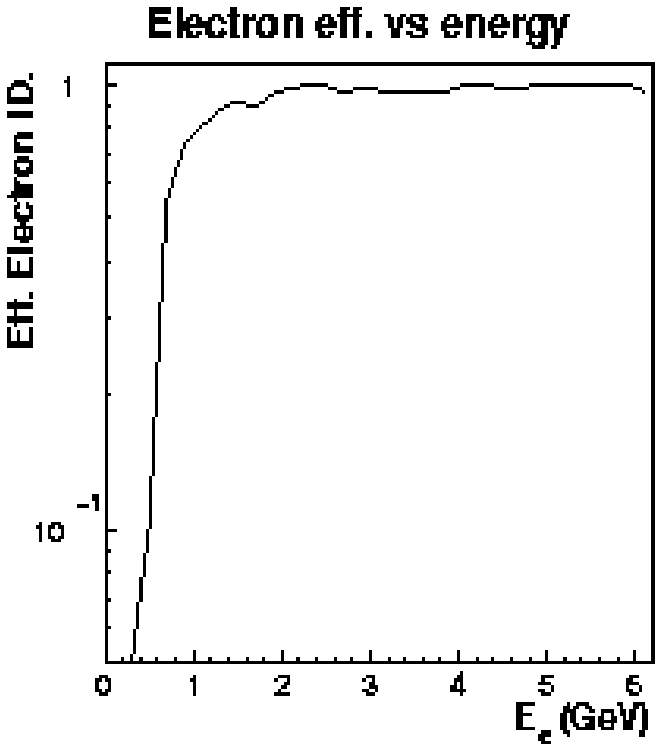
E_π(MeV)

~20% at 1 GeV
~50% at 2 GeV

Detection Efficiencies and Background Rejection

- ν_e QE efficiency

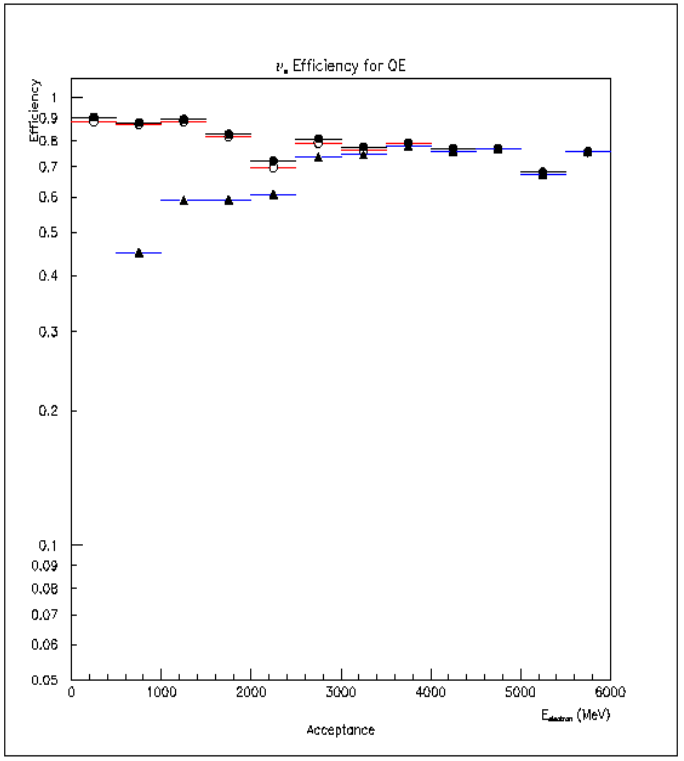
- BNL proposal



~75% at 1 GeV
~95% at 2 GeV

E_e(GeV)

- This study



~50% at 1 GeV
~60% at 2 GeV

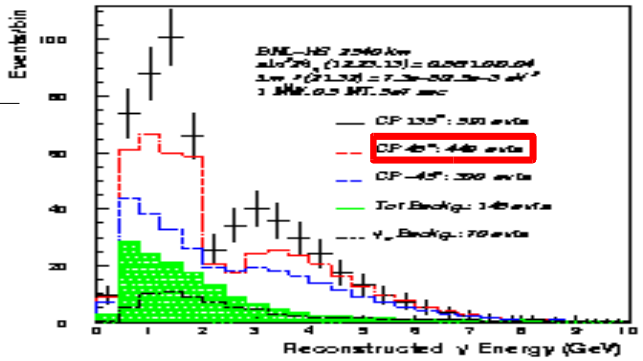
E_e(MeV)

Singnal and Background

BNL proposal

Before any cut

	ν_μ QE	$1\pi^0$
no OSC	13,290	4,238
w/ OSC	6,538	4,238



Number of signal and background events

Signal 449 events

All bkgs 146
(76 from π^0)
(70 from ν_e)

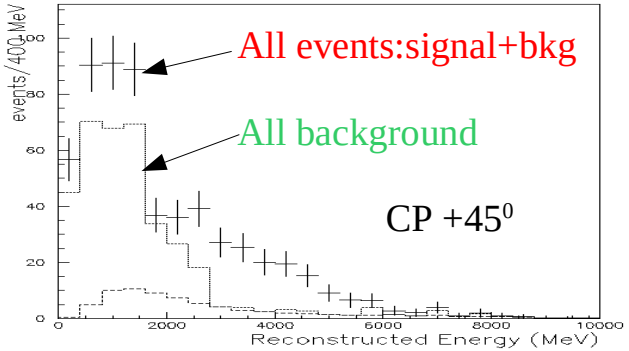
This study

	ν_μ QE	$1\pi^0$
no OSC	12,000	3,275
w/ OSC	5,547	3,275

15% less

13% less

10% less



Compare ..... with +

Signal 219 events
(445->372->367->219)

All bkgs 362
(292 from π^0)
(70 from ν_e) ← should be smaller

•Conclusions

- First realistic MC simulation study was performed for BNL very long baseline proposal with a water Cherenkov detector
  - Estimates on the signal and background level seem optimistic in the proposal
  - However, there is some room to improve SN ratio by optimizing various cuts within the current available software
  - With all intereactions turned on SN ratio probably gets worse
- It is still some room to improve SN ratio by reducing the background level while keeping a good signal detection effciency
  - Improvement of algorithm/software is essential
  - Improvement of hardware may be possible: FADCS, direction sensitive photo- detector etc.