

# Generator study for 10 GeV MIND

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April 16, 2012

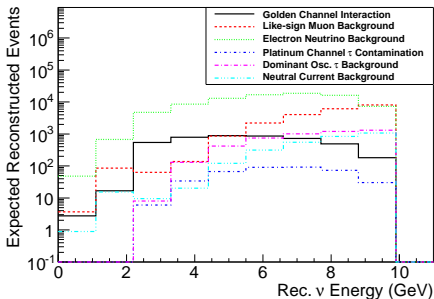
# Generator Study

- With the discovery of  $\theta_{13} = 8.8 \pm 3.6 \pm 2.0^\circ$  MIND must be reoptimized.
- Need to produce a generator study to establish the sensitivities required by neutrino factory detector system.

## Directives for Study

- Use GENIE to generate proportion of neutrino samples
- Assume perfect efficiency for all neutrino species.
- Use NUTS to calculate relative proportion of each species during experiment given  $\theta_{13}$  and  $\delta_{CP}$ .
- Extract relative number of counts for various species.
- Separate events by interaction type.
- Goal is to determine the background rejection necessary to measure  $\delta_{CP}$ .

# Event Rates for $\nu_\mu$ Golden Channel



- Store  $\mu^+$ .
- $\nu_e$  and  $\bar{\nu}_\mu$  in beam.
- Look for  $\nu_e \rightarrow \nu_\mu$  oscillations

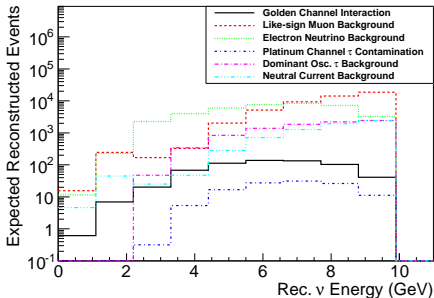
## • Assumed

- EW beam flux in GENIE.
- $10^{21}$   $\mu^+$  over 5 years
- 50 kTon detector at 2000 km
- GENIE output used in NUTS
- $\delta_{CP} = 45^\circ$ ,  $\theta_{13} = 8.8^\circ$

## Total Counts

$\nu_\mu$ CC	4501
$\bar{\nu}_\mu$ CC	21626
$\nu_e$ CC	86206
$\nu_\tau$ CC	393
$\bar{\nu}_\tau$ CC	4828
All NC	2939

# Event Rates for $\bar{\nu}_\mu$ Golden Channel



- Store  $\mu^-$ .
- $\bar{\nu}_e$  and  $\nu_\mu$  in beam.
- Look for  $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$  oscillations

## • Assumed

- EW beam flux in GENIE.
- $10^{21}$   $\mu^+$  over 5 years
- 50 kTon detector at 2000 km
- GENIE output used in NUTS
- $\delta_{CP} = 45^\circ$ ,  $\theta_{13} = 8.8^\circ$

## Total Counts

$\bar{\nu}_\mu$ CC	624
$\nu_\mu$ CC	50059
$\bar{\nu}_e$ CC	38818
$\nu_\tau$ CC	118
$\bar{\nu}_\tau$ CC	9154
All NC	6722

# Observations from Total Rates

- $\bar{\nu}_\mu$  CC signal produces the smallest relative event rate
- Smallest ratio between signal and background at highest momentum bin
- To establish good signal at all momenta need to set target background suppression using worst case.
  - $\bar{\nu}_\mu$  oscillation with  $\nu_\mu$  background
  - $S/B \sim 30/15000 = 0.002$
  - Assume target significance  $> 5\sigma$
  - If signal efficiency is 60%, charge background suppression of  $1/15000 = 6.6 \times 10^{-3}$  required.
- Requirements for detection of oscillation to  $\nu_\mu$  less stringent.
  - Assume target significance  $> 5\sigma$
  - If signal efficiency is 60%, charge background suppression of  $198/8000 = 0.02$  required

# Selecting Events by Interaction Type

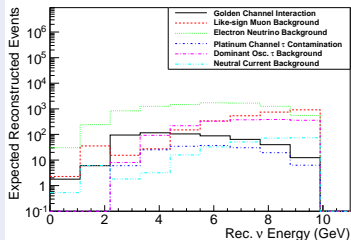
- Events are already separated into CC and NC interactions.
- QES, DIS, etc. processes will result in different event topologies.
- Will affect reconstruction optimization.
- Assumption is that QES will be more important for 10 GeV factory.

## A general observation

- Only QES, DIS, resonant pion production, and coherent pion production contributes to total event rates.
- inverse muon decay below threshold.
- neutrino-electron elastic scattering too rare.

# Quasi Elastic Scatter Event Rates

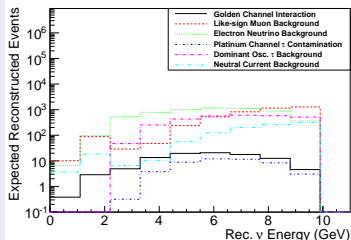
## Stored $\mu^+$



- Presents a possible background

- $\nu_\mu + n \rightarrow \mu^- + p$
- Must be able to suppress proton background at the level of the ratio between the QES rate and the total rate.

## Stored $\mu^-$

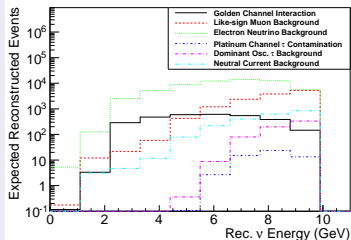


## Total Counts

$\nu_\mu$ CC	528	$\bar{\nu}_\mu$ CC	97
$\bar{\nu}_\mu$ CC	2756	$\nu_\mu$ CC	4184
$\nu_e$ CC	9041	$\bar{\nu}_e$ CC	5933
$\nu_\tau$ CC	158	$\bar{\nu}_\tau$ CC	47
$\bar{\nu}_\tau$ CC	1766	$\nu_\tau$ CC	3009
All NC	258	All NC	995

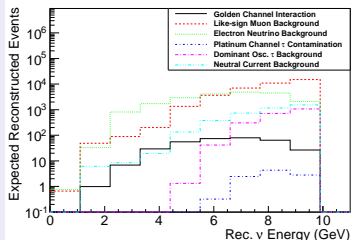
# Deep Inelastic Scatter Event Rates

## Stored $\mu^+$



- Majority of signal events are DIS.
- Hadron showers still need to be reconstructed (for energy reconstruction).
- Are other backgrounds possible from these events?

## Stored $\mu^-$



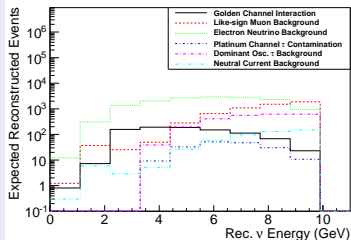
## Total Counts

$\nu_\mu$ CC	3052	$\bar{\nu}_\mu$ CC	336
$\bar{\nu}_\mu$ CC	13124	$\nu_\mu$ CC	38328
$\nu_e$ CC	61300	$\bar{\nu}_e$ CC	21079
$\nu_\tau$ CC	55	$\bar{\nu}_\tau$ CC	10
$\bar{\nu}_\tau$ CC	618	$\nu_\tau$ CC	2133
All NC	2182	All NC	3989



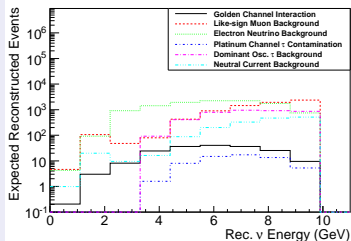
# Resonant Pion Production Event Rates

## Stored $\mu^+$



- Presents possible backgrounds in the production of  $\pi^+$  and  $\pi^-$  in addition to protons.

## Stored $\mu^-$

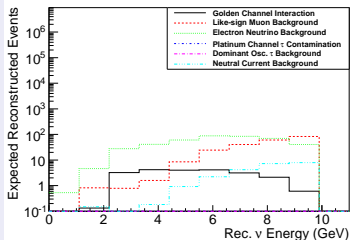


## Total Counts

$\nu_\mu$ CC	899	$\bar{\nu}_\mu$ CC	184
$\bar{\nu}_\mu$ CC	5526	$\nu_\mu$ CC	7344
$\nu_e$ CC	25446	$\bar{\nu}_e$ CC	11360
$\nu_\tau$ CC	181	$\bar{\nu}_\tau$ CC	60
$\bar{\nu}_\tau$ CC	2443	$\nu_\tau$ CC	4012
All NC	476	All NC	1646

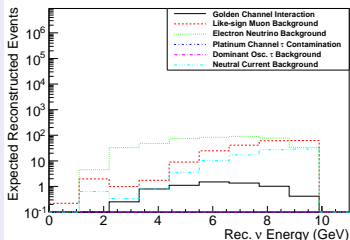
# Coherent Pion Production Event Rates

## Stored $\mu^+$



- Smallest contribution of presented interactions
- Again produces a possible pion background

## Stored $\mu^-$



## Total Counts

$\nu_\mu$ CC	21	$\bar{\nu}_\mu$ CC	7
$\bar{\nu}_\mu$ CC	219	$\nu_\mu$ CC	203
$\nu_e$ CC	445	$\bar{\nu}_e$ CC	445
$\nu_\tau$ CC	0	$\bar{\nu}_\tau$ CC	0
$\bar{\nu}_\tau$ CC	0	$\nu_\tau$ CC	0
All NC	22	All NC	88

## Limits on Charge ID Rates for Given Signal Significance

- Want to set a goal on signal significance for a given efficiency.
- Question: what charge mis-id rate is allowed.
- Consider the significance from

$$R = \frac{S}{\sqrt{S+B}}$$

- $S = \epsilon p$  is the measured signal for an efficiency  $\epsilon$  and true signal  $p$ .
- $B = \kappa q$  is the measured background for a rejection rate  $\kappa$  and a true background sample  $q$ .
- The rejection rate is

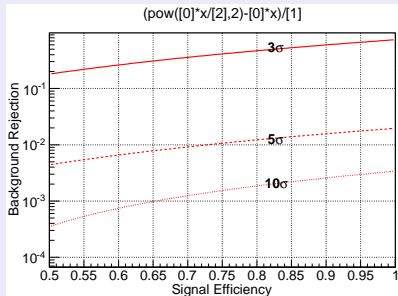
$$\kappa = \frac{1}{q} \left( \left( \frac{\epsilon p}{R} \right)^2 - \epsilon p \right)$$

# Significance Contours from Worst Case

- Scale bin with largest  $B/S$  ratio to full spectrum range

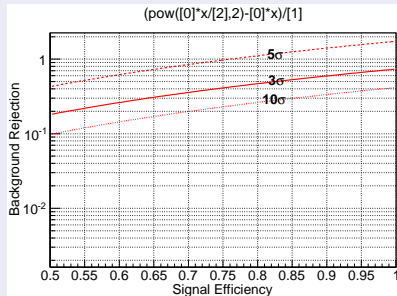
## Stored $\mu^-$

- worst case is
  - 30 signal counts over 9 bins ( $p = 270$ )
  - 15000 background counts over 9 bins ( $q = 135000$ ).



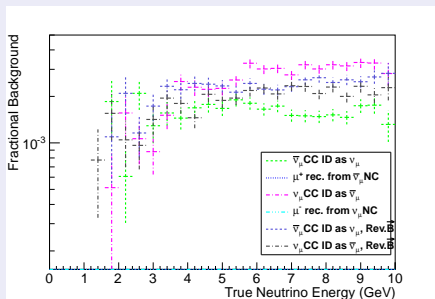
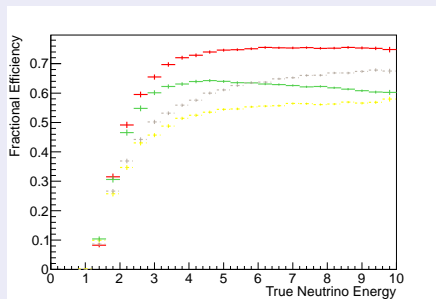
## Stored $\mu^+$

- Less stringent requirement.
  - 198 signal counts over 9 bins ( $p = 1782$ )
  - 8000 background over 9 bins ( $q = 72000$ )



# Where we are right now?

All species in 10 GeV MIND using cuts based analysis.



- Ignoring input energy range, background is at required level.
- Will have to do more careful study to determine sensitivity to  $\delta_{CP}$ .