

Neutrinos and the "Big Ideas of the SM"

- generation of mass via Yukawa couplings with Higgs field – how does this work for neutrinos? Why are neutrino masses so small? (e,u,d) have masses ~ 1 MeV scale while ν_e is at least 5-6 orders of magnitude smaller.
- Does the neutrino interact with Higgs field at all? Or is mass generated by some other way?
- Are neutrinos related at all to dark matter or dark energy?
- Neutrinos and BAU?
- Neutrinos and GUTs scale physics?
- Is the SM Lagrangian the whole story?

The “seesaw” mechanism

(there are many variations!)

LH Light neutrinos may have heavy RH partners that may mix via couplings that link LH and RH

The mass of the light neutrino goes roughly as:

$$m_\nu \sim m^2/M$$

Where m is the mass associated with our low energy EW scale (~ 246 GeV) and M is the mass of the heavy RH partner.

Oscillation measurements imply $M \sim 10^{15}$ GeV

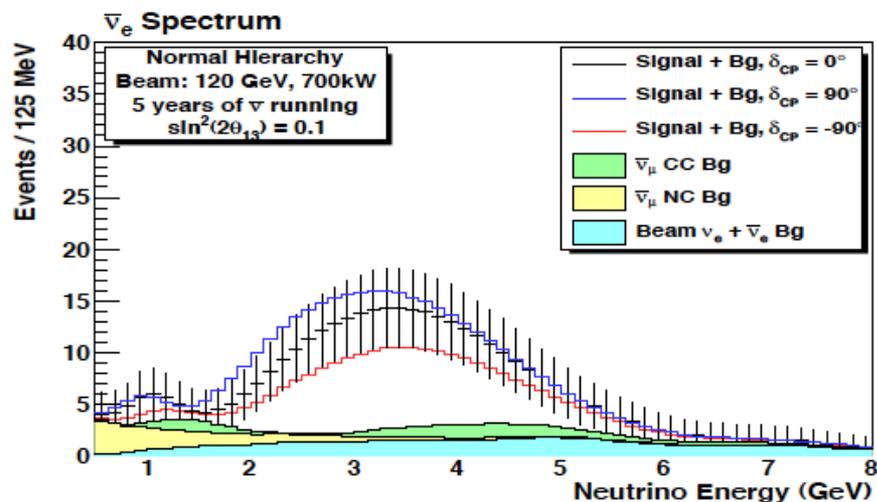
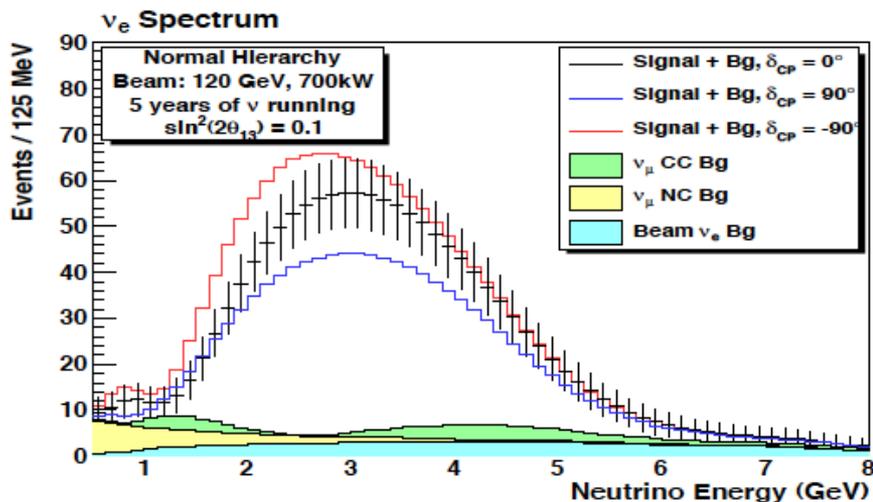
δ_{CP} and Leptogenesis

- If there *does* exist a RH heavy partner for the LH neutrinos, *and* if such a partner violates CP in its decay, it could influence the baryon/anti-baryon symmetry of the universe via (B+L) violating decays of RH neutrinos.
- CP violation in the light neutrinos **does not prove** that neutrinos have a heavy CP-violating partner, but it is strong circumstantial evidence
- You need a GUT "see saw" like scale, CP violation, and non-equilibrium decay conditions (e.g. oscillation among RH neutrinos could do this) for the heavy RH partners.
- **Simply measuring δ_{CP} does not guarantee great science**
- **We need to think about a broad, long-term program that gets at the heart of 21st century science**
- **Do not assume we know the physics of 2030!**

L=1300km, LBNE LE

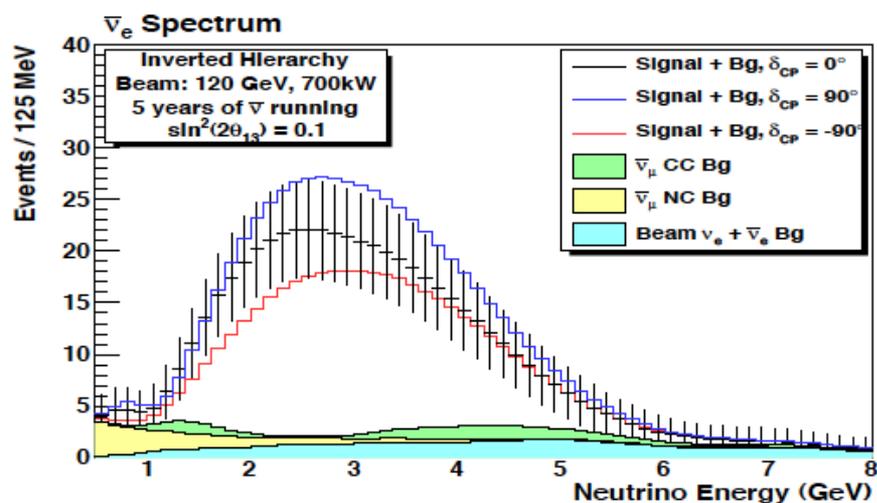
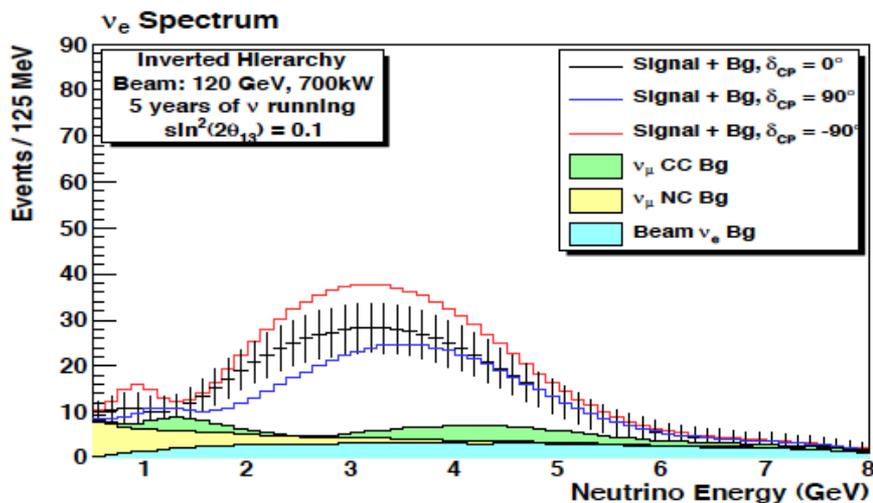
ν normal hierarchy

$\bar{\nu}$ normal hierarchy



ν inverted hierarchy

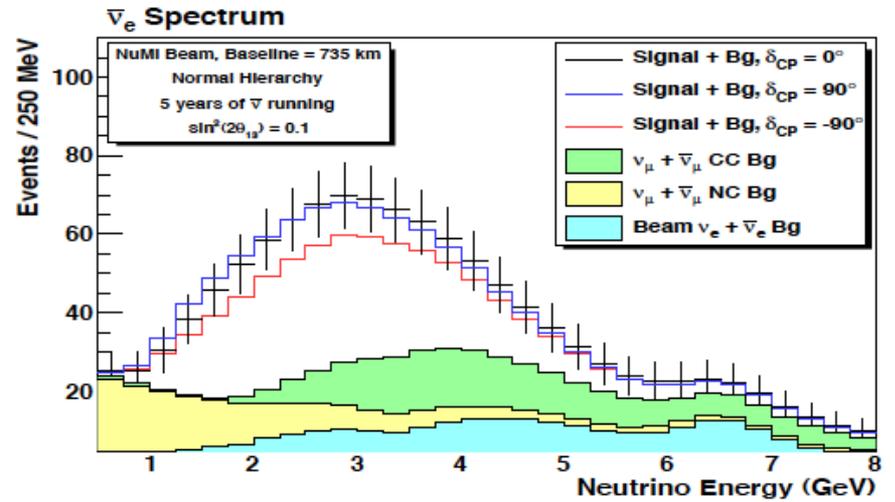
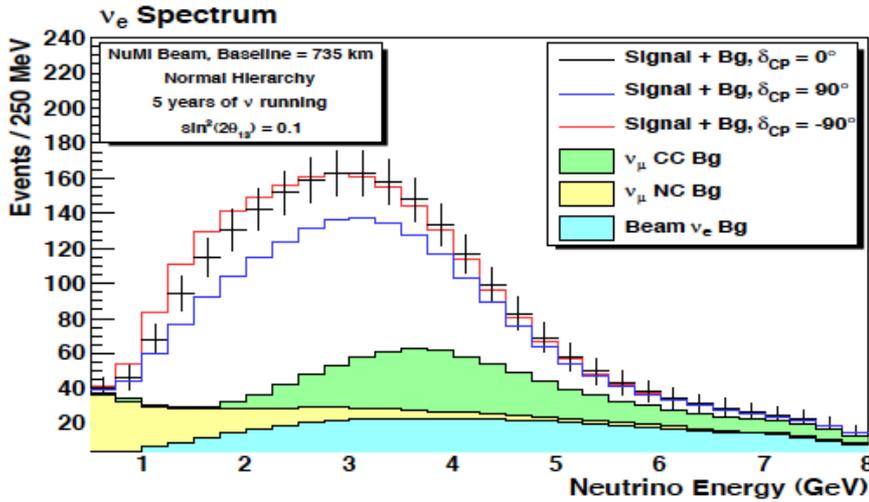
$\bar{\nu}$ inverted hierarchy



L=735km, NuMI LE

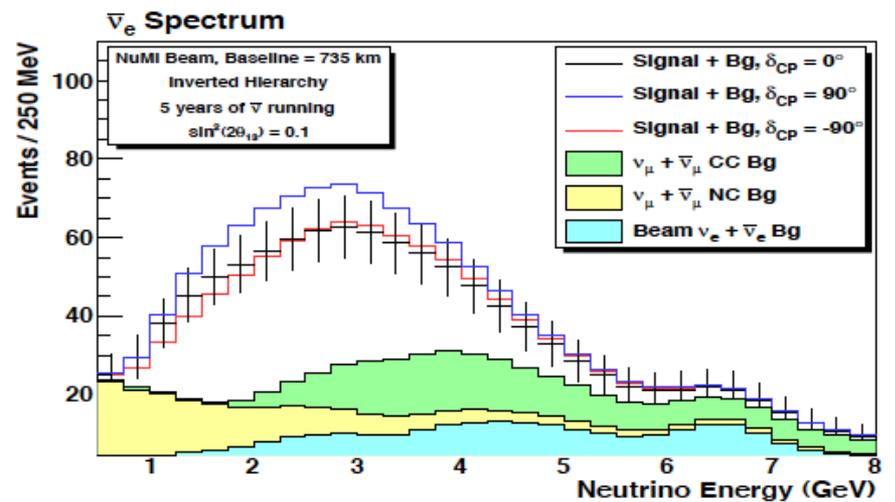
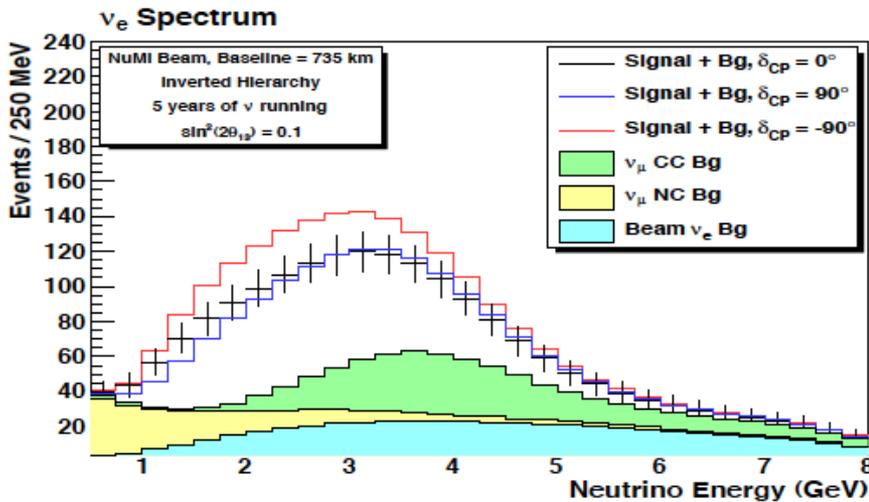
ν normal hierarchy

$\bar{\nu}$ normal hierarchy



ν inverted hierarchy

$\bar{\nu}$ inverted hierarchy



A "Discovery-Oriented" Approach

- Broad band beam with at least two oscillations to not only measure MH and CPV, but also to have a tool to see how well the whole story "sticks together". i.e. a "LEP" for neutrino physics. Detailed measurement of oscillations with the highest power beam available. **Be open to beam upgrades to 2.3 MW to explore anomalies.**
- Be open to potential opportunities to look for proton decay if SUSY is found at LHC, or if SK sees even one "golden" event.
- A galactic SN is an opportunity to make neutrino measurements with a baseline of light years and an event rate as large as the beam measurements.