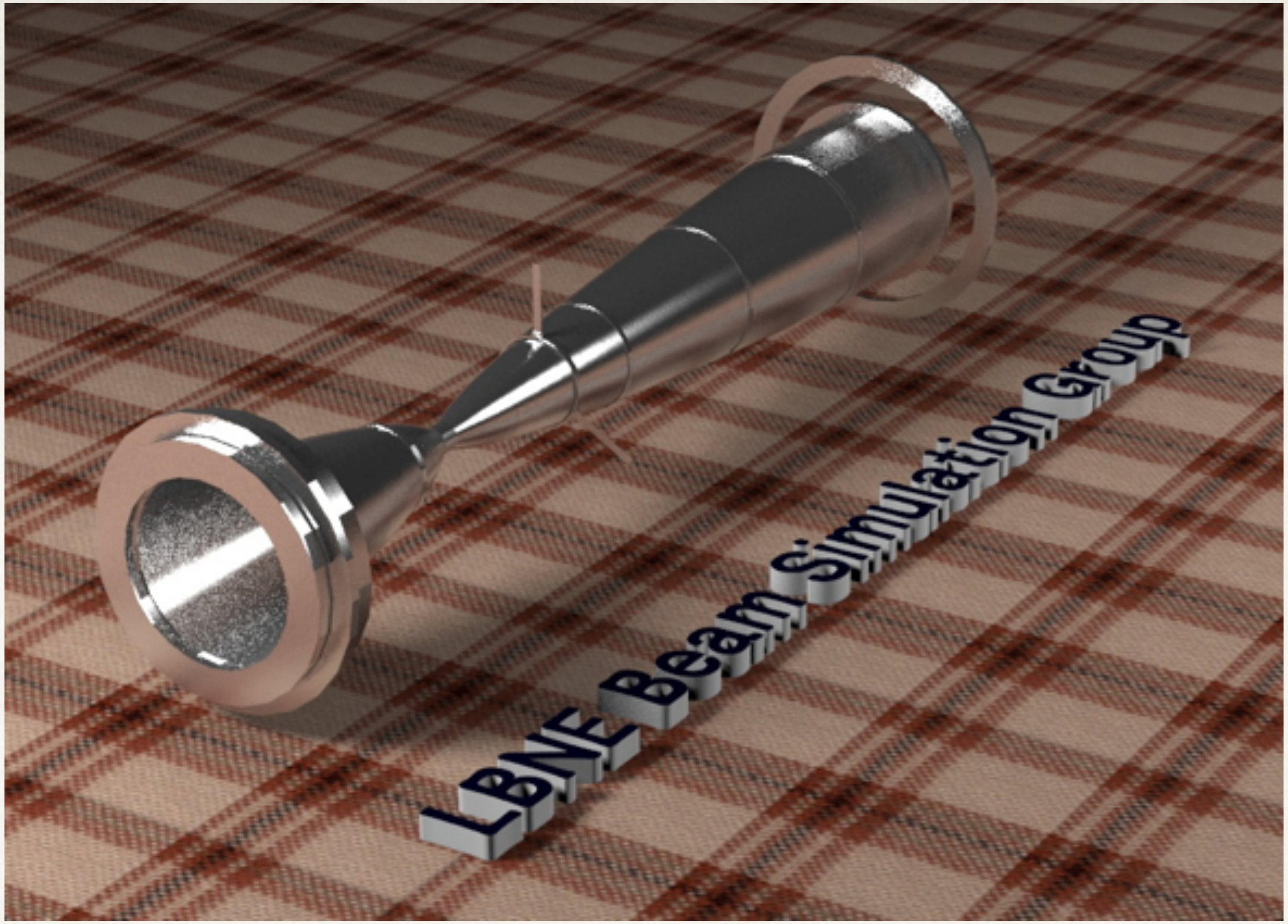


LBNE Neutrino Yields vs Proton Energy

PIP II Collaboration Meeting

Laura Fields & Dan Cherdack
Northwestern / Colorado State

29 May 2014

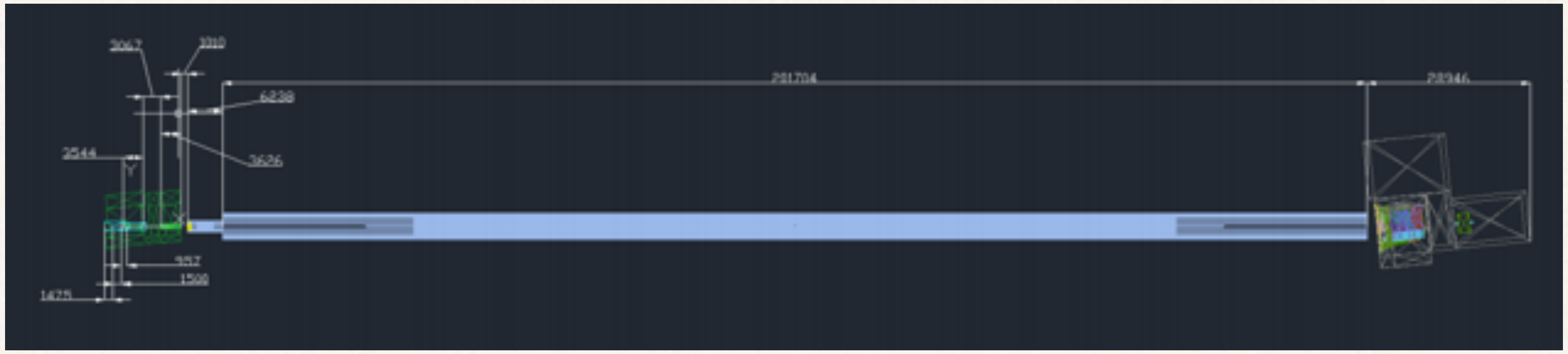
Introduction

- This talk is an attempt to quantify to physics impact of lowering the LBNE primary beam energy while preserving beam power
- We used two basic tools to study this:
  - G4LBNE (the official LBNE beam simulation for physics studies)
  - The LBNE Fast Monte Carlo
- **I am not making any statement about what energy the LBNE collaboration prefers; my goal is just to provide information about the impact of proton energy to the PIP II collaboration**

G4LBNE

- G4LBNE is a GEANT4-based simulation of the LBNE beam line (based on G4NuMI):

Visualization of the G4LBNE Geometry:



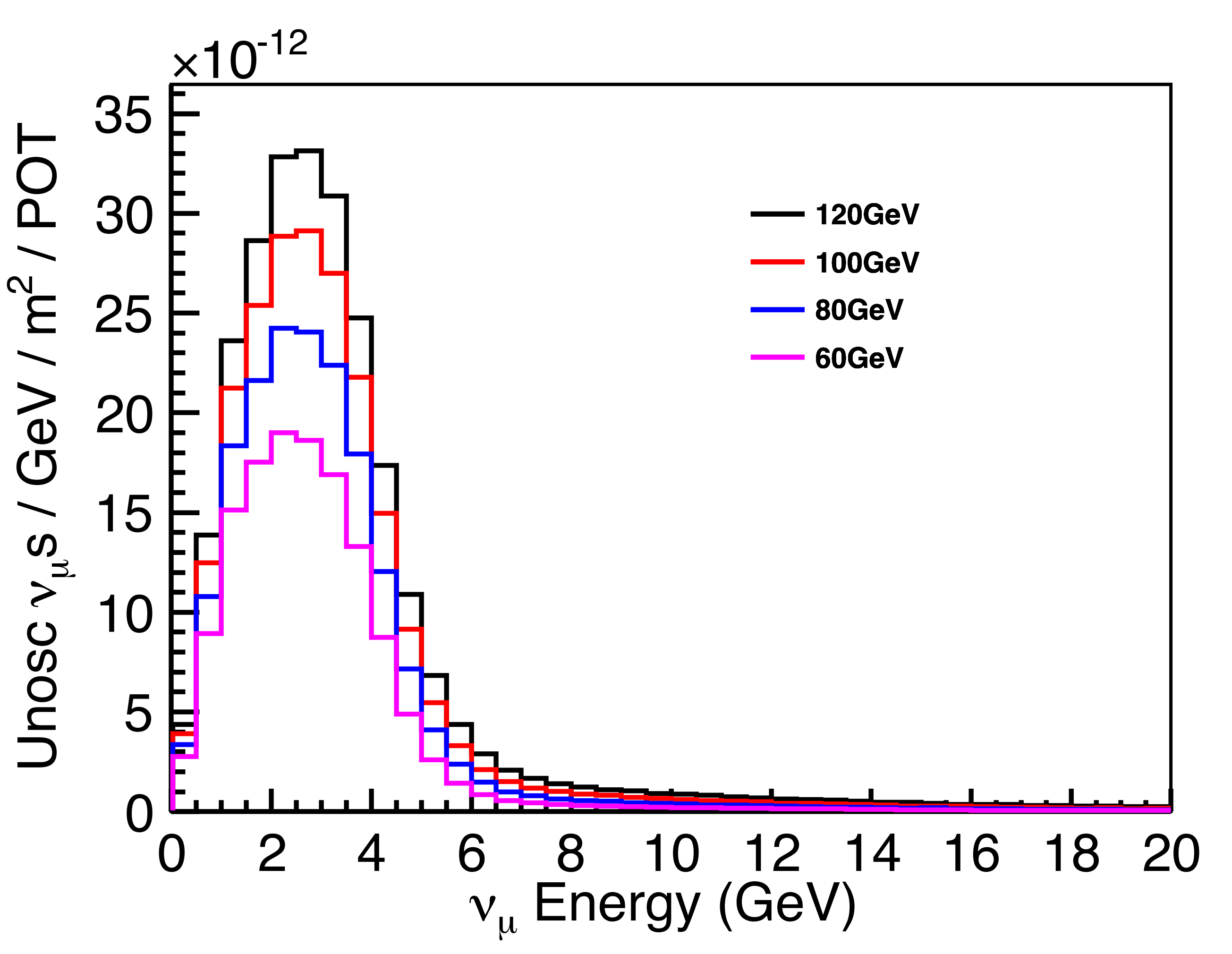
Seongtae Park

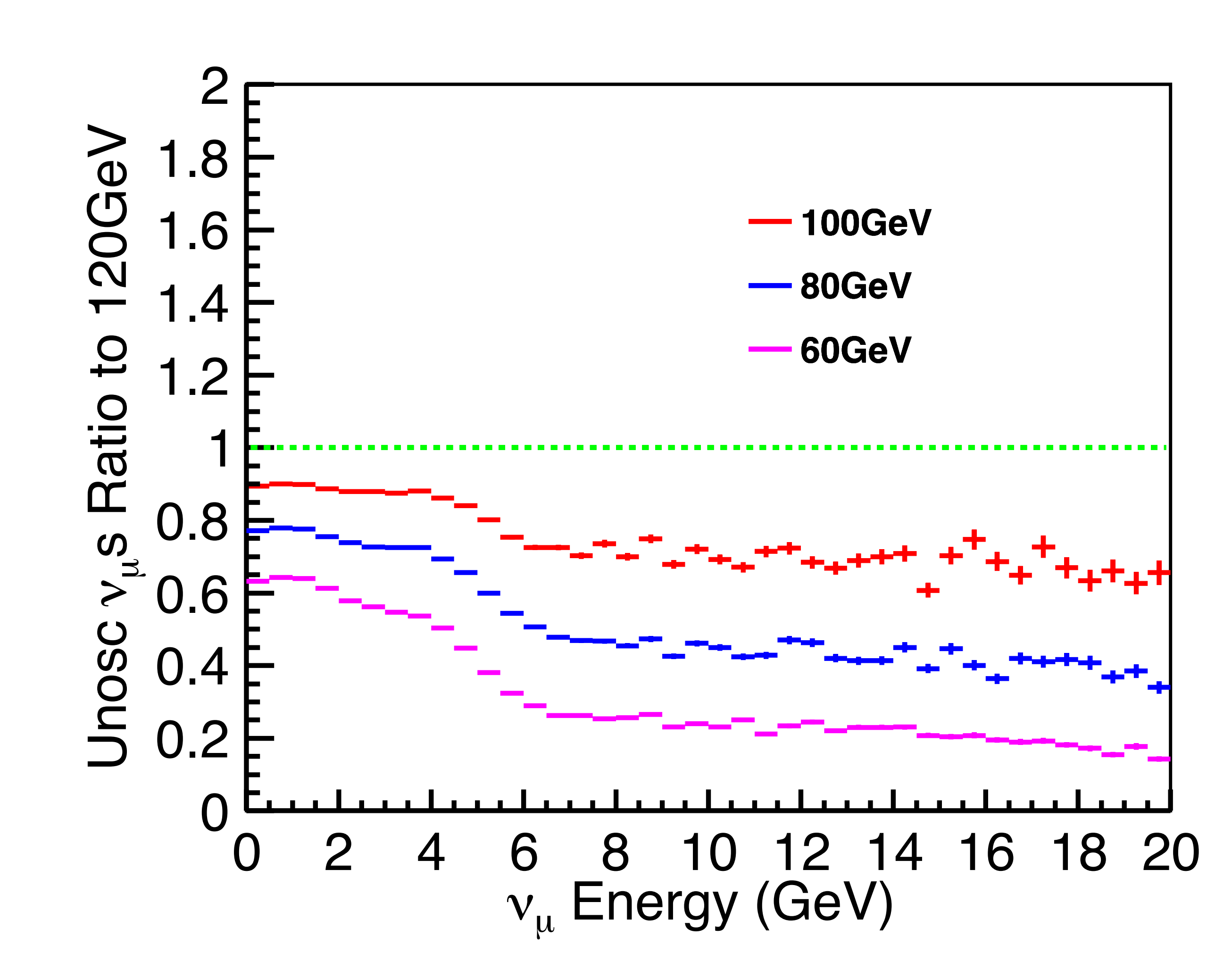
Target/Horns/Shielding Decay Pipe Hadron Absorber

- G4LBNE stays up to date with the LBNE beam design
  - Current Nominal: 120 GeV protons, NuMI horns, 1.2 MW Target, 4 m diameter/ 200 m long decay pipe w/ Helium
  - Very flexible: can be easily modified to study alternate beam designs

G4LBNE Flux per POT

- Flux per POT for several proton energies:

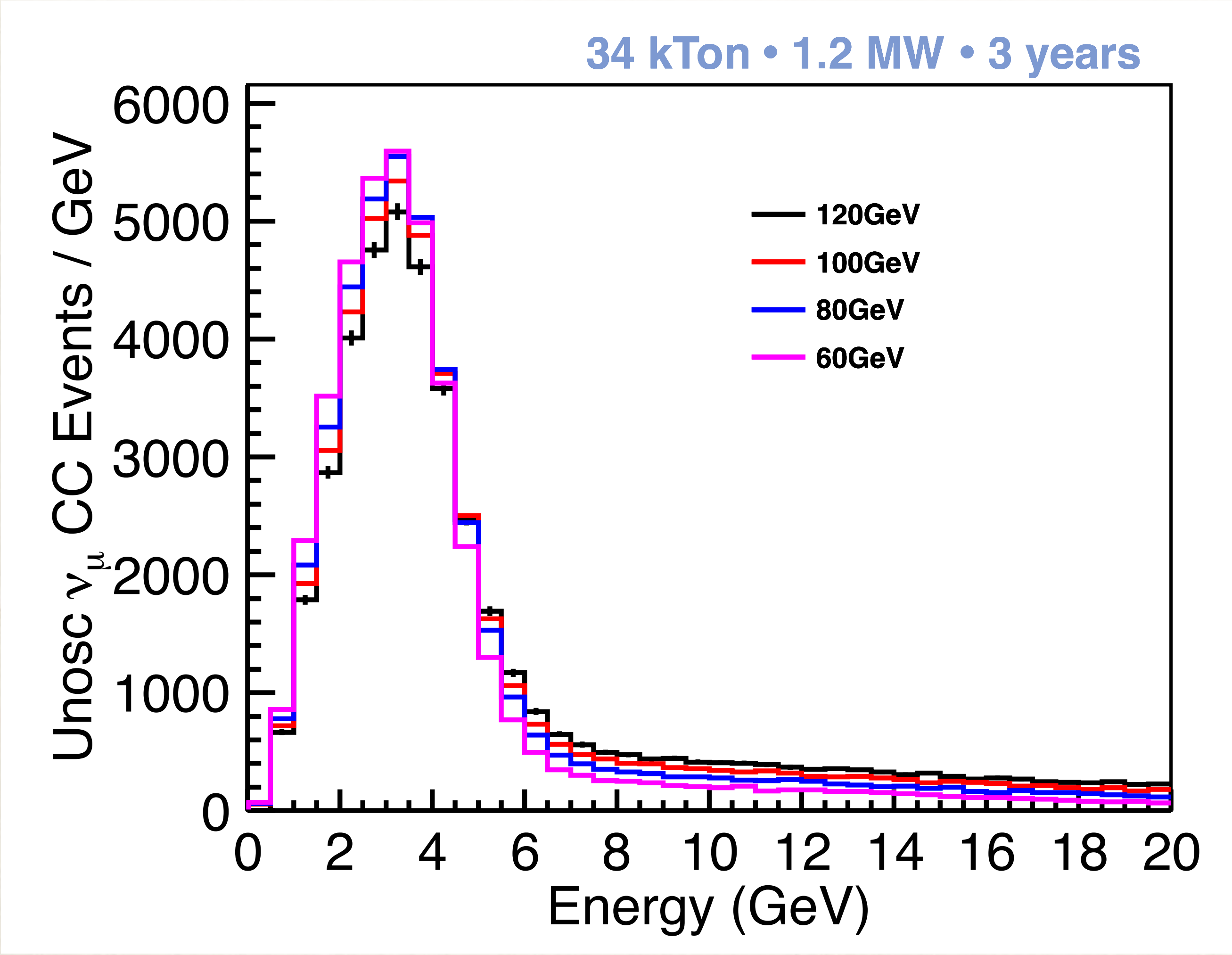


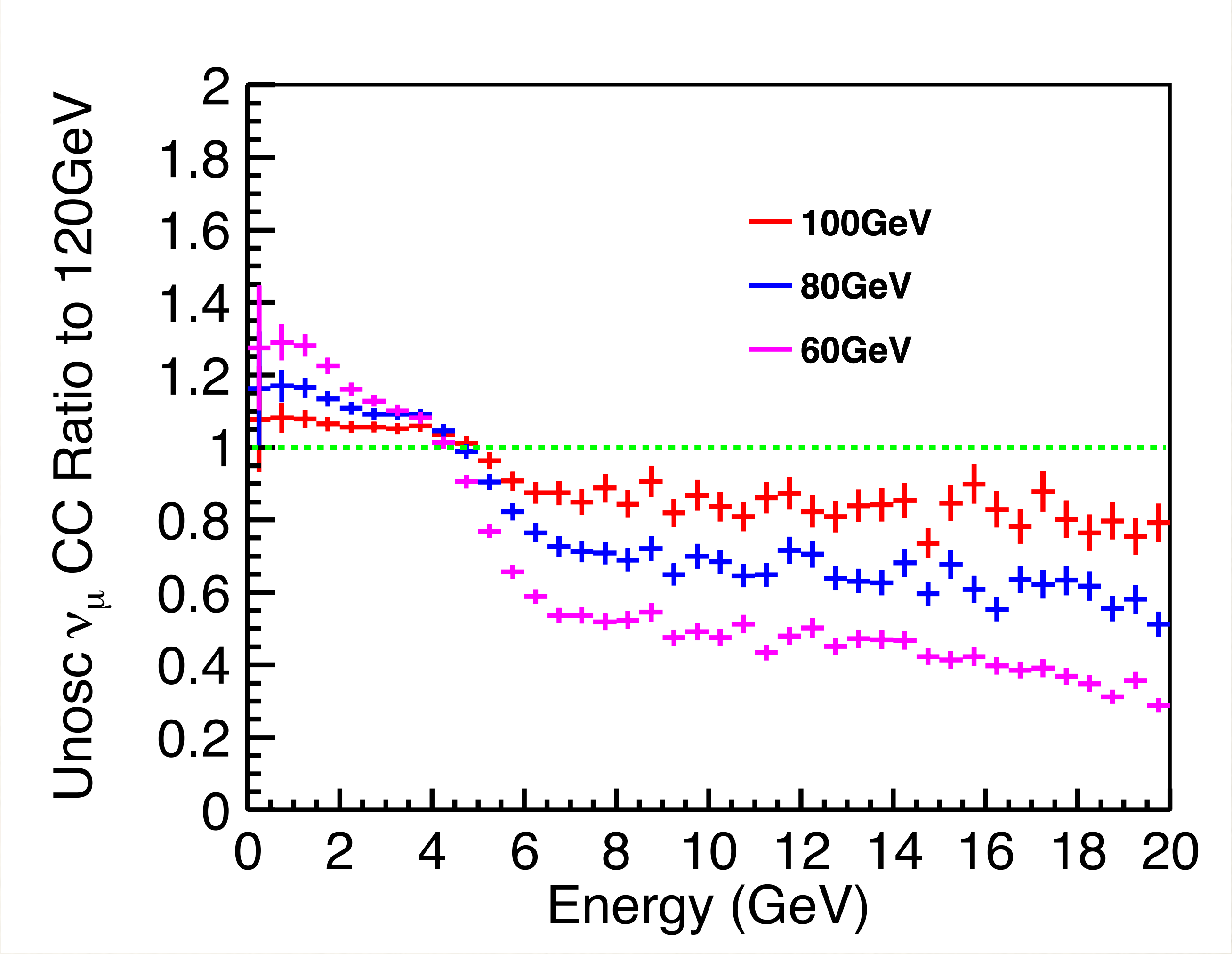


Less neutrinos per POT at lower energies
But expect more POT / time at lower energies — see event rate comparison on next slides

G4LBNE + GENIE Event Rates

- Unoscillated charged current event rates at different proton energies (**assuming constant beam power**):





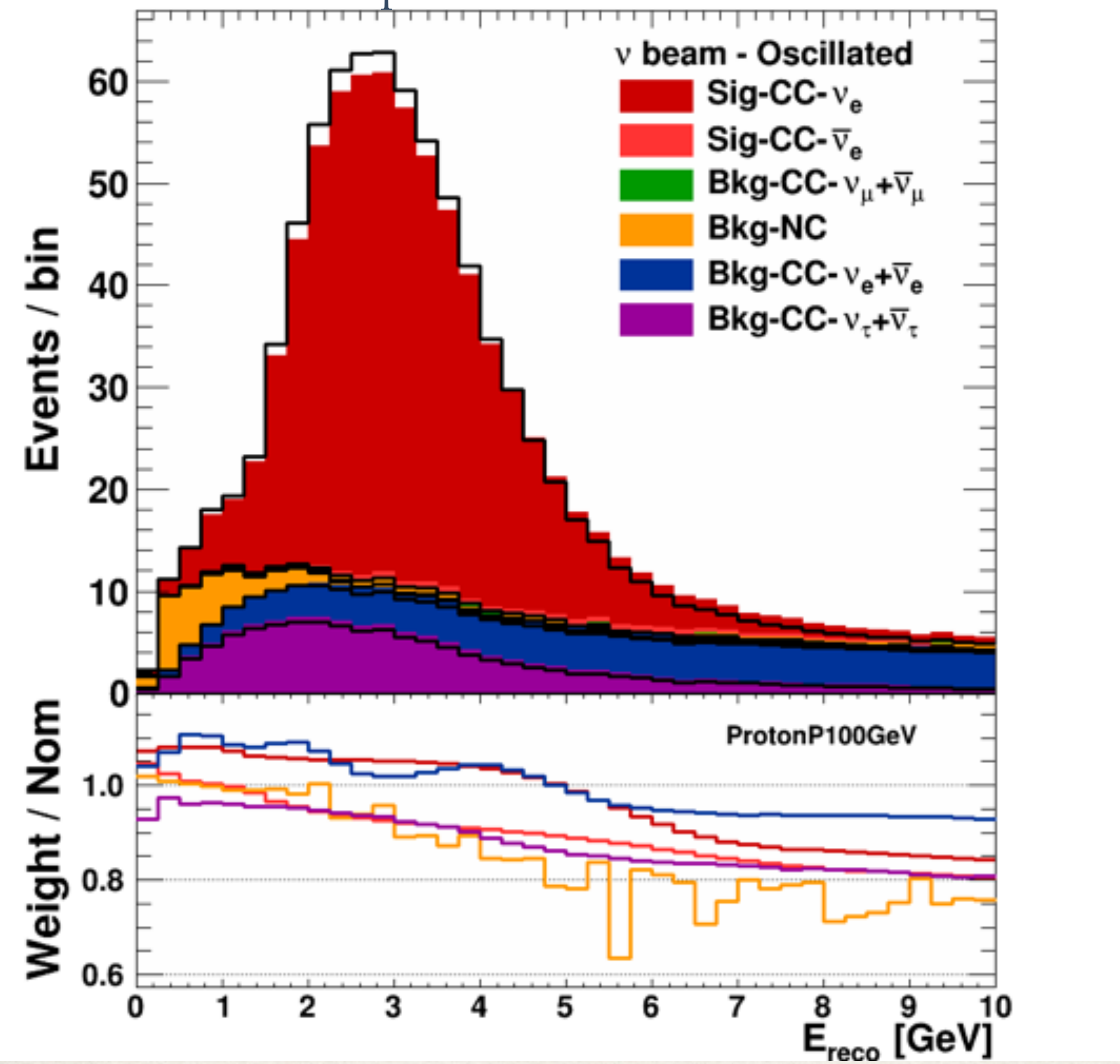
As proton energy goes down, event rates go up in the focusing peak and down in the high energy tail

LBNE Fast Monte Carlo

- Simple flux/event rate comparisons show that lower proton energies are better
  - But how much better is not clear
- For more information, we turn to the "LBNE Fast MC"
  - Starts with full G4LBNE beam simulation + GENIE event generator
  - Applies parameterized smearing, acceptance, background rejection (this is why it's called "Fast")
    - Produces reconstructed neutrino energy distributions for nu_e appearance and nu_mu disappearance measurements
  - For more info, see section A3 of the LBNE Science Document (arXiv 1307.7335)

Event Rates in Fast MC — FHC

Normal Hierarchy, δCP = 0
Other osc params from arXiv:1312.2878

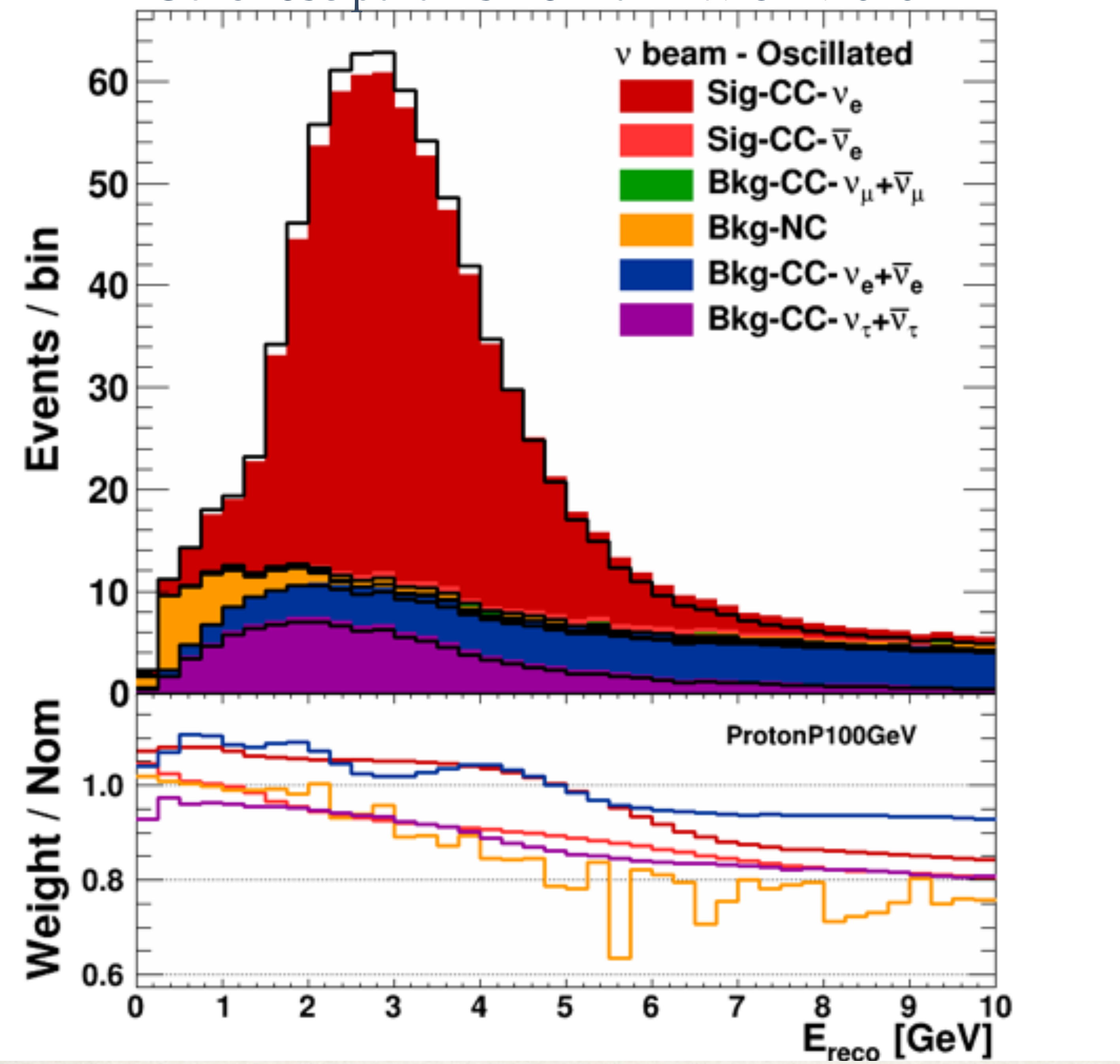


- Colored plots show estimated signal and background for ν_e appearance measurement using the nominal beam configuration (120 GeV)
- Top black line is the spectrum with 100 GeV protons (same power)
- This (and its partner in RHC mode) is the distribution that will be used to measure neutrino CP violation.

Event Rates in Fast MC — FHC

Normal Hierarchy, δCP = 0

Other osc params from arXiv:1312.2878

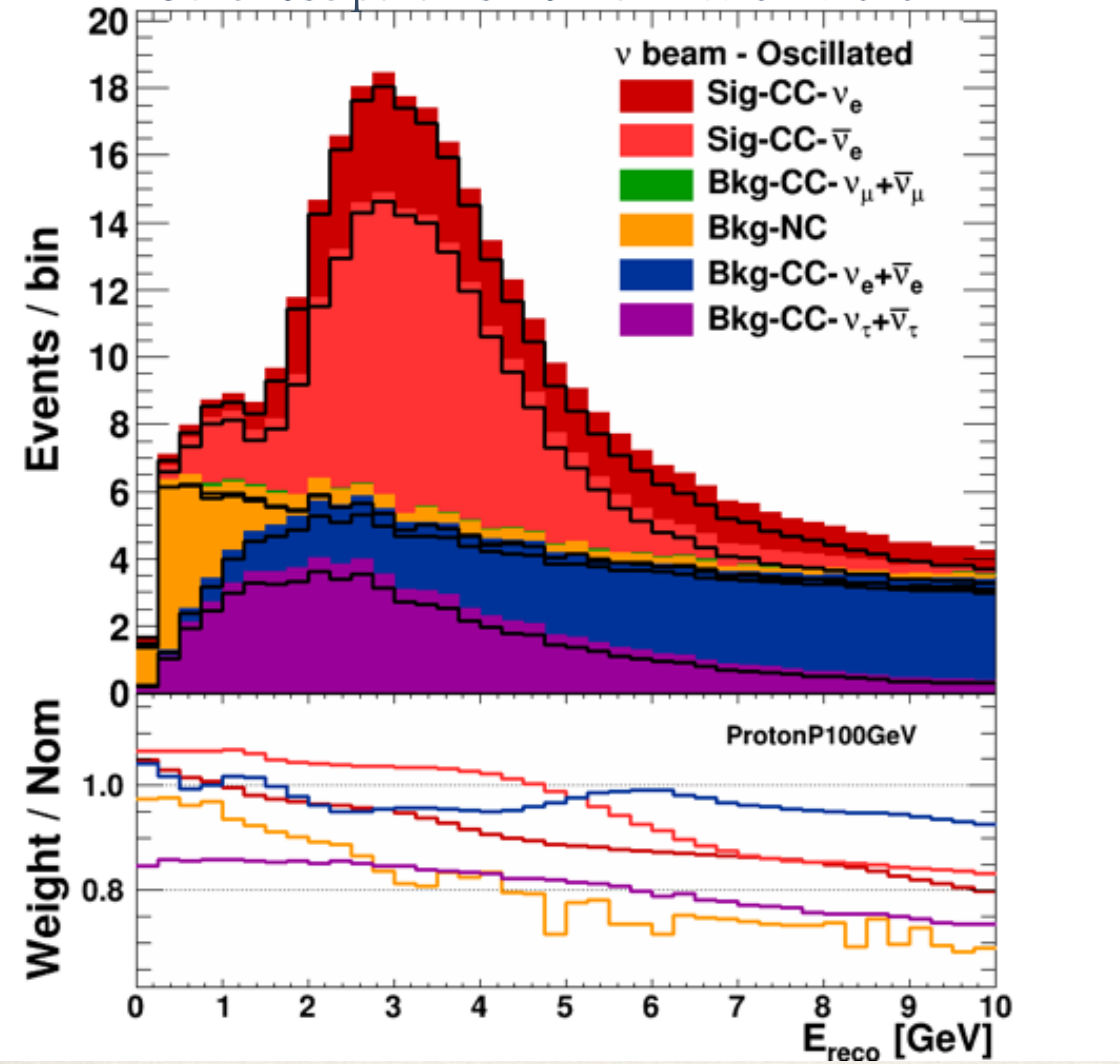


- Bottom panel shows ratio of various signal and background channels at 100 GeV vs nominal 120 GeV
- Summary of channel changes in FHC mode:
  - Signal rates (red) increase by ~7 % in peak at 100 GeV
  - Intrinsic electron neutrino backgrounds also increase
  - Neutral current Background rates are unchanged below 1 GeV, but decrease by ~10% in peak
  - Tau-induced backgrounds are reduced by ~5% at the 2nd maximum and by ~10% in the peak (large uncertainty due to little xsec data, no ND constraint)
  - Small wrong sign backgrounds decrease

Event Rates in Fast MC — RHC

Normal Hierarchy, δCP = 0

Other osc params from arXiv:1312.2878

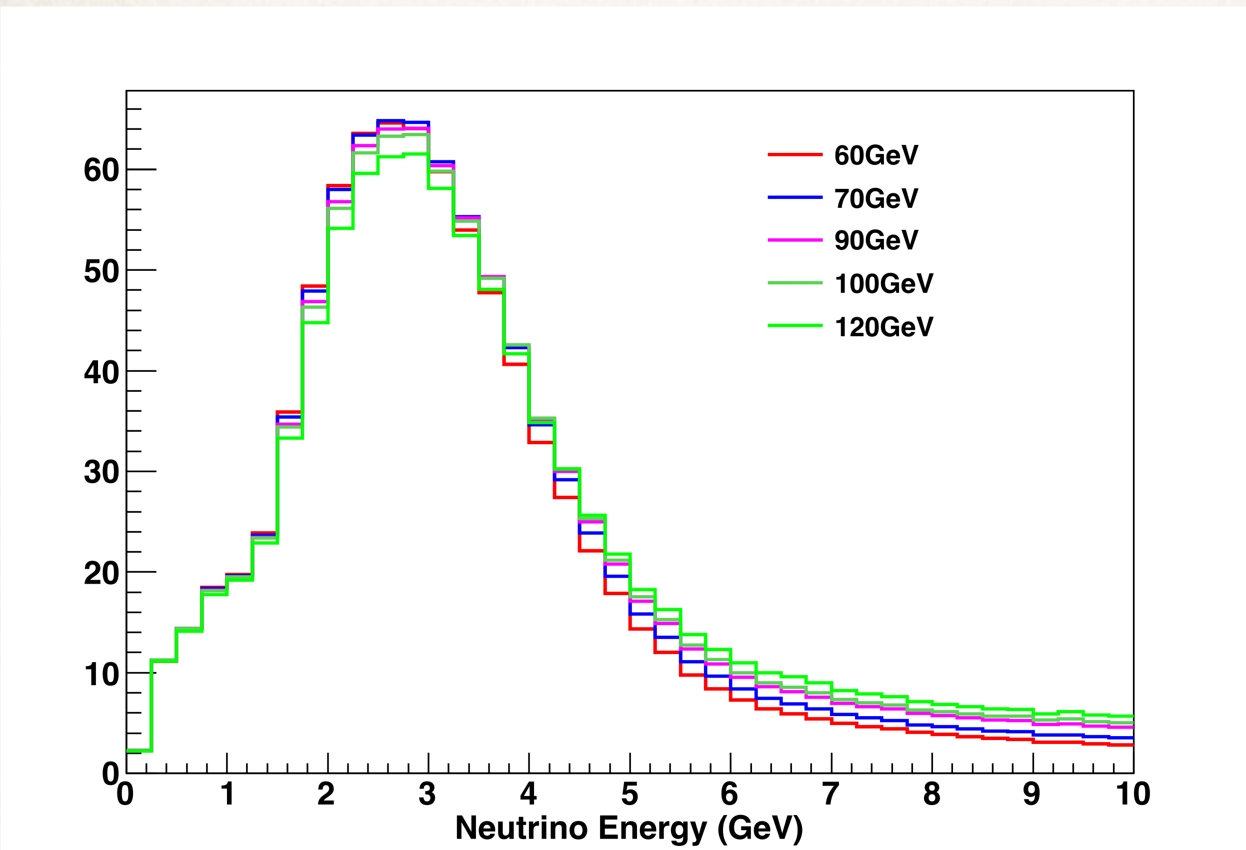


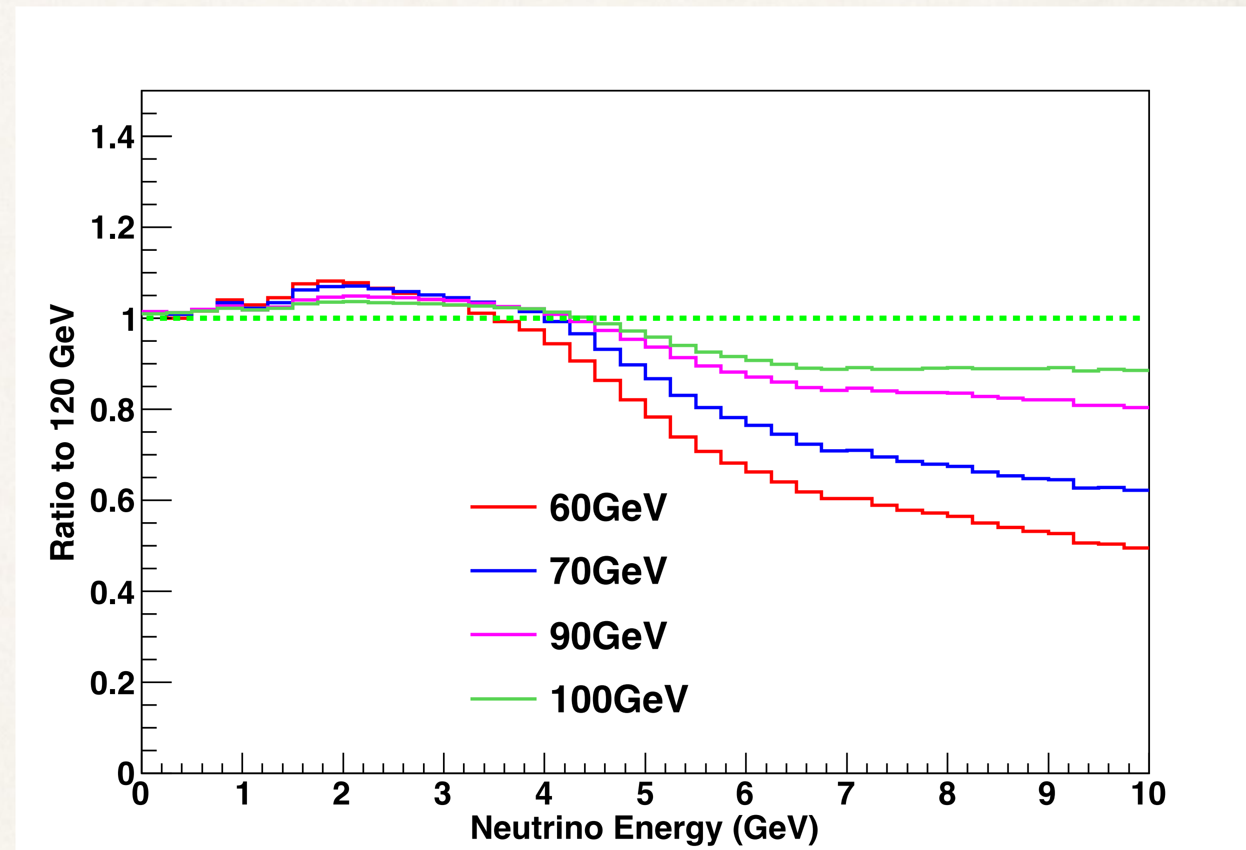
- Summary of channel changes in RHC mode:
  - Signal rates (red) increase by ~7 % in peak at 100 GeV
  - Intrinsic electron neutrino backgrounds decrease slightly
  - Neutral current and tau-induced background rates decrease substantial
    - More so than in FHC mode
  - Wrong sign backgrounds decrease
  - **There are significant uncertainties on the background estimates that are I do not attempt to quantify in this talk**

Event Rates in Fast MC — FHC

Total event rates for different proton energies

(Just the total signal + background from previous slide, plus two additional energies)

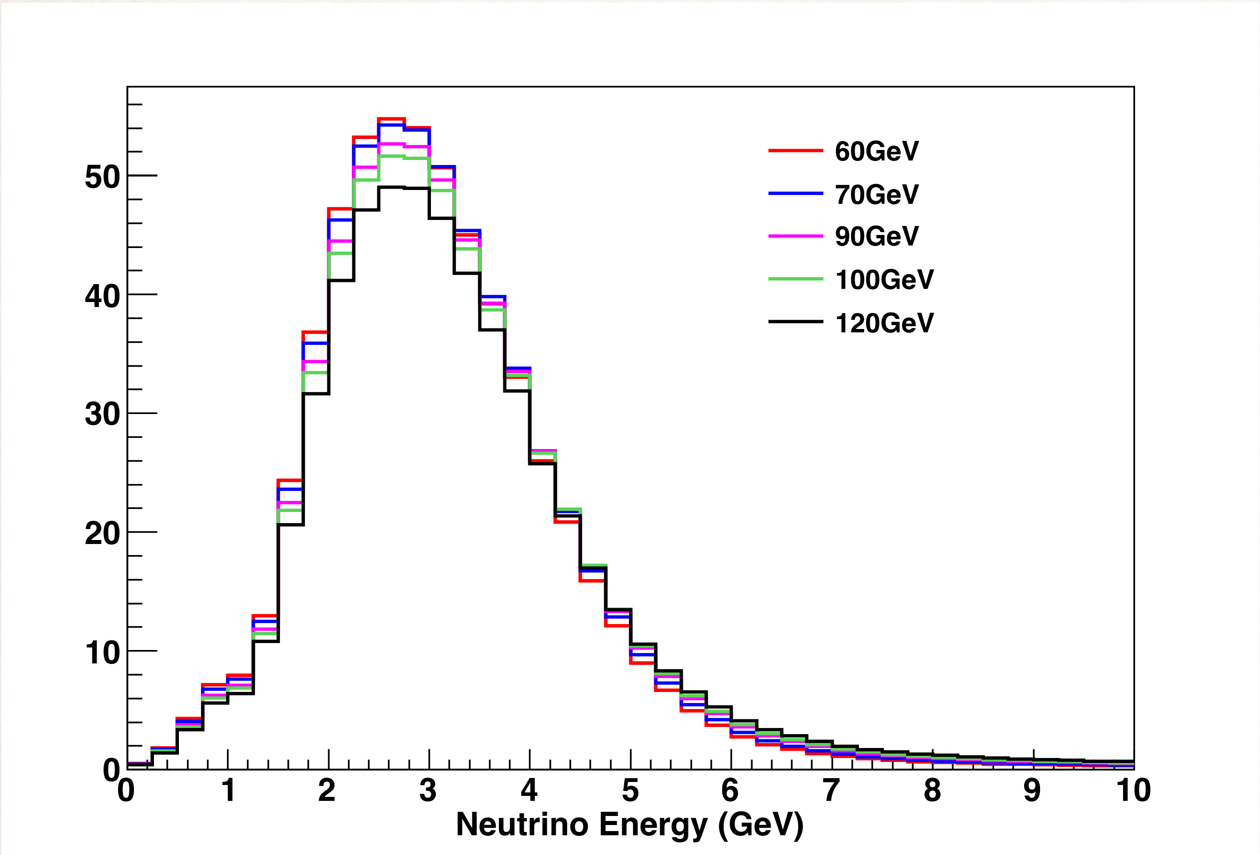


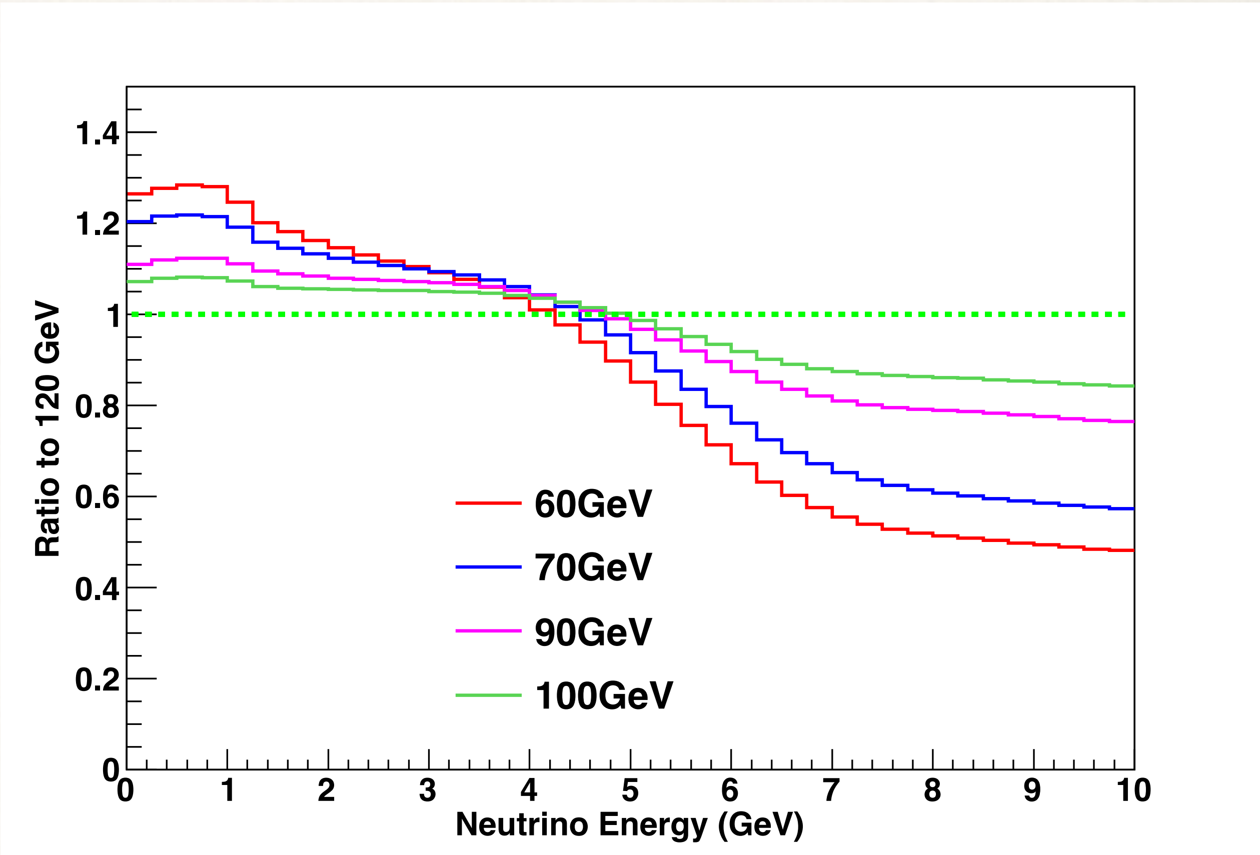


Lower proton energies increase rates below 4 GeV and decrease rates above 4 GeV

Signal Rates in Fast MC — FHC

Signal event rates for different proton energies
(ie the portion of event rate that is oscillated ν_e)



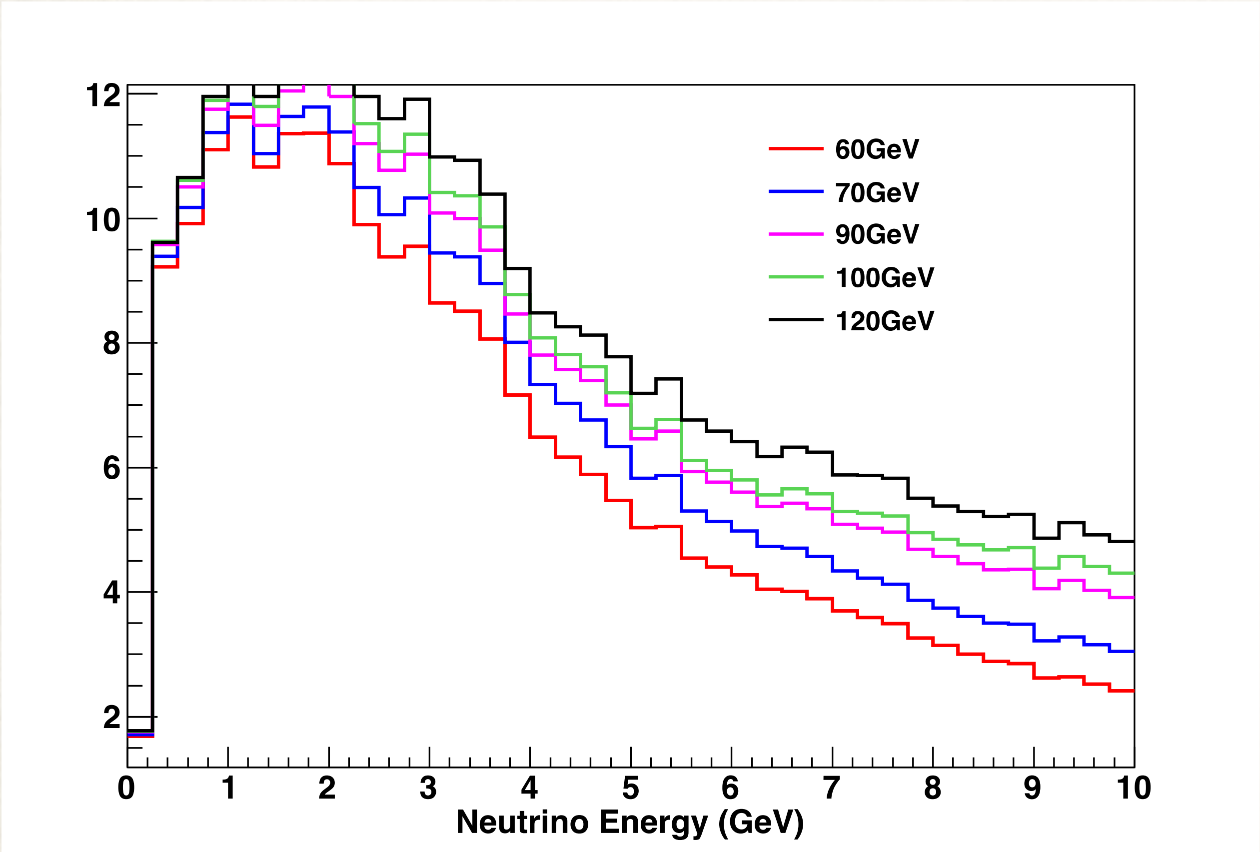


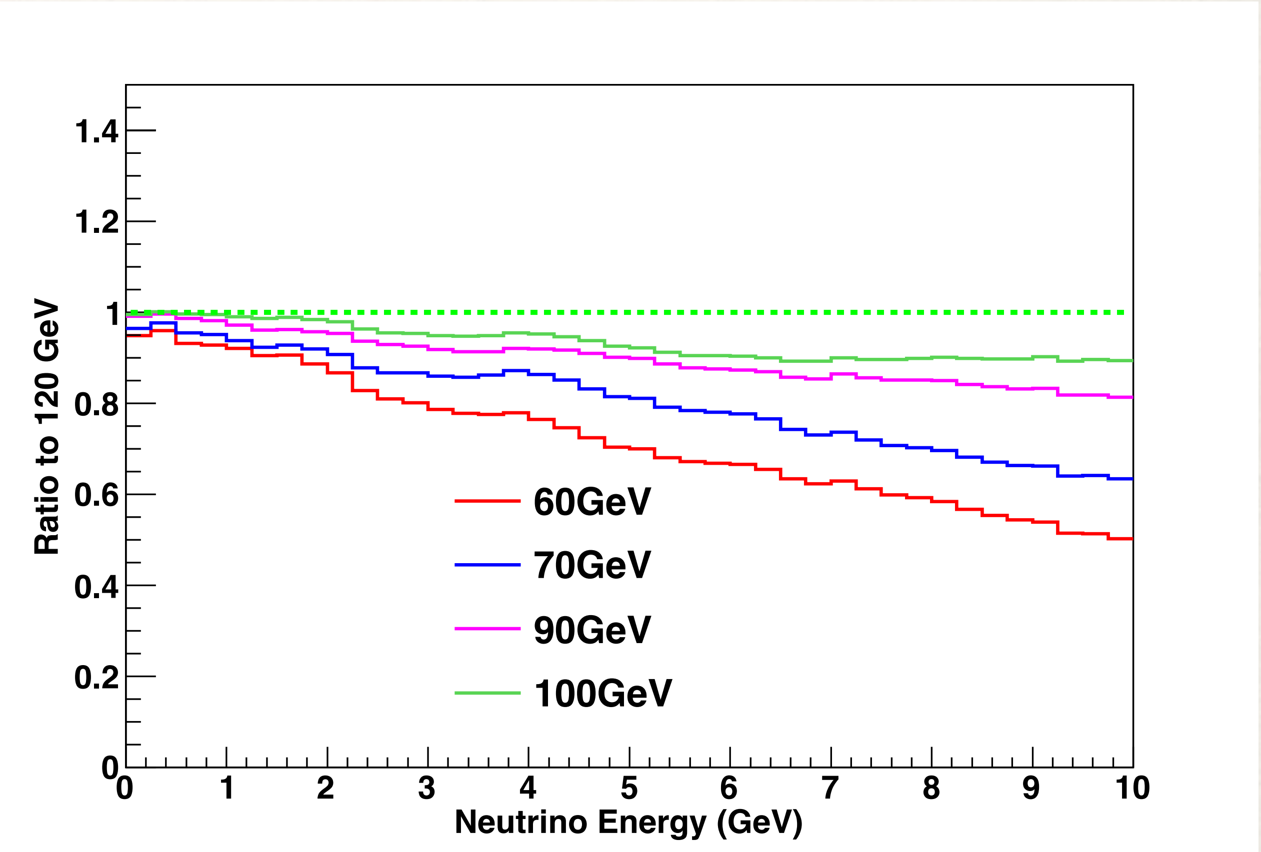
Same trend here as in total event rates: lower proton energies increase rates below 3 GeV and decrease rates above 6 GeV
3-6 GeV is more complicated — 80 GeV optimizes statistics

Background Rates in Fast MC — FHC

Background rates for different proton energies

(ie the portion of event rate that is **not** oscillated ν_e or $\bar{\nu}_e$)

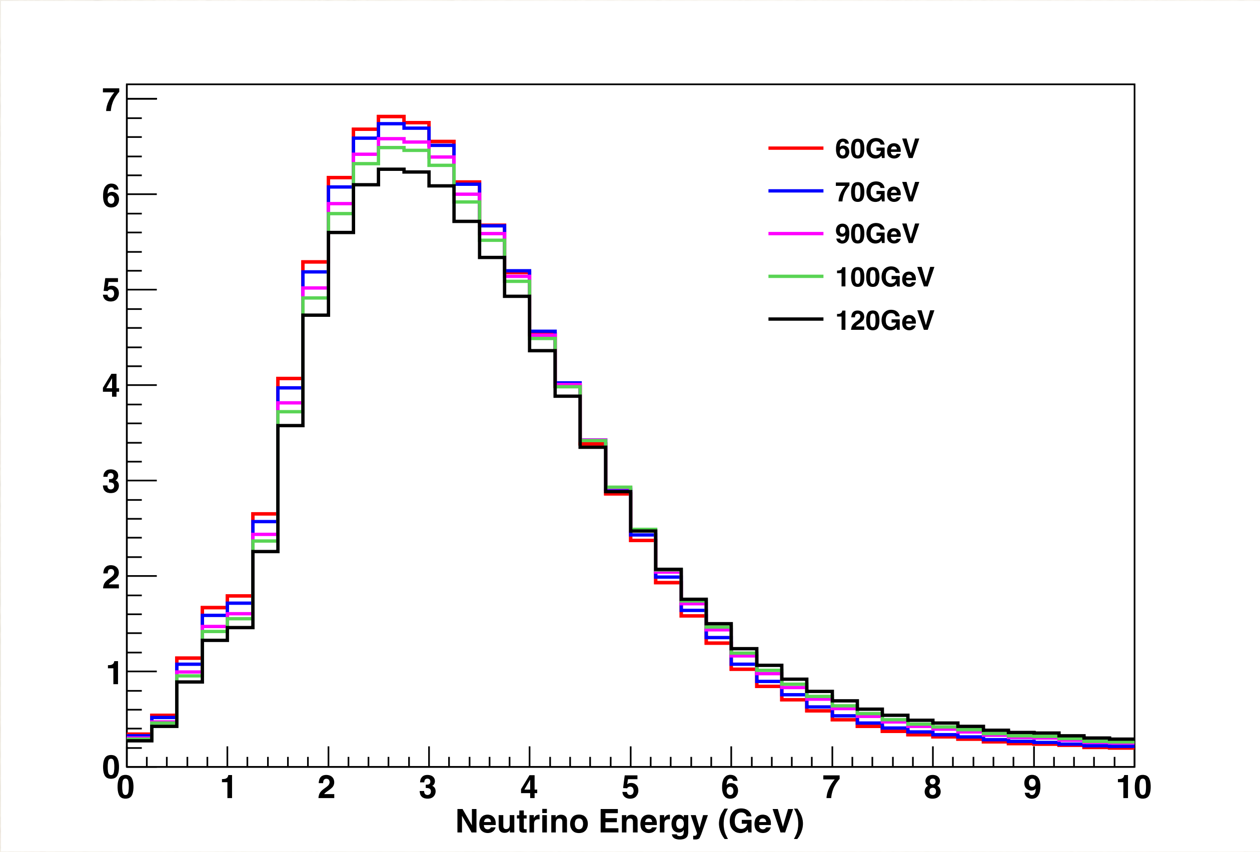




Lower proton energies increase backgrounds near 2 GeV and decrease backgrounds in high energy tail.

Figure of Merit from Fast MC — FHC

A Figure of Merit: Signal/Sqrt(Signal+Background)



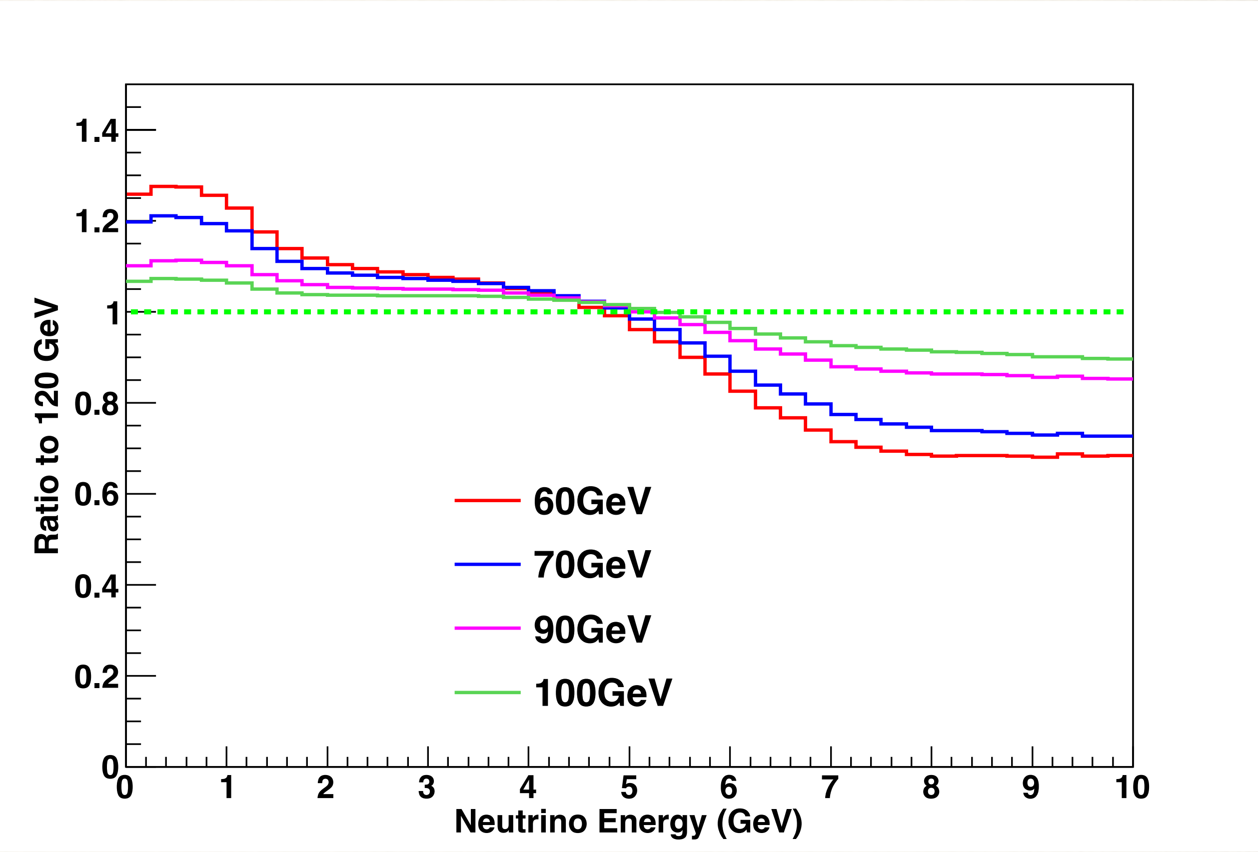


Figure of Merit vs Proton Energy — FHC

Integrated Figure of Merit — FHC
Integral of Signal/Sqrt(Integral of Signal+Integral of Background)
Integrals are over 0-10 GeV in neutrino energy

Neither signal nor background include oscillated $\bar{\nu}_e$

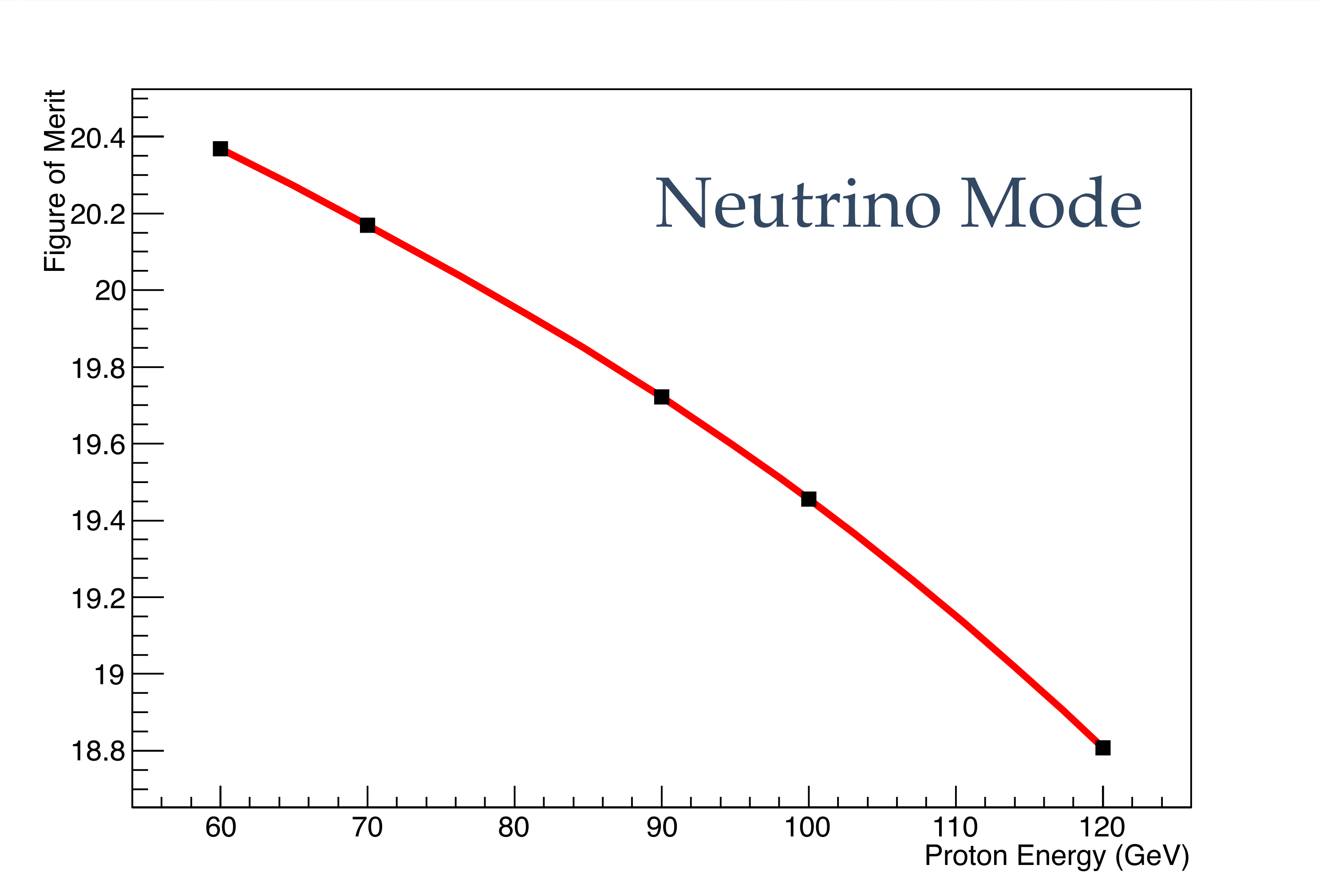
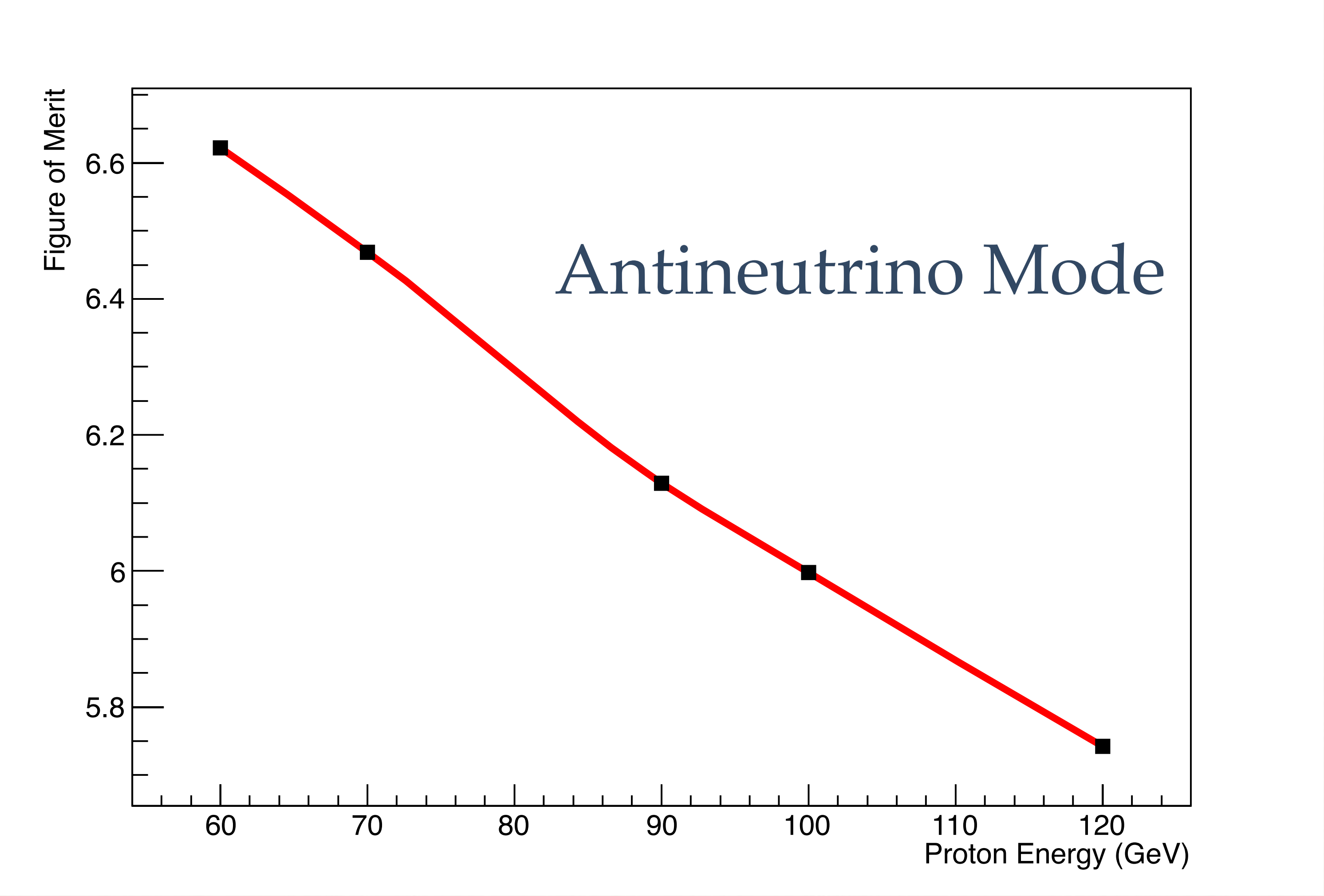


Figure of Merit increases roughly linearly as proton energy decreases
Difference between 60 and 120 GeV = 8.5%

Figure of Merit vs Proton Energy — RHC

Integrated Figure of Merit — RHC
Sqrt(Integral of Signal)/Sqrt(Integral of Signal+Integral of Background)
Integrals are over 0-10 GeV in neutrino energy

Neither signal nor background include oscillated ν_e



See backup for further antinu-mode plots

Figure of Merit increases roughly linearly as proton energy decreases
Difference between 60 and 120 GeV = 16%

Conclusion

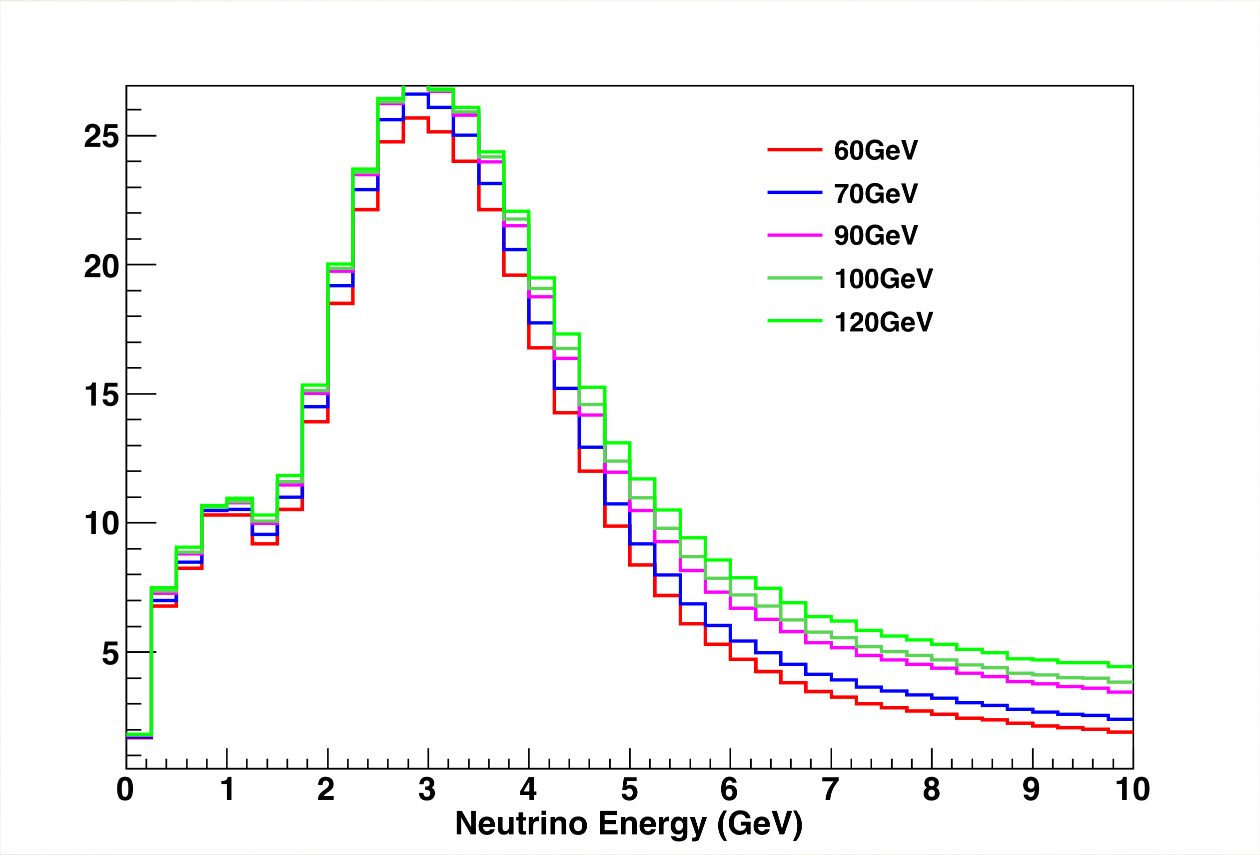
- Lowering the energy of the LBNE primary beam increases neutrino flux in the signal region and decreases the high energy tail
- According to the simple study described here, ν_e appearance signal/background is improved modestly by lowering energy; impact is more significant in antineutrino mode
- Consistent with past studies done at Brookhaven
- This study considers only one set of oscillation parameters; GLOBES sensitivity plots not yet available
  - Will be available this week
- Everything reported here is very preliminary and has significant unaccounted for systematic uncertainties
  - But it use LBNE's best available knowledge and infrastructure for evaluating beam designs

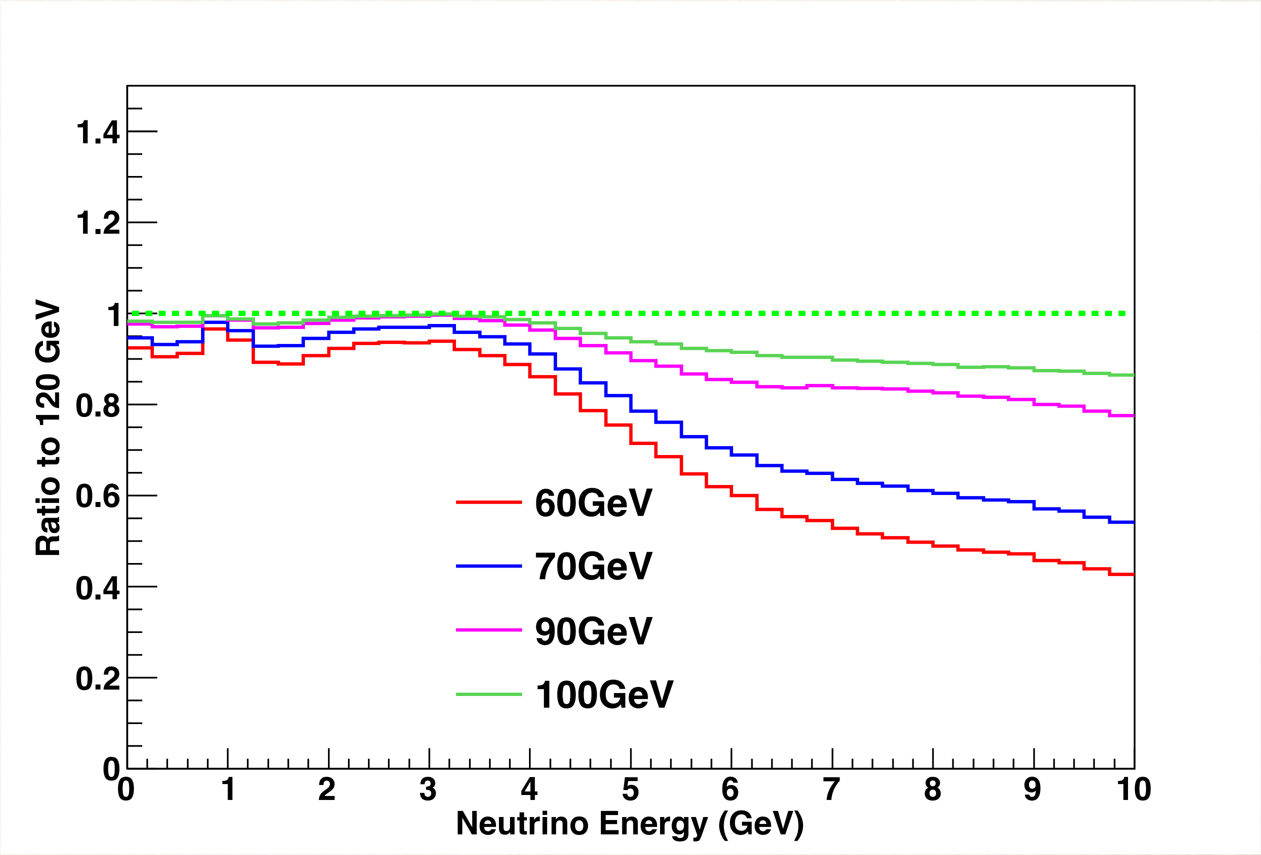
The End

Event Rates in Fast MC — RHC

Total event rates for different proton energies

(Just the total signal + background from previous slide, plus two additional energies)





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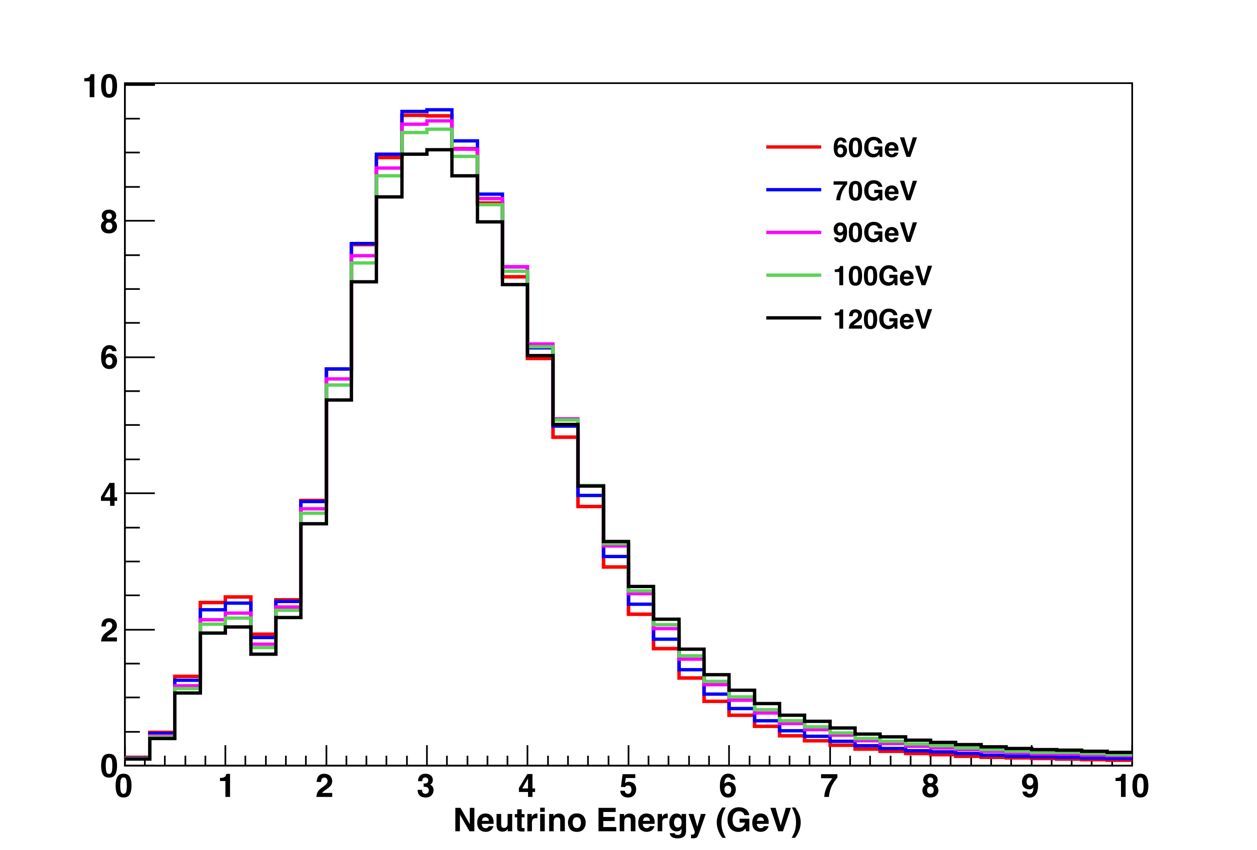

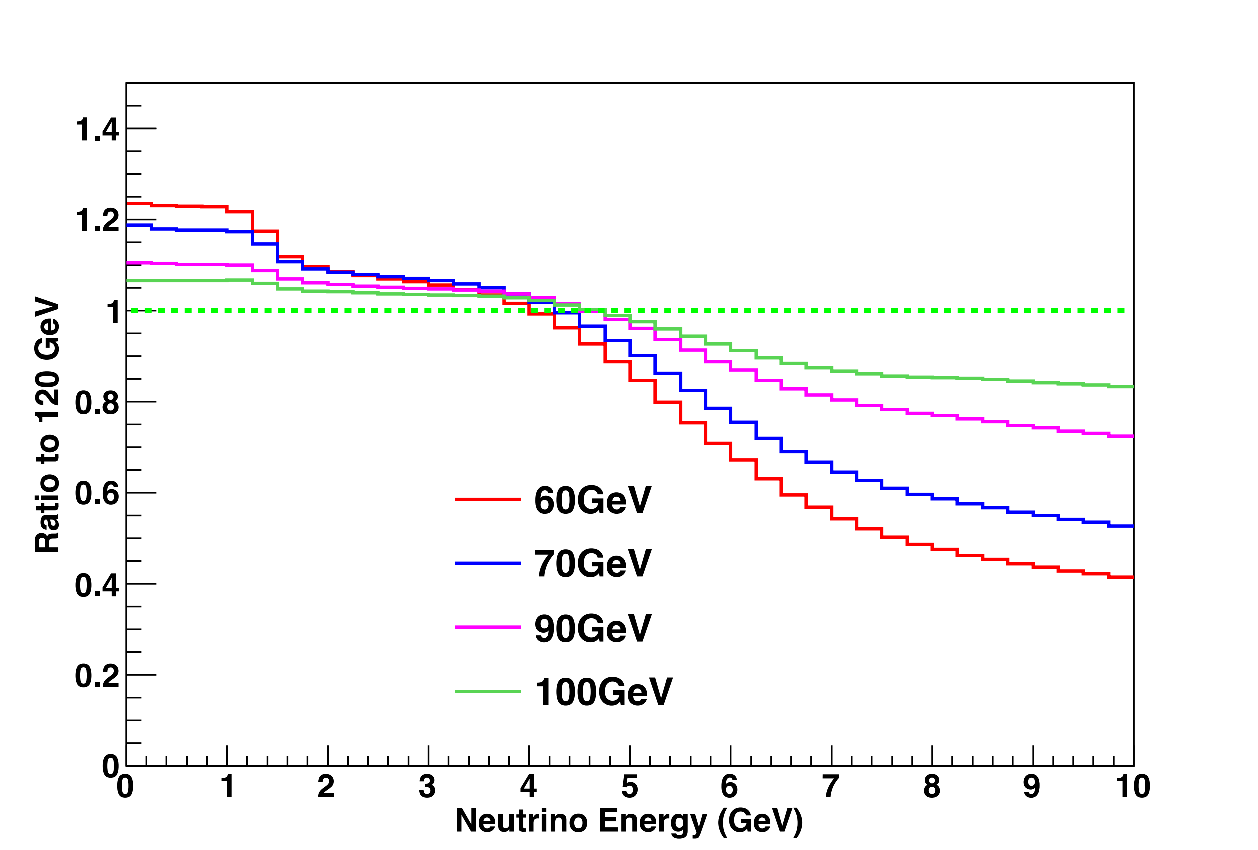

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Background Rates in Fast MC — RHC

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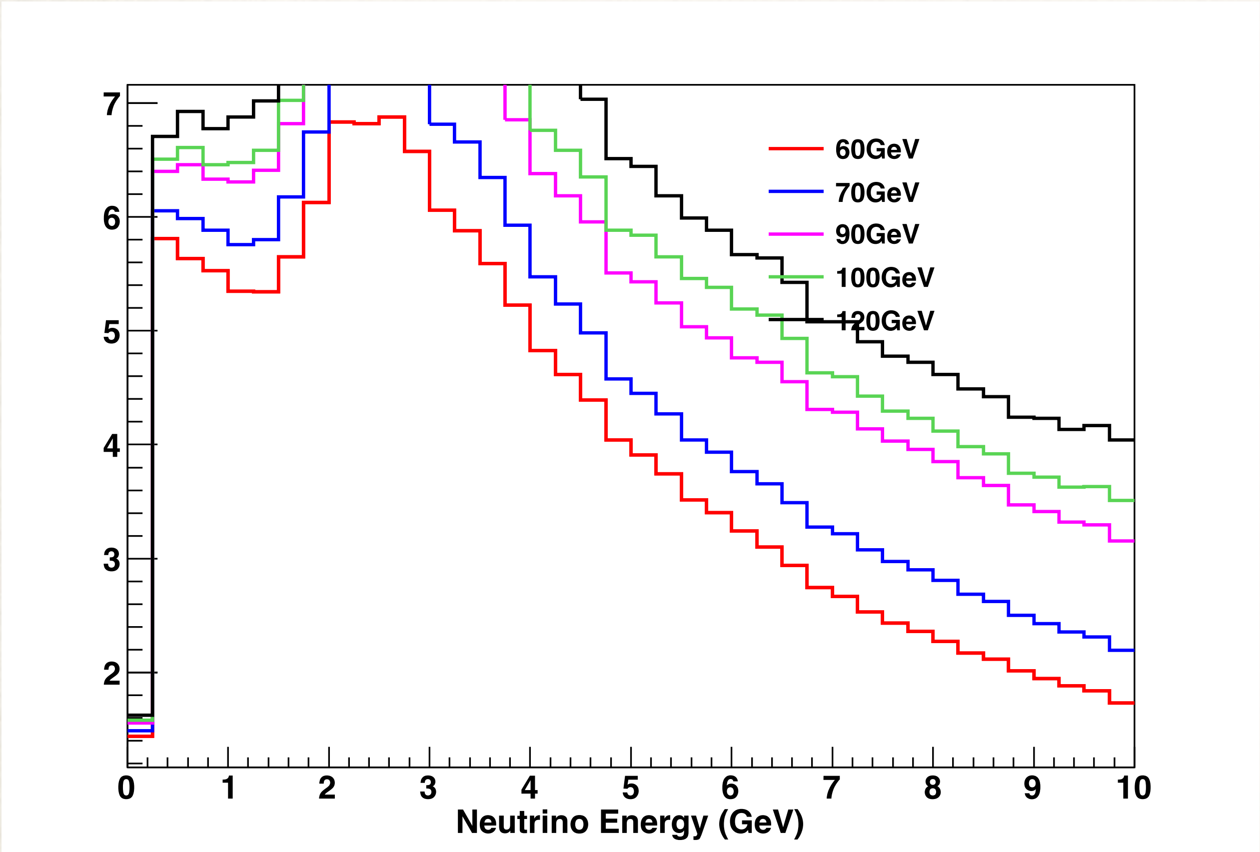

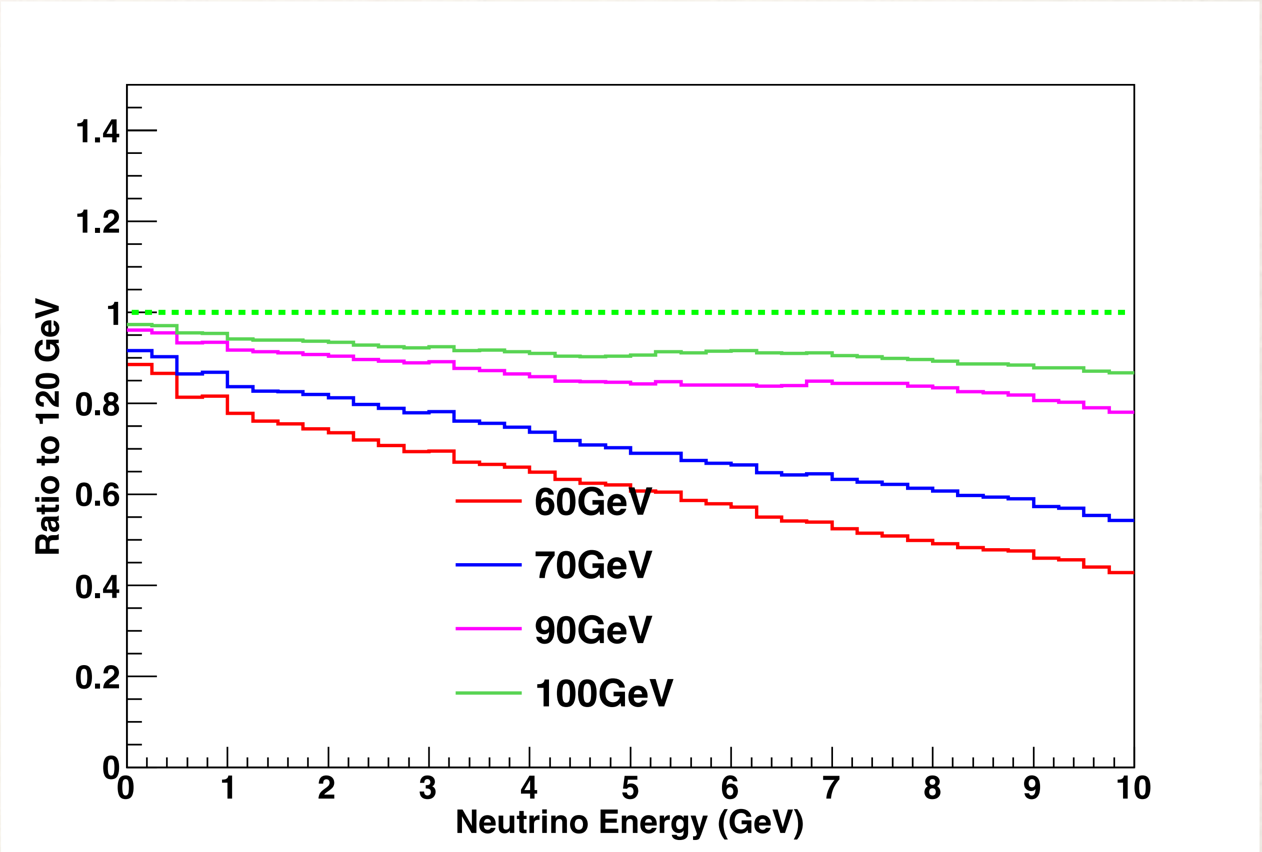

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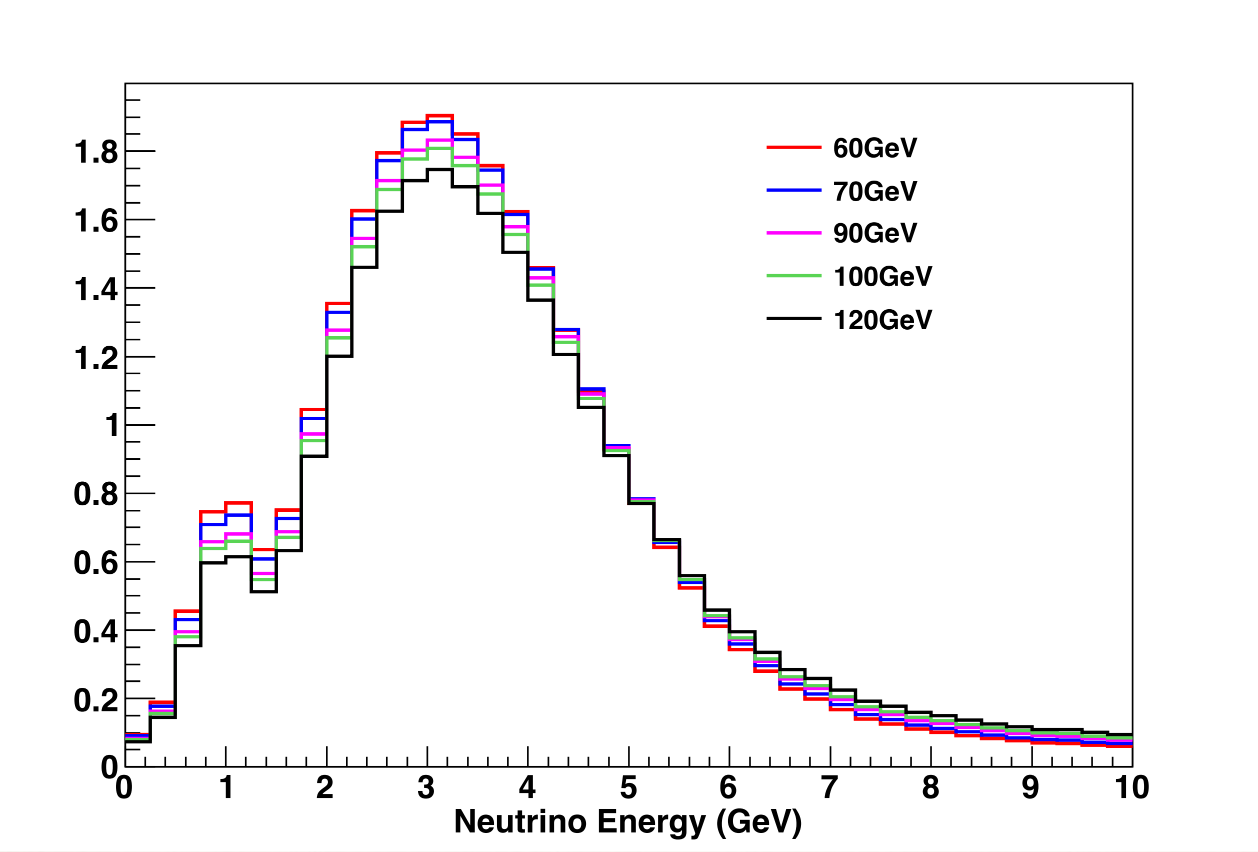
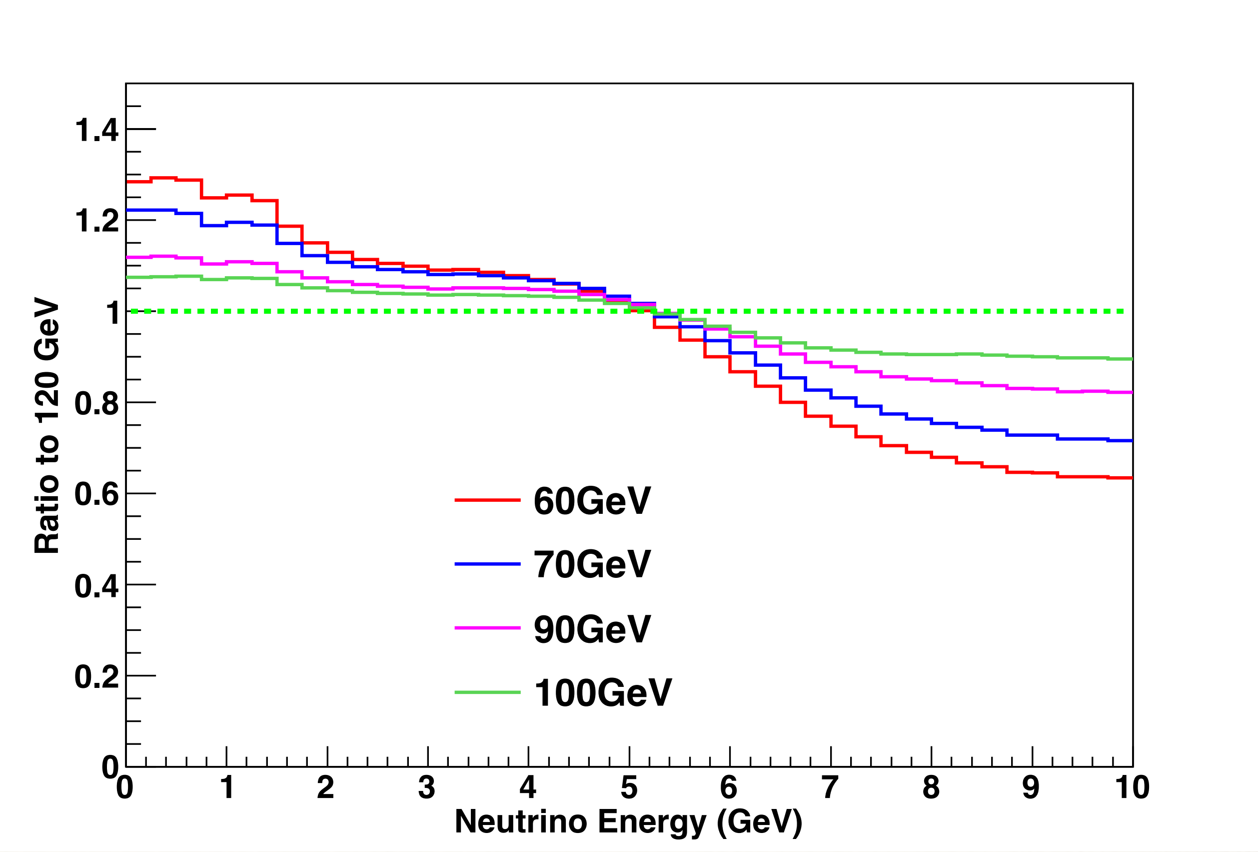
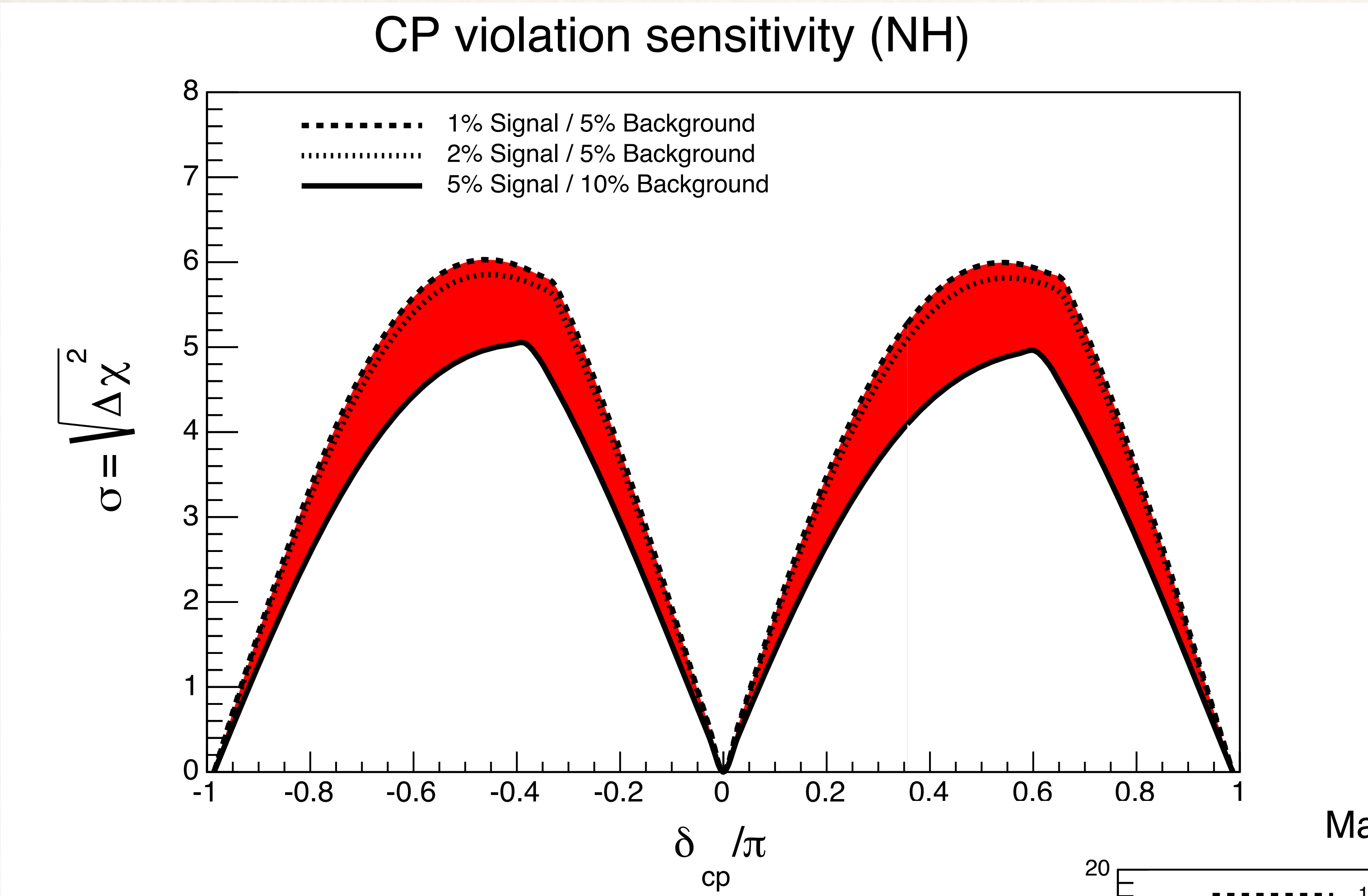


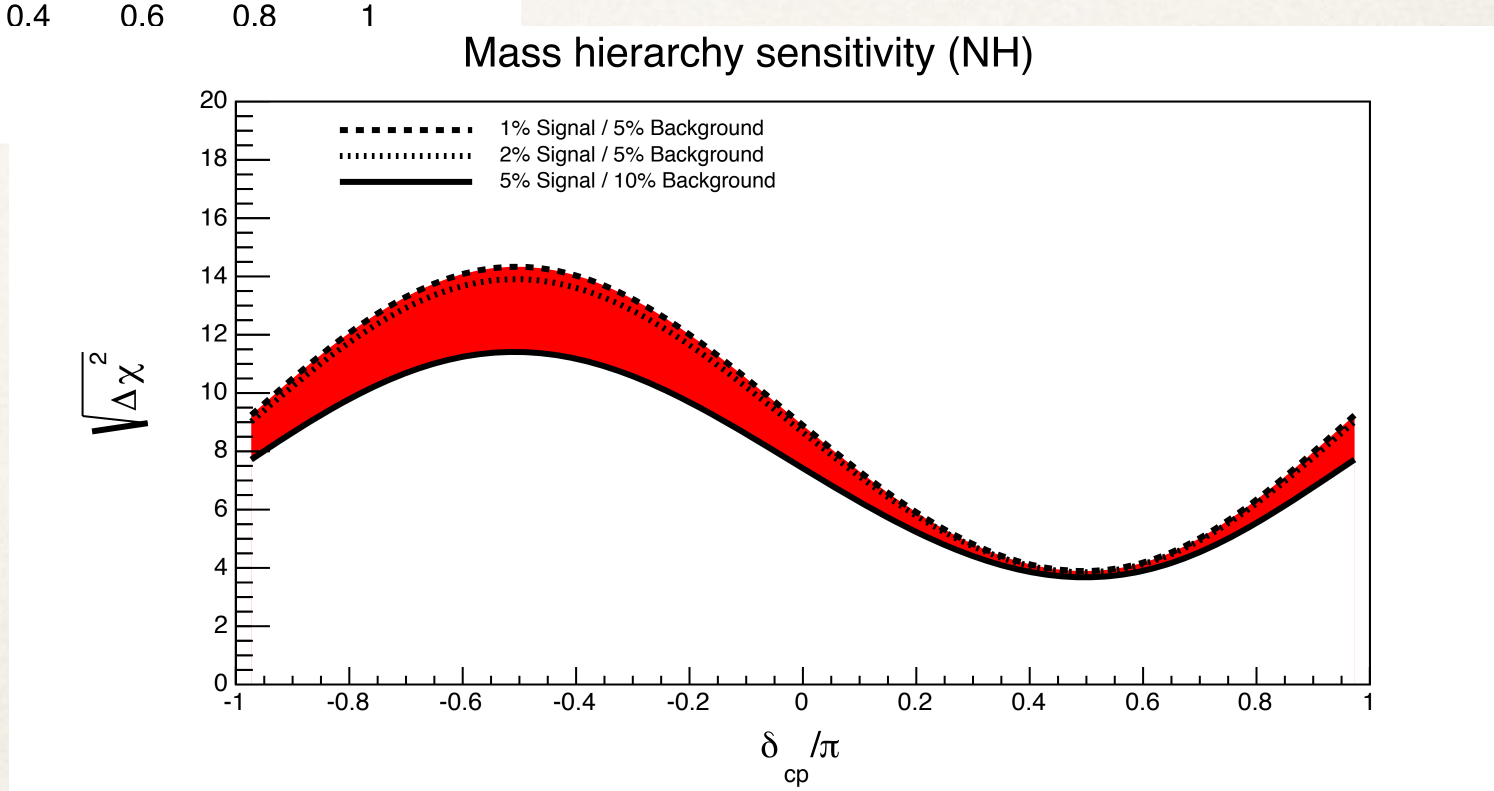


GLOBES Study



Sensitivities @ 120 GeV

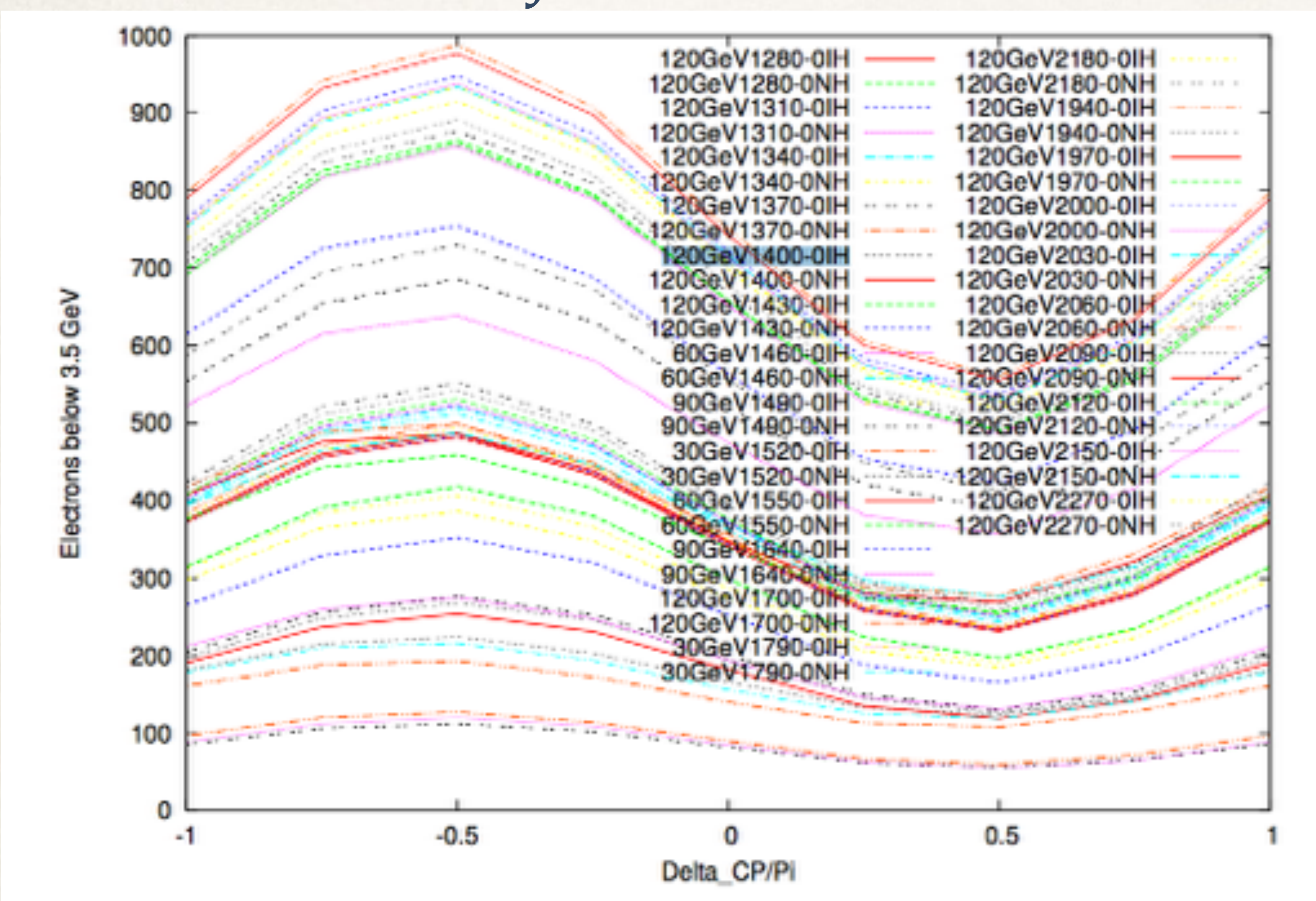
Band shows difference between LBNE's systematics goal and systematics comparable to current experiments



Impact of CP Phase

- Raw signal events (before acceptance/efficiency) versus CP phase for many different beam configurations

J. LoSecco



Total amount of signal varies with CP phase

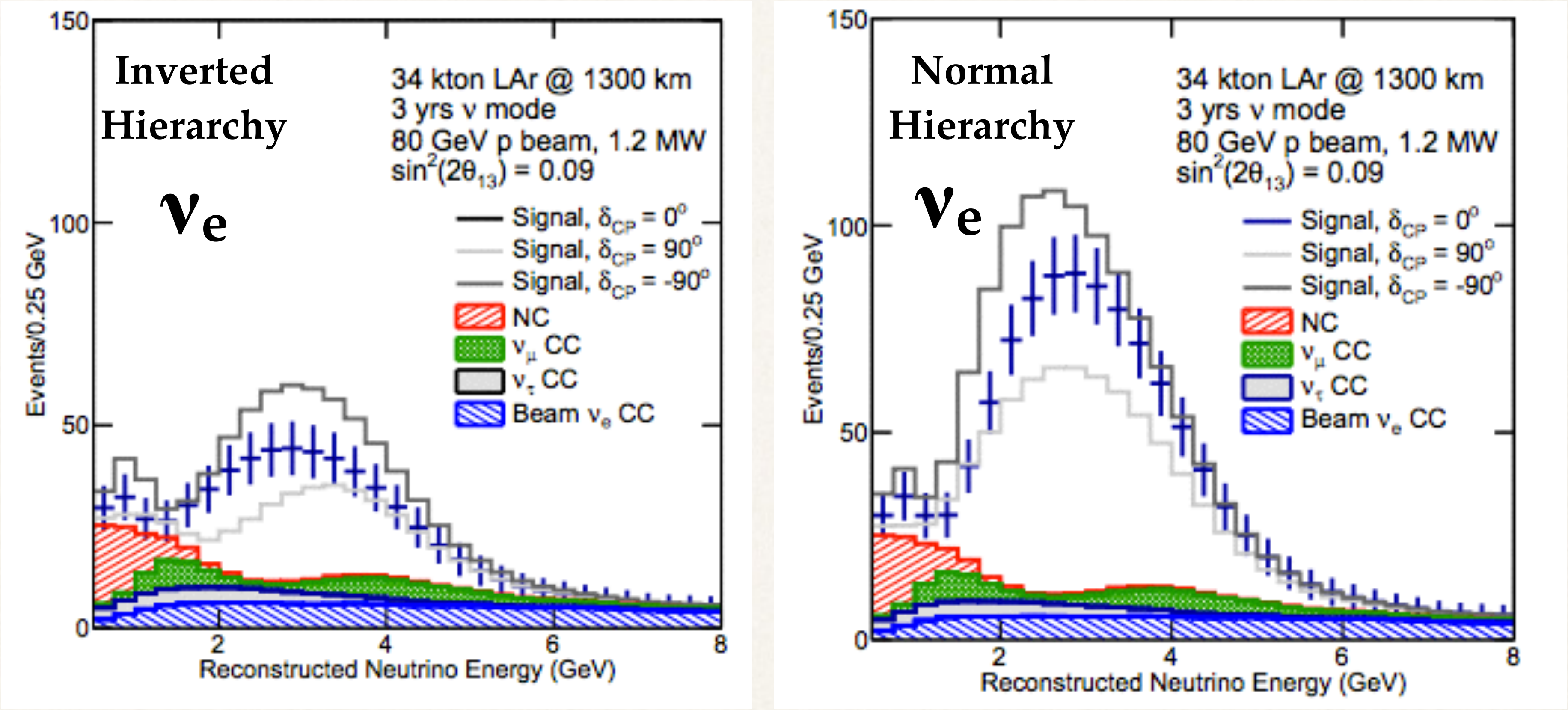
But optimal (highest signal) beam configurations retain that status for all values of CP phase

Extraction of CP Phase

- LBNE will study the CP phase and mass hierarchy by measuring $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ transitions

LBNE Collaboration arXiv:1307.7335

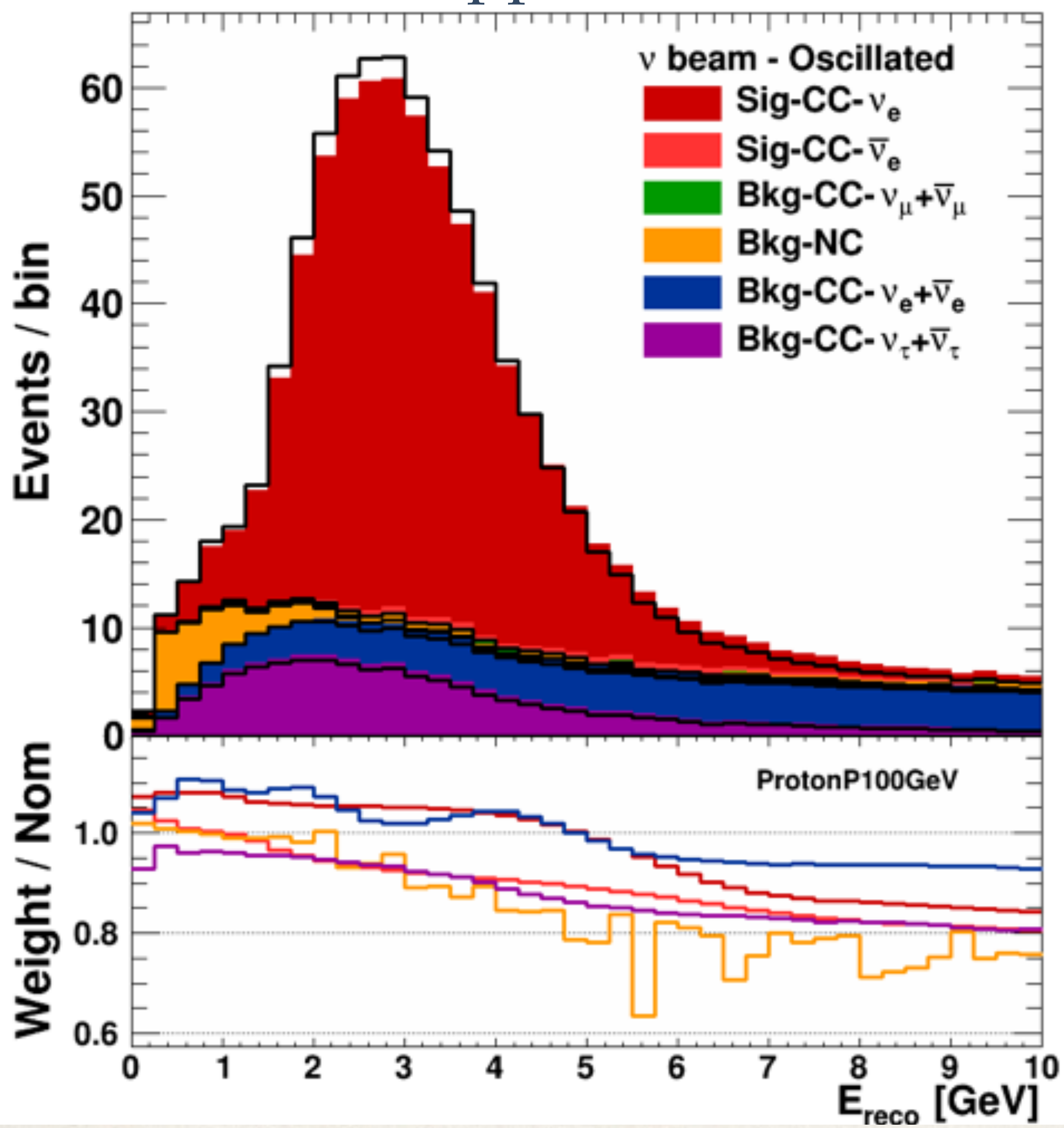
Predicted energy spectrum of electron neutrinos at the LBNE far detector for different values of CP phase and mass hierarchy



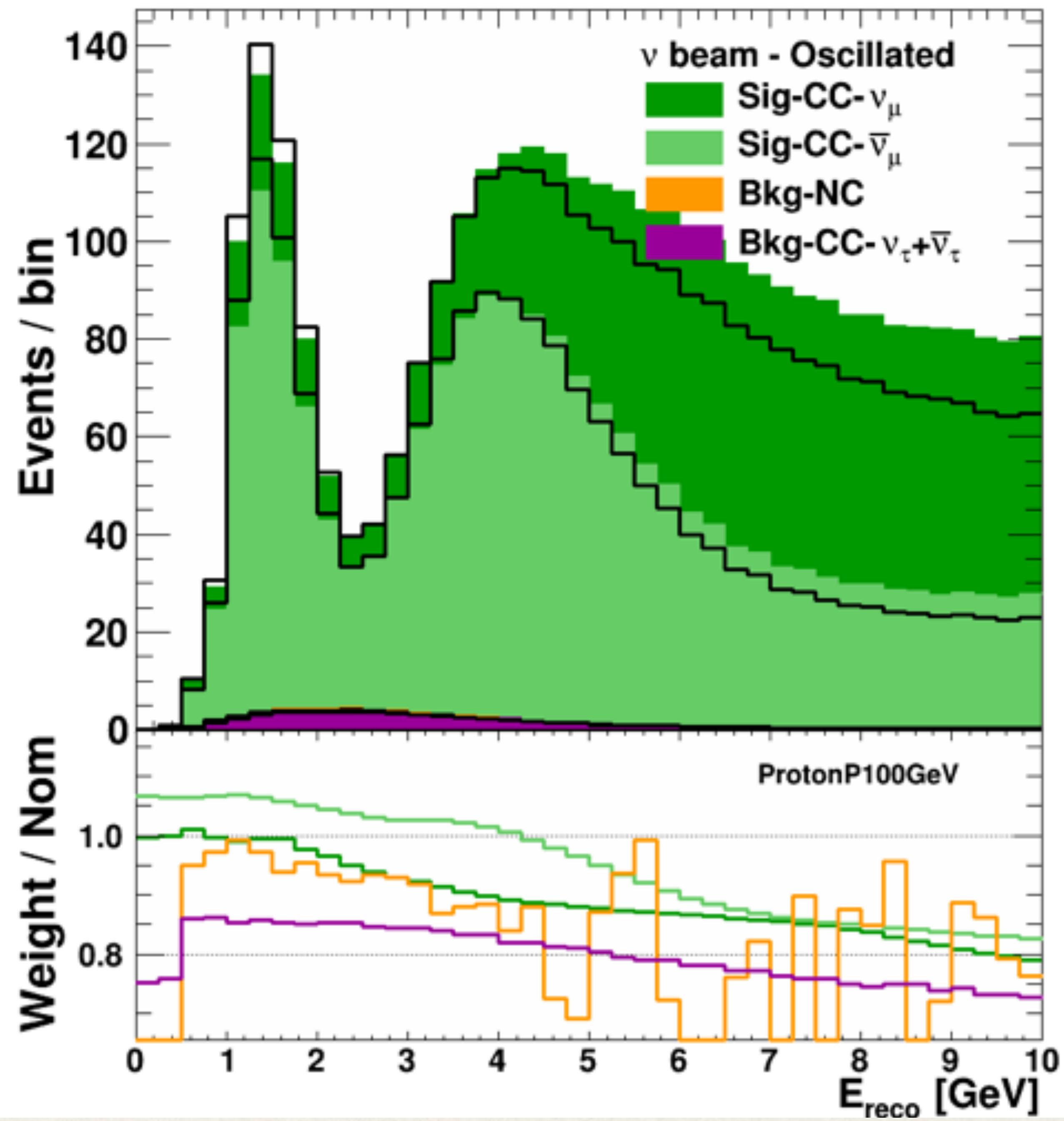
The energy spectrum of ν_e's and $\bar{\nu}_e$'s at the far detector is subtly different for different values of CP violation and substantially different for the two mass hierarchies

Fast MC Event Rates — 100 GeV — FHC

nu_e appearance

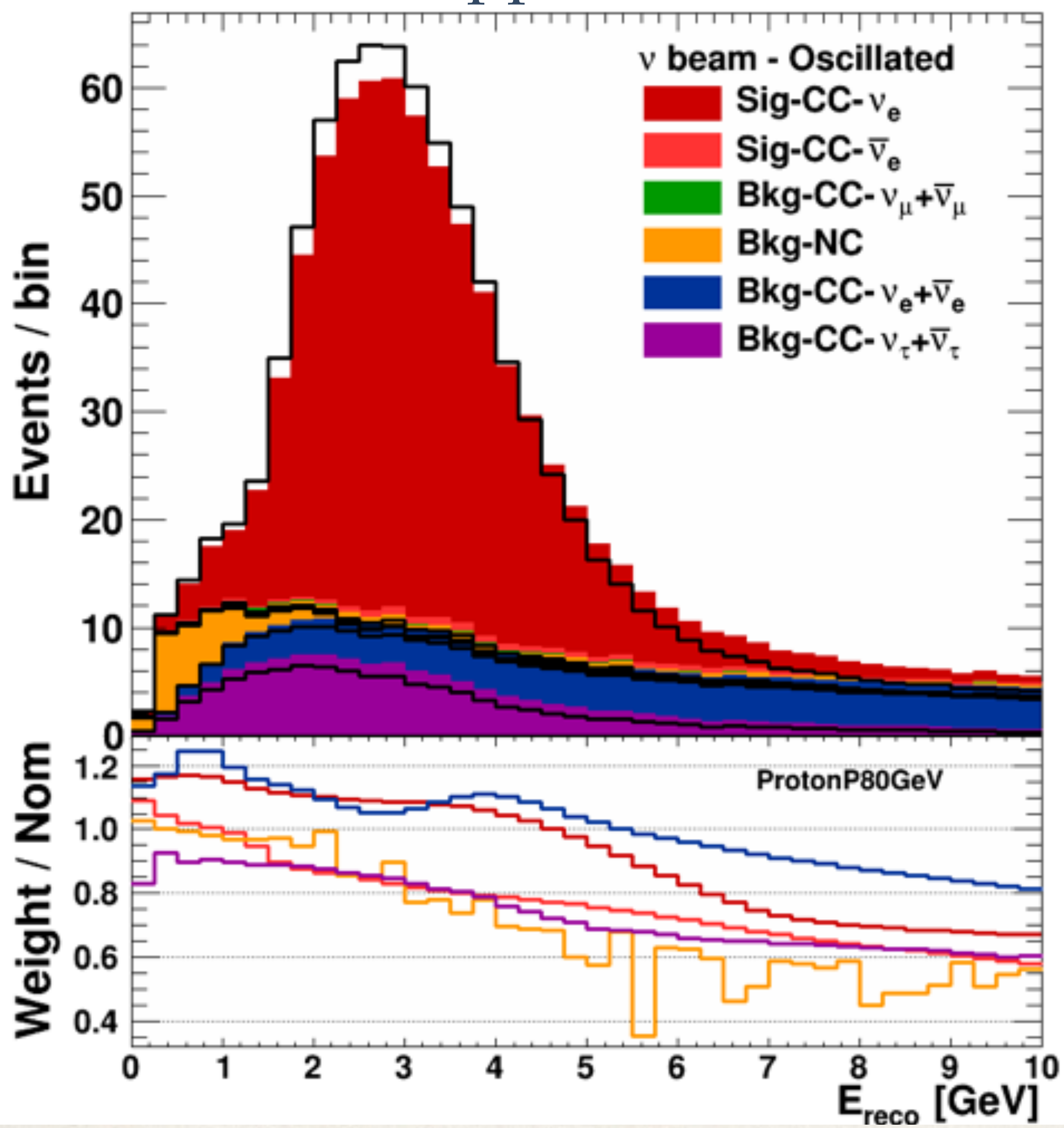


nu_mu disappearance

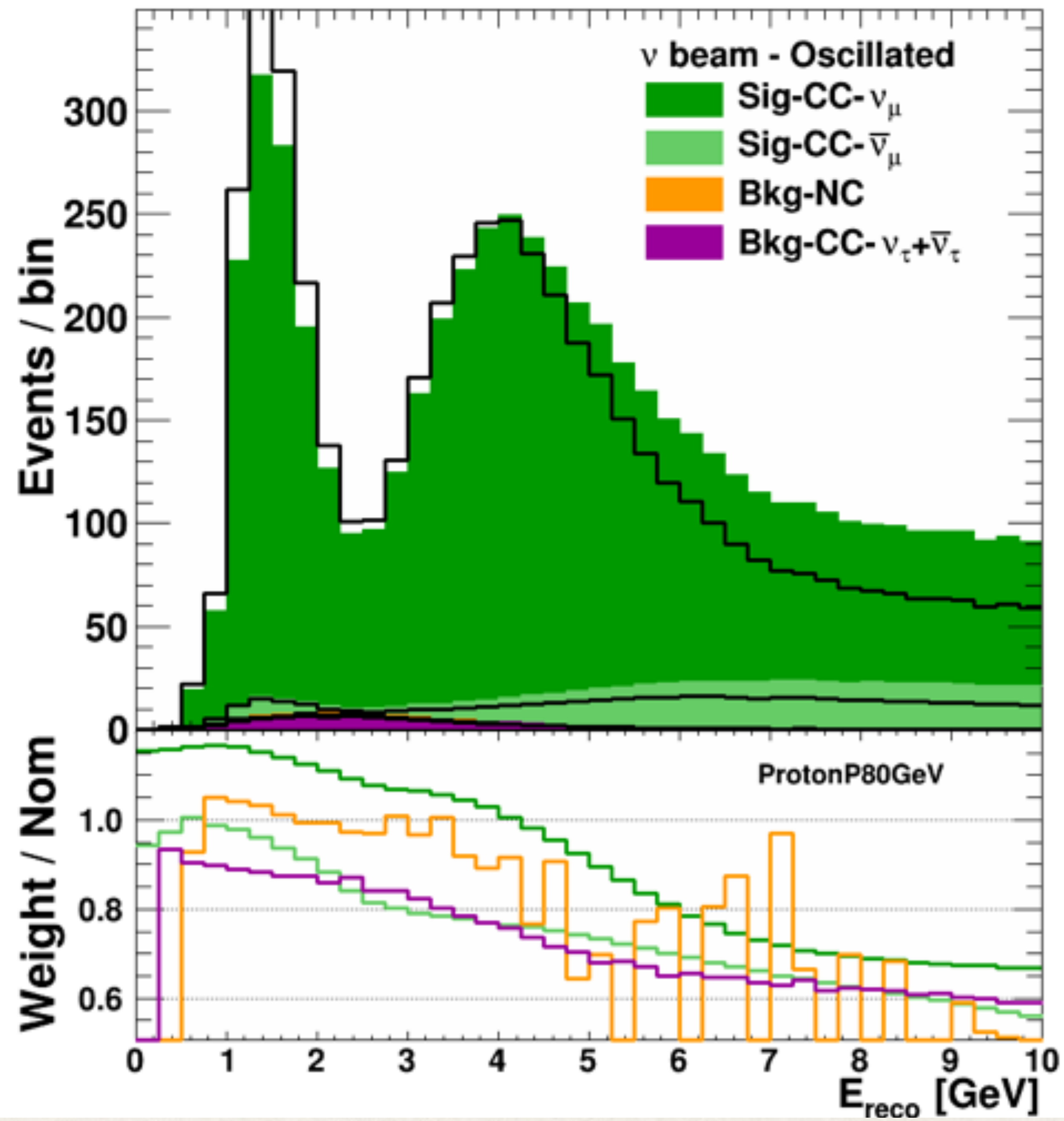


Fast MC Event Rates — 80 GeV — FHC

nu_e appearance

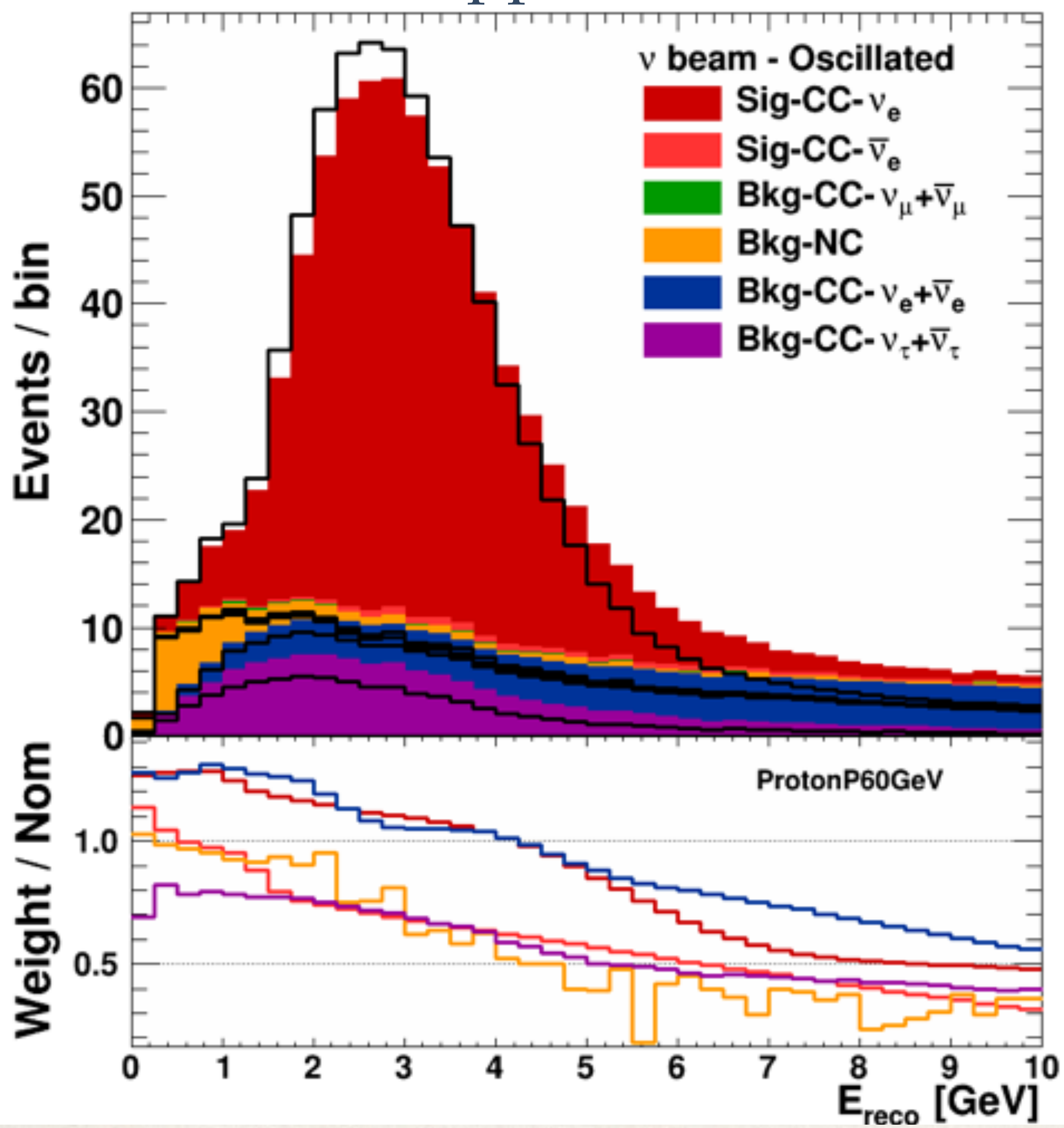


nu_mu disappearance

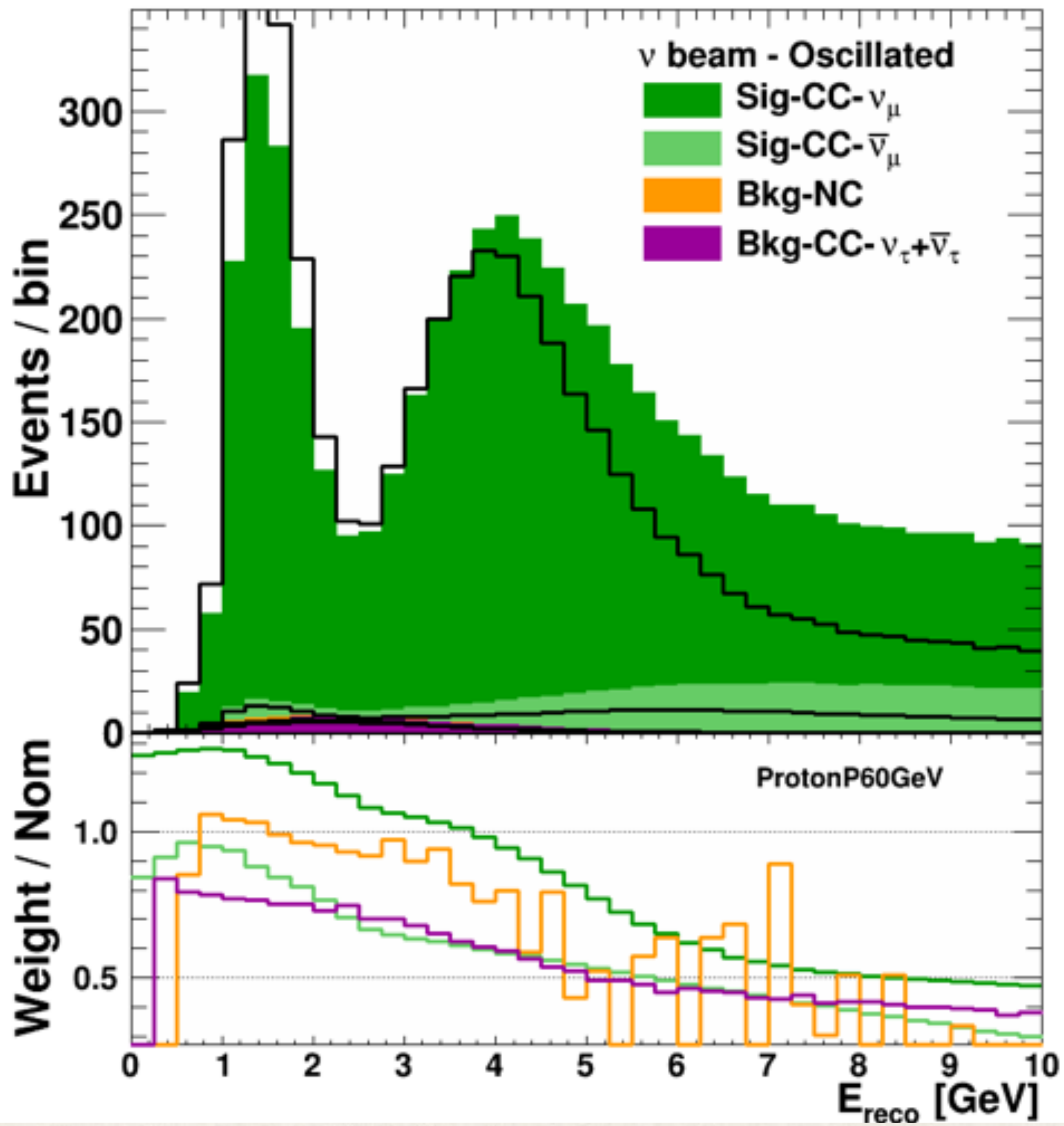


Fast MC Event Rates — 60 GeV — FHC

nu_e appearance

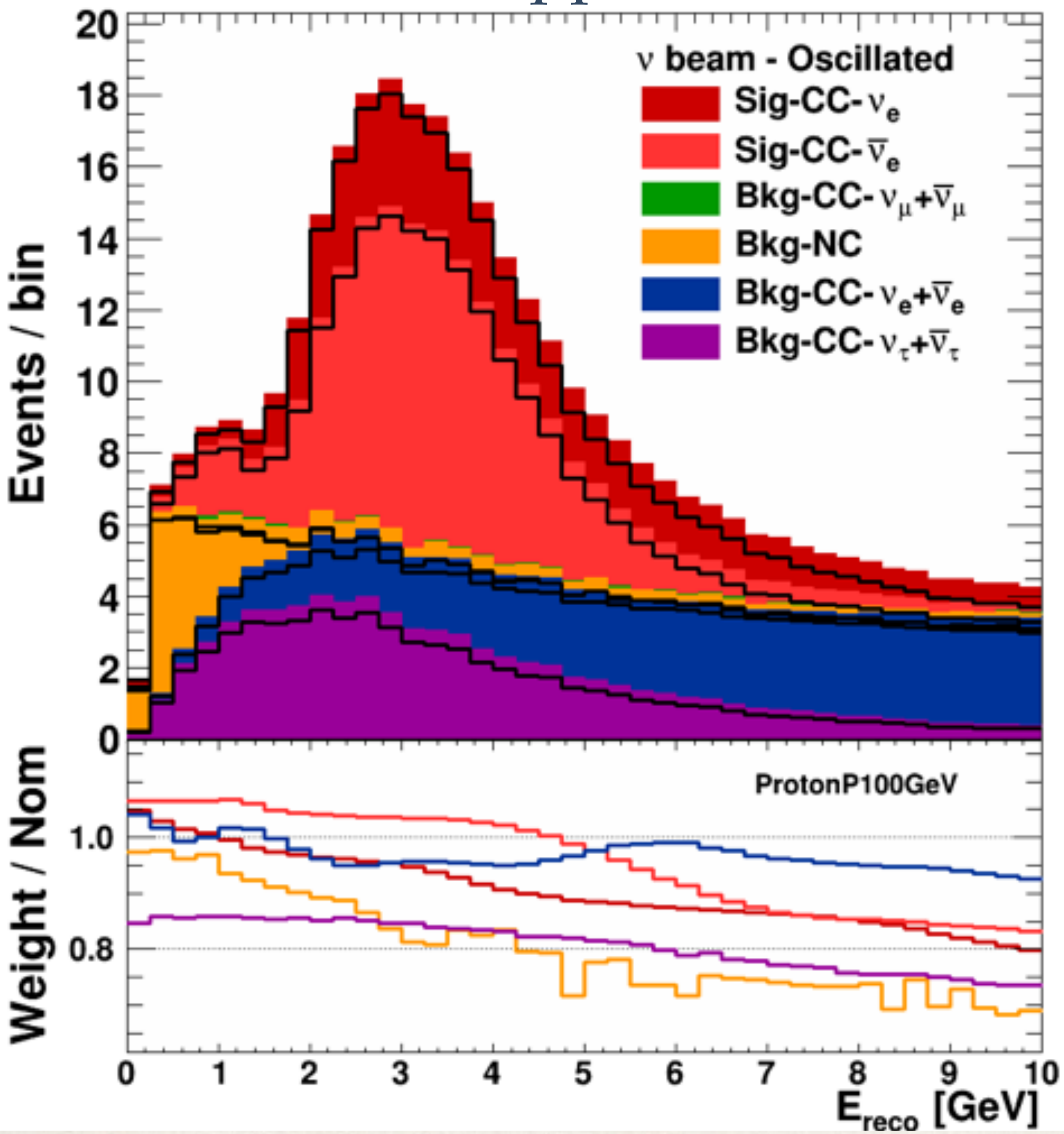


nu_mu disappearance

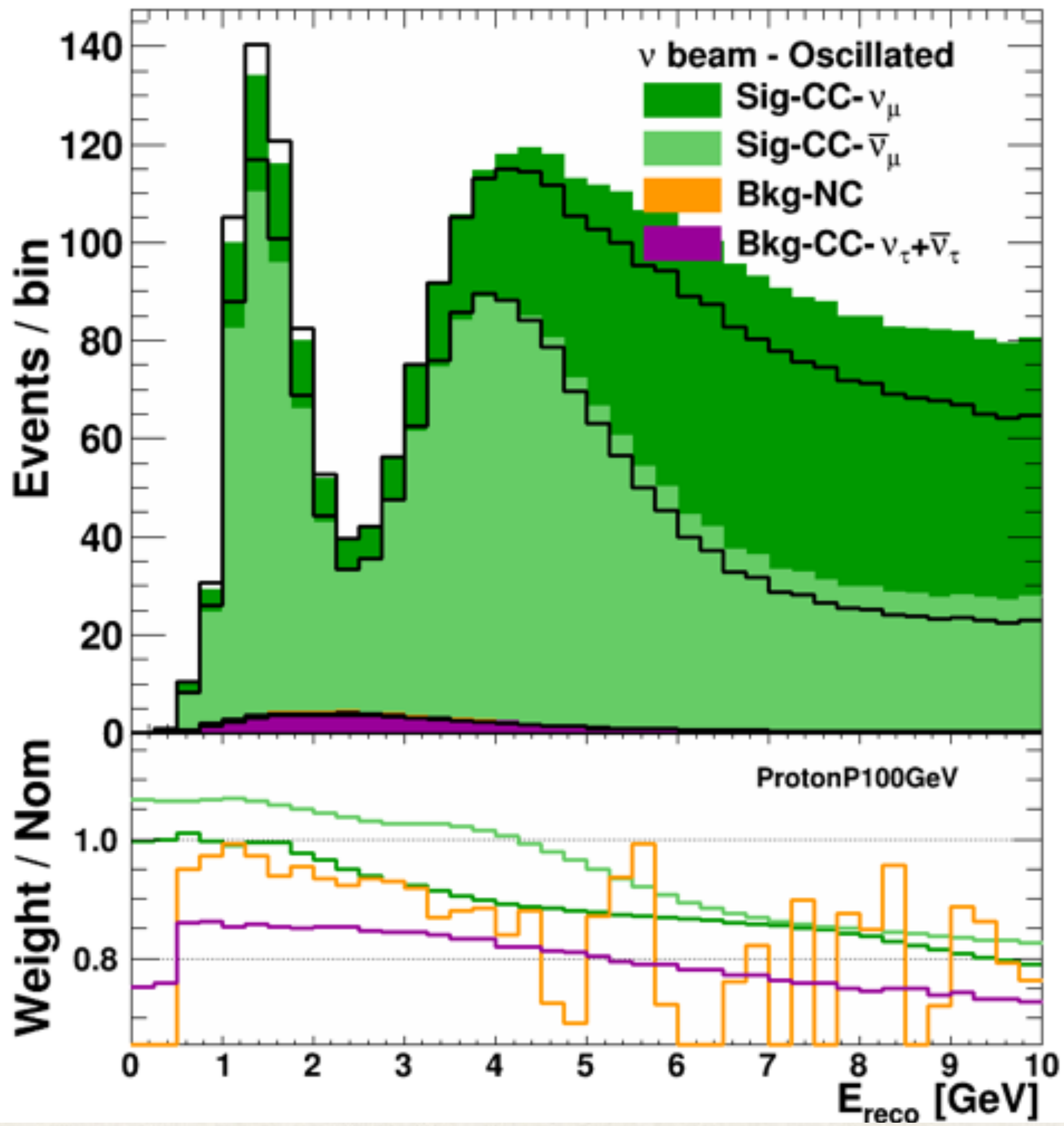


Fast MC Event Rates — 100 GeV — RHC

nu_e_bar appearance

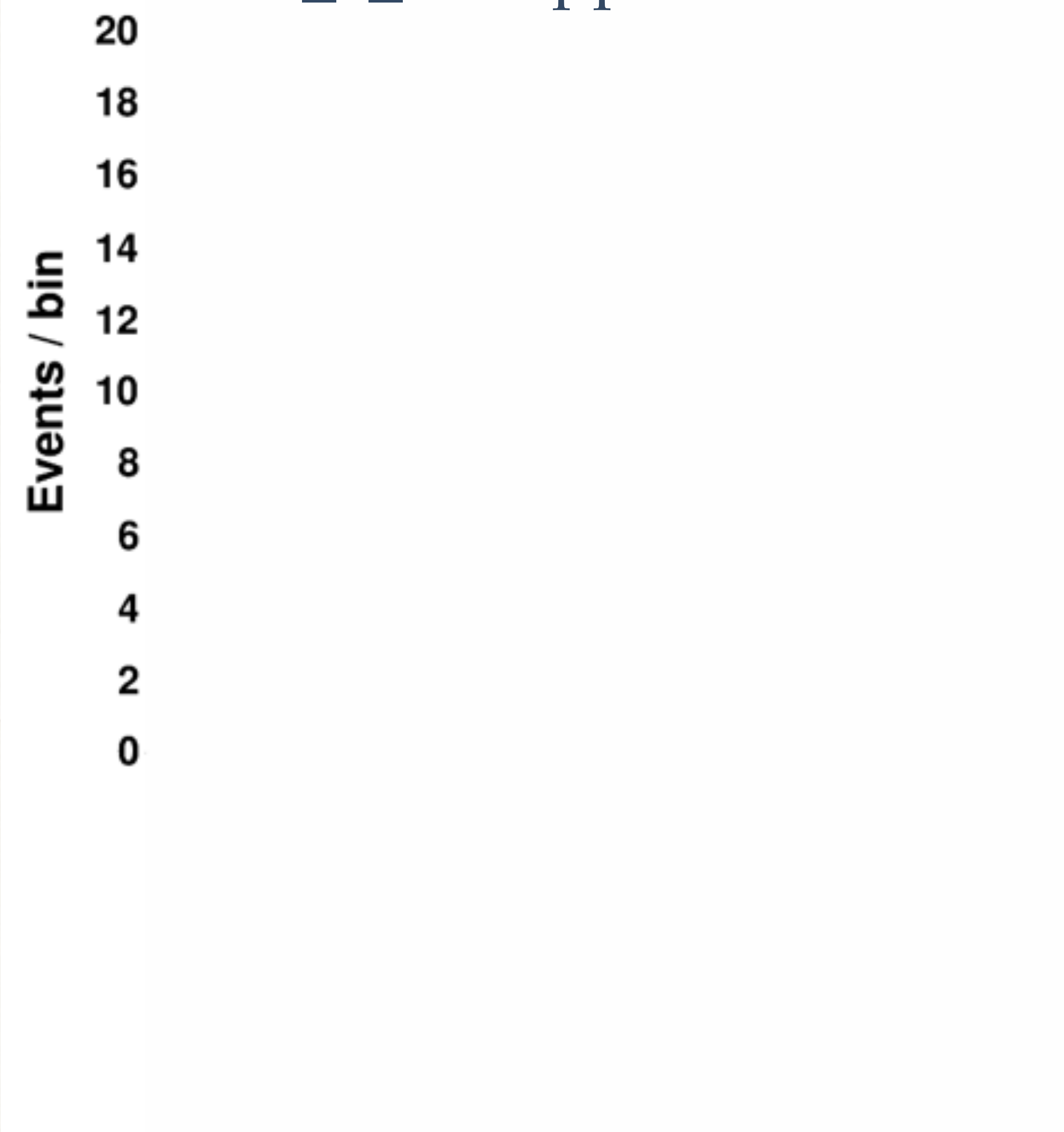


nu_mu_bar disappearance

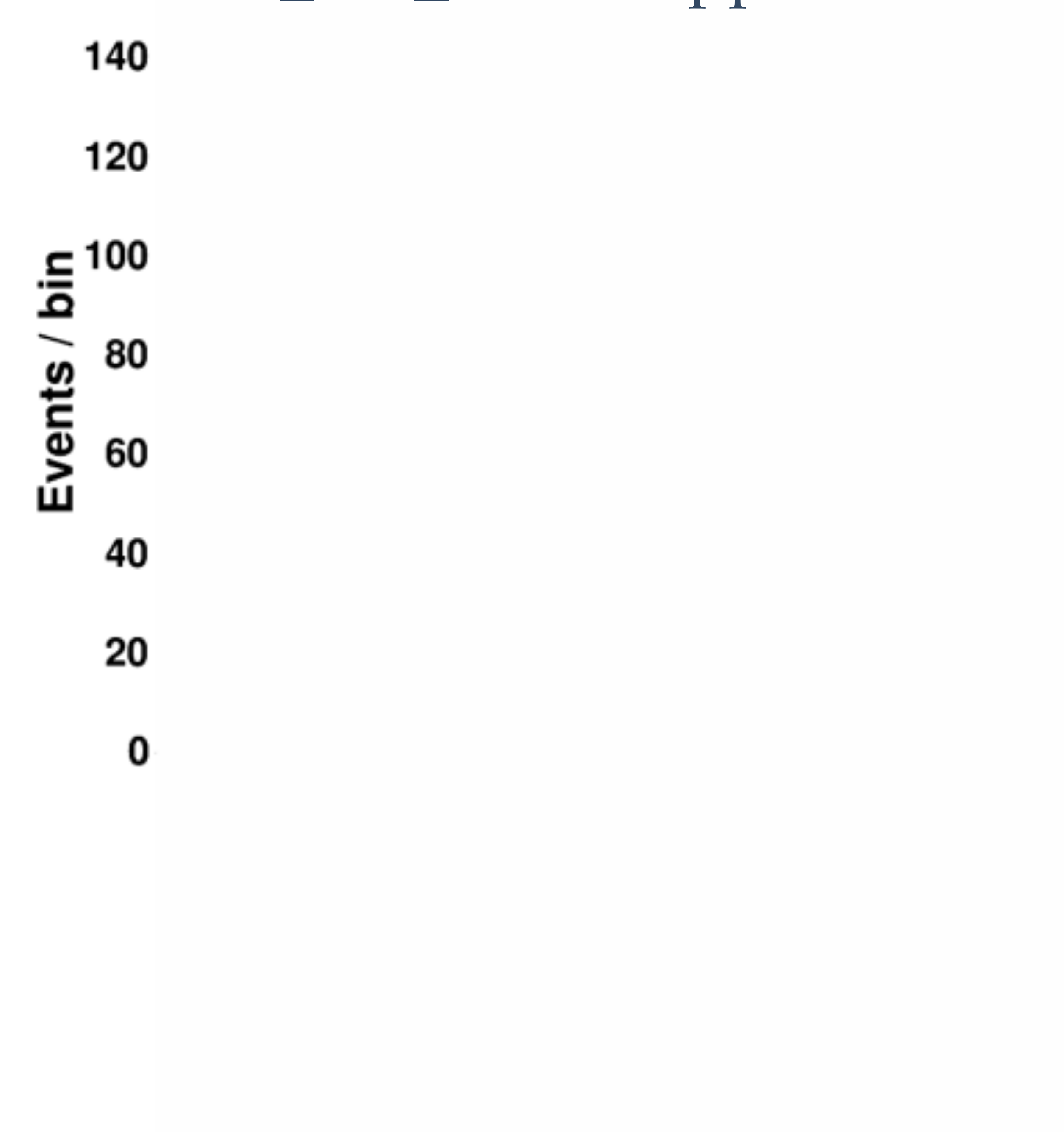


Fast MC Event Rates — 80 GeV — RHC

nu_e_bar appearance

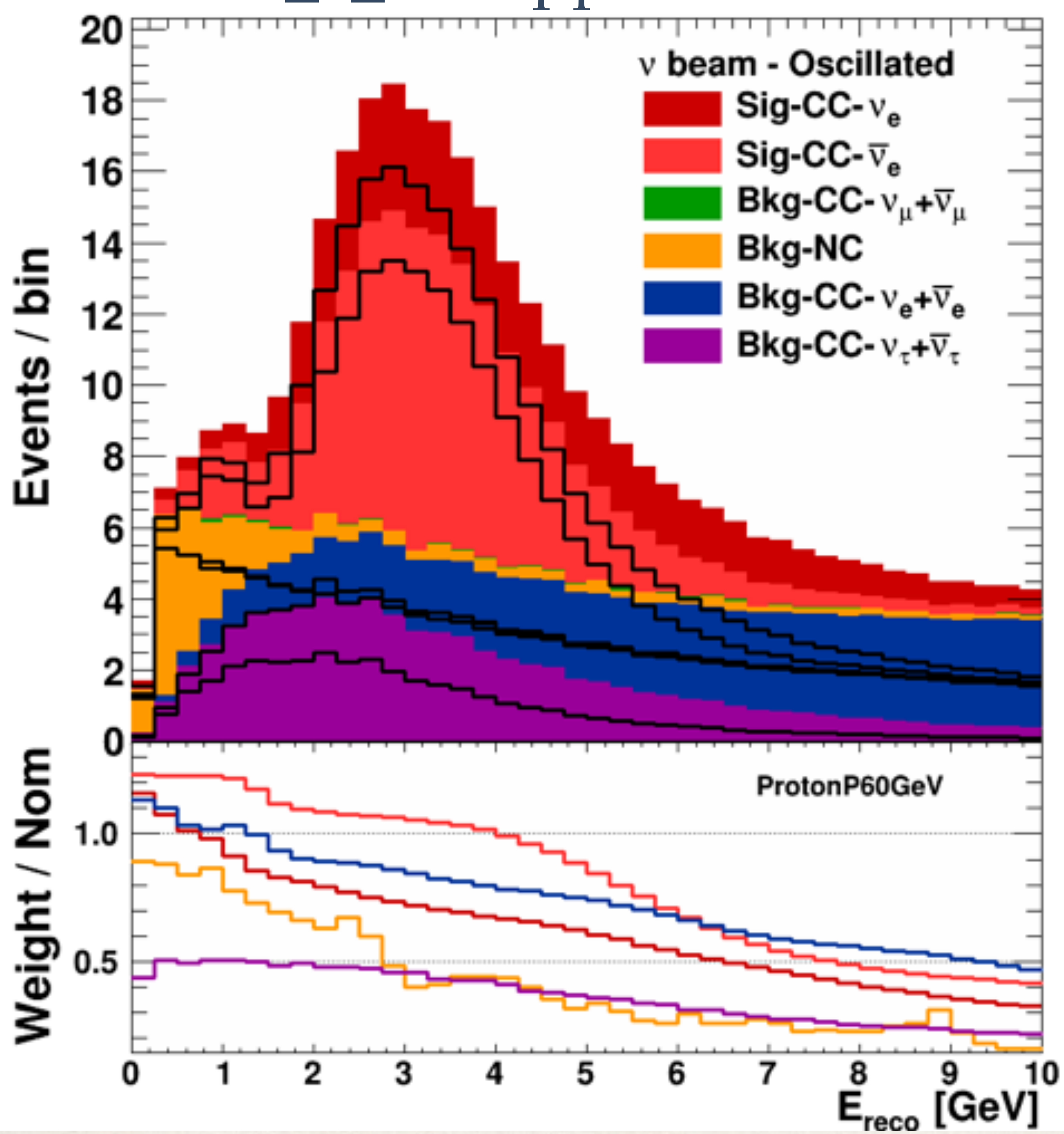


nu_mu_bar disappearance

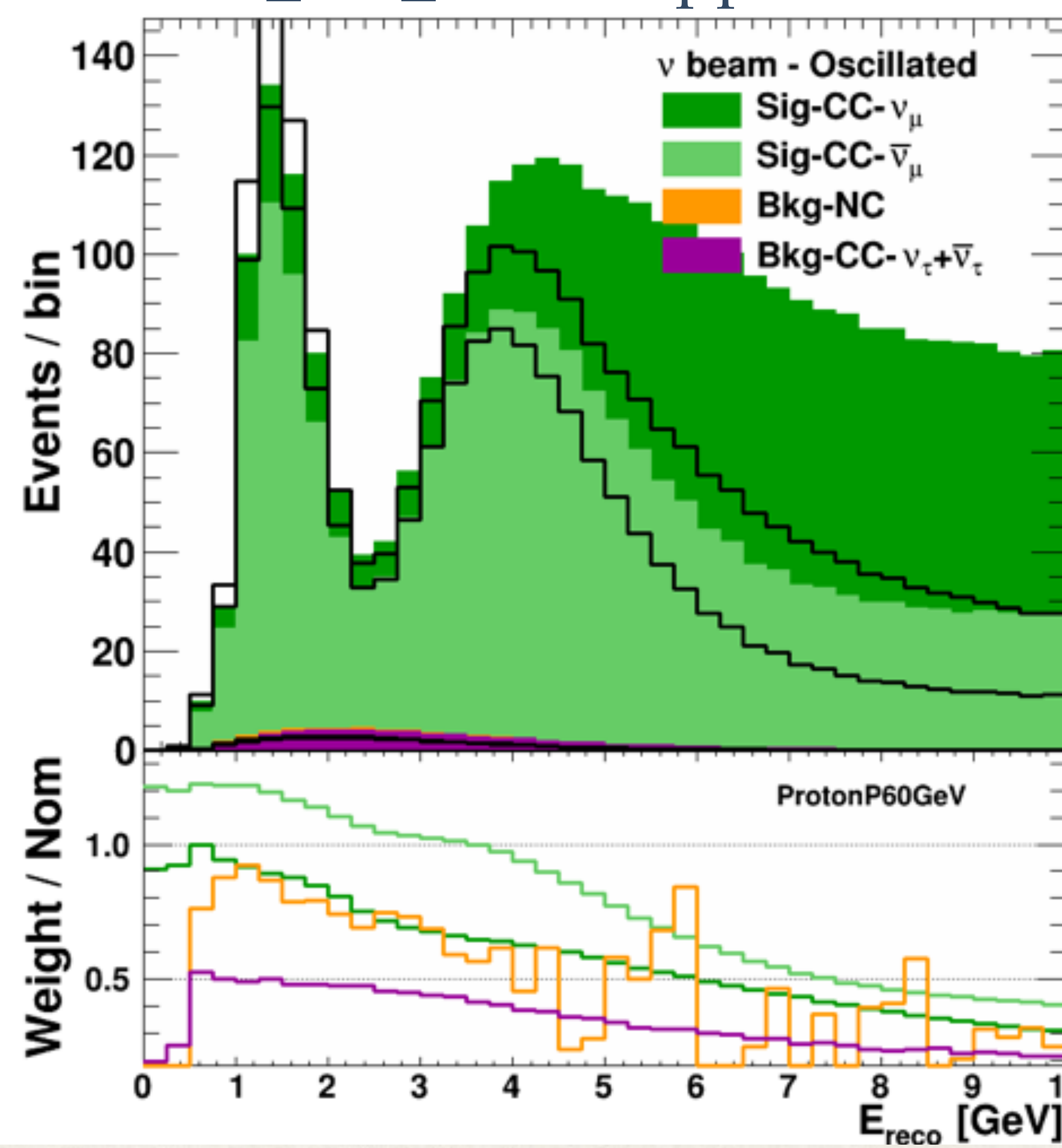


Fast MC Event Rates — 60 GeV — RHC

nu_e_bar appearance

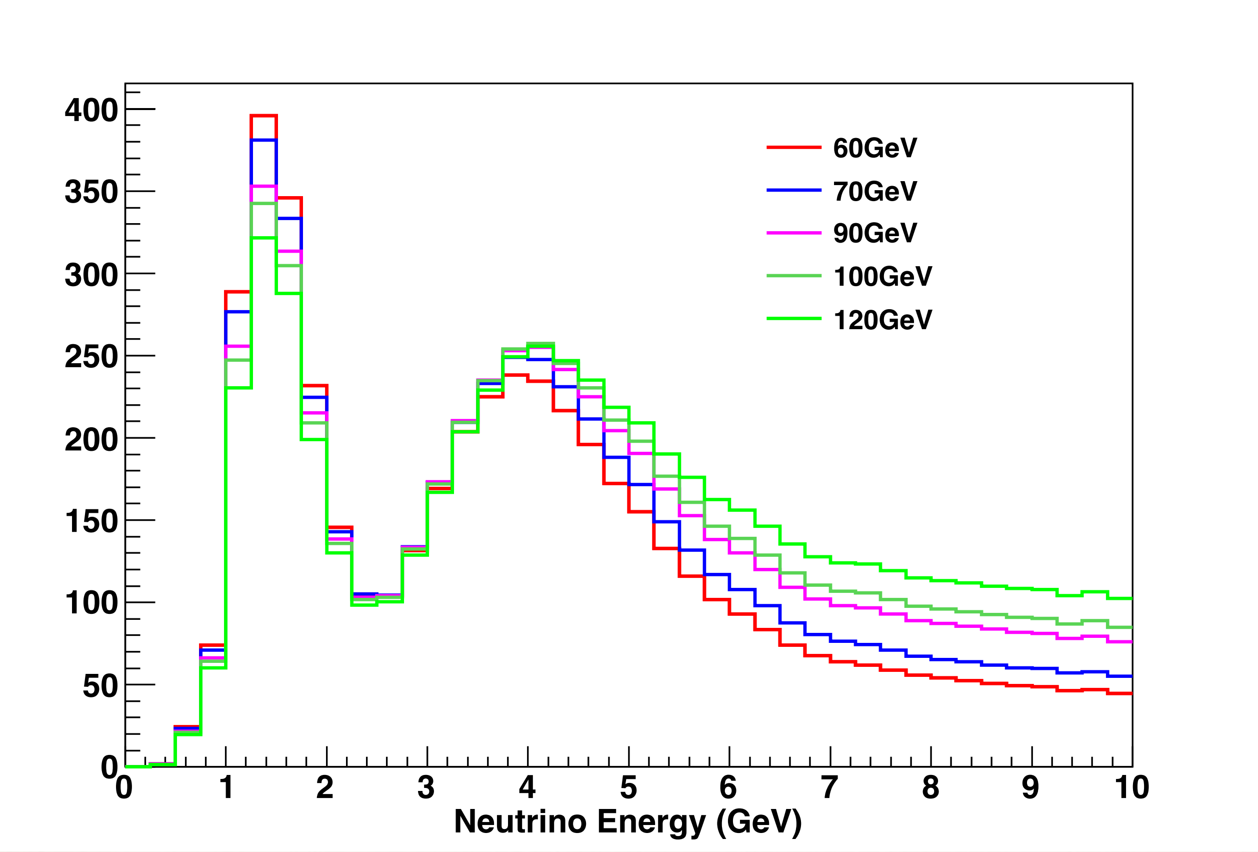


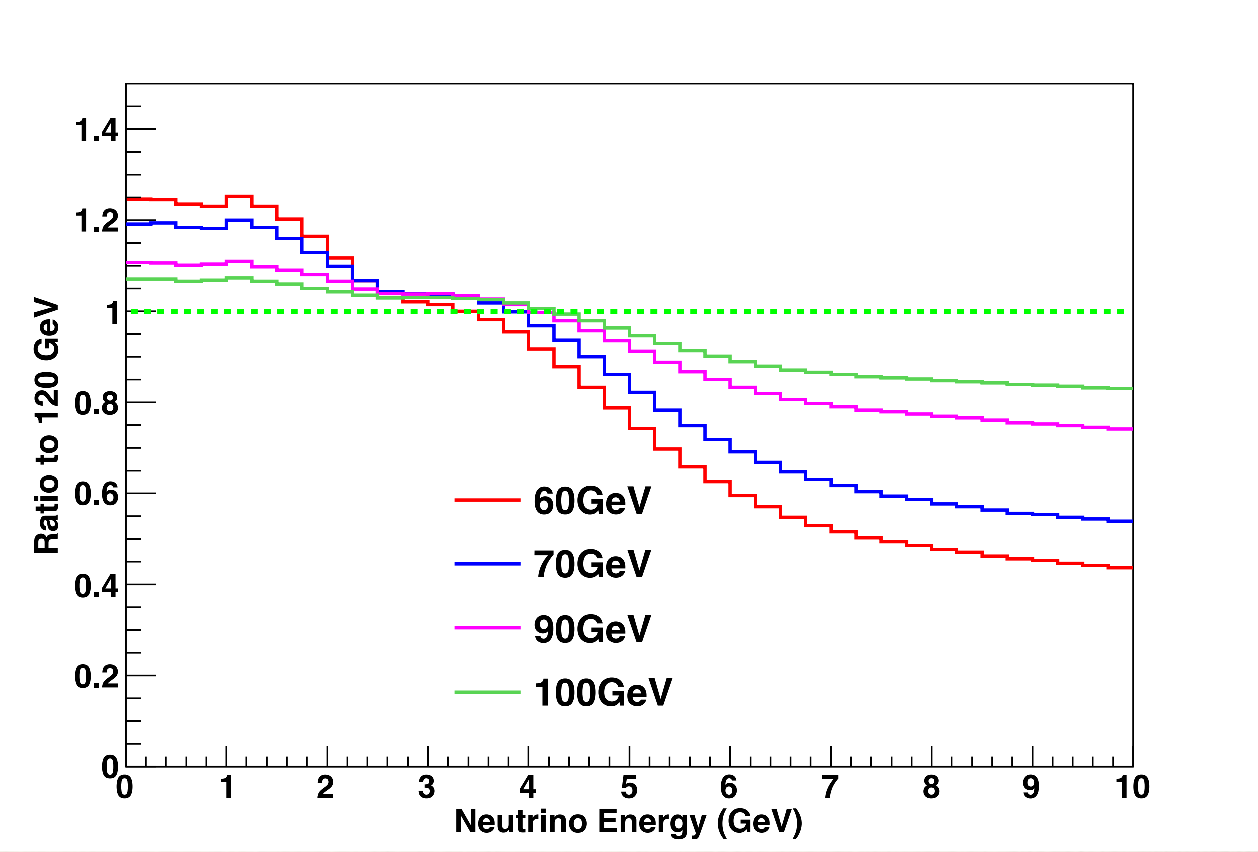
nu_mu_bar disappearance



Fast MC Event Rates — Disappearance — FHC

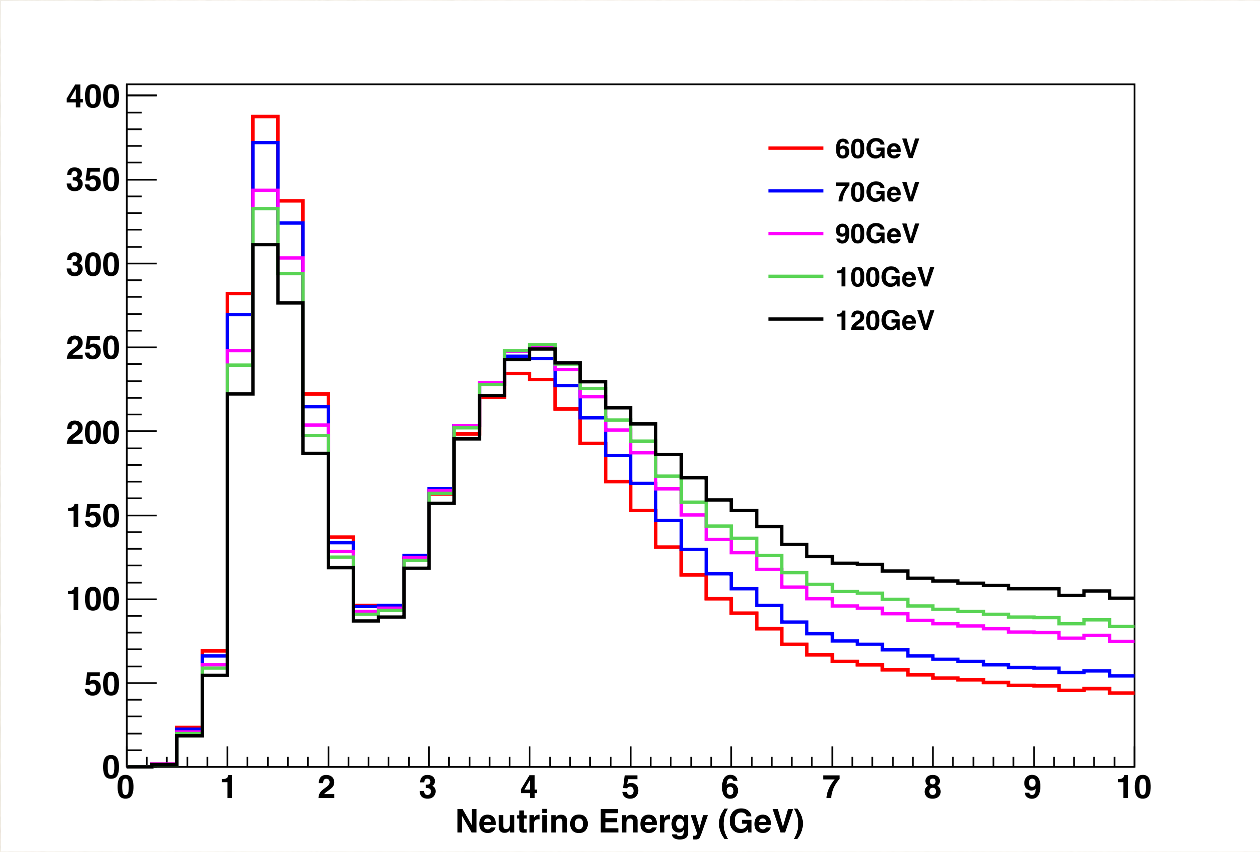
Total Event Rates, nu_mu disappearance

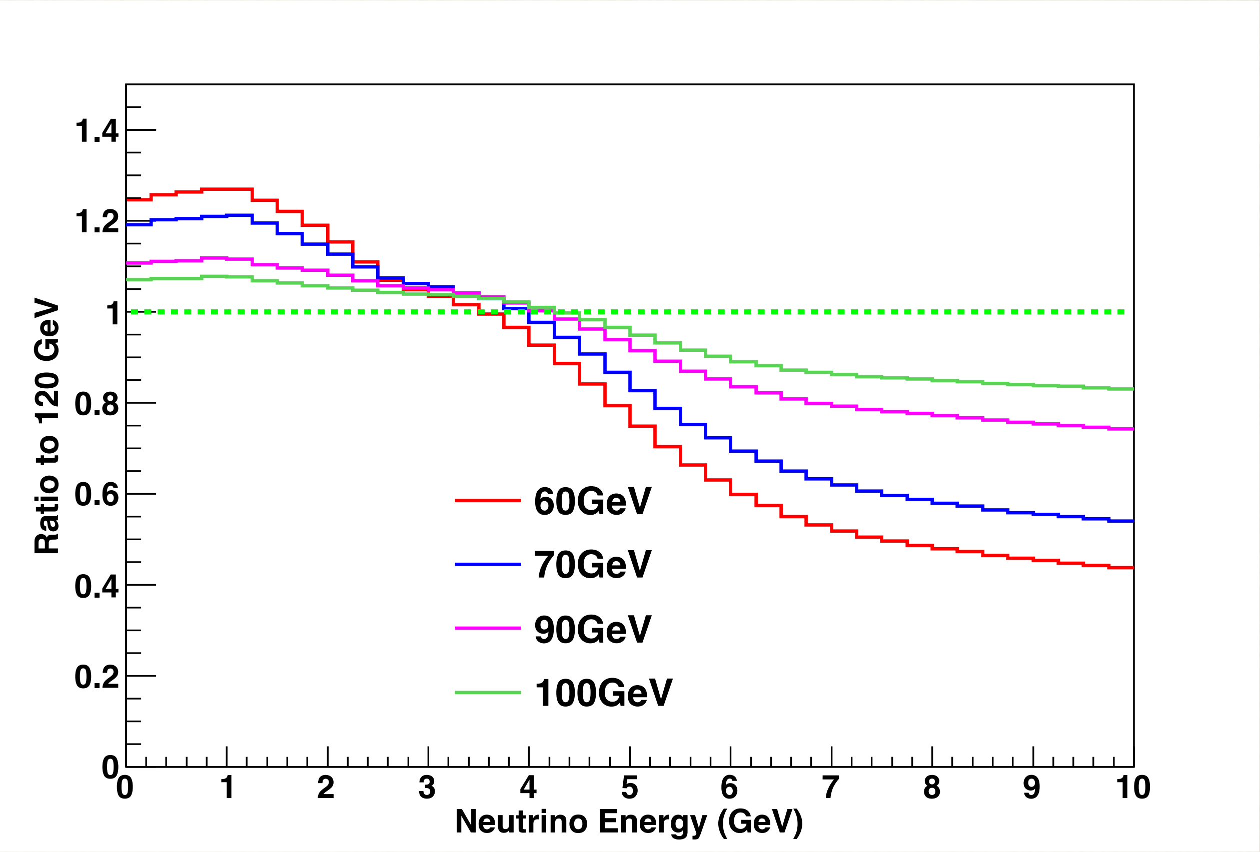




Signal Rates in Fast MC — Disappearance — FHC

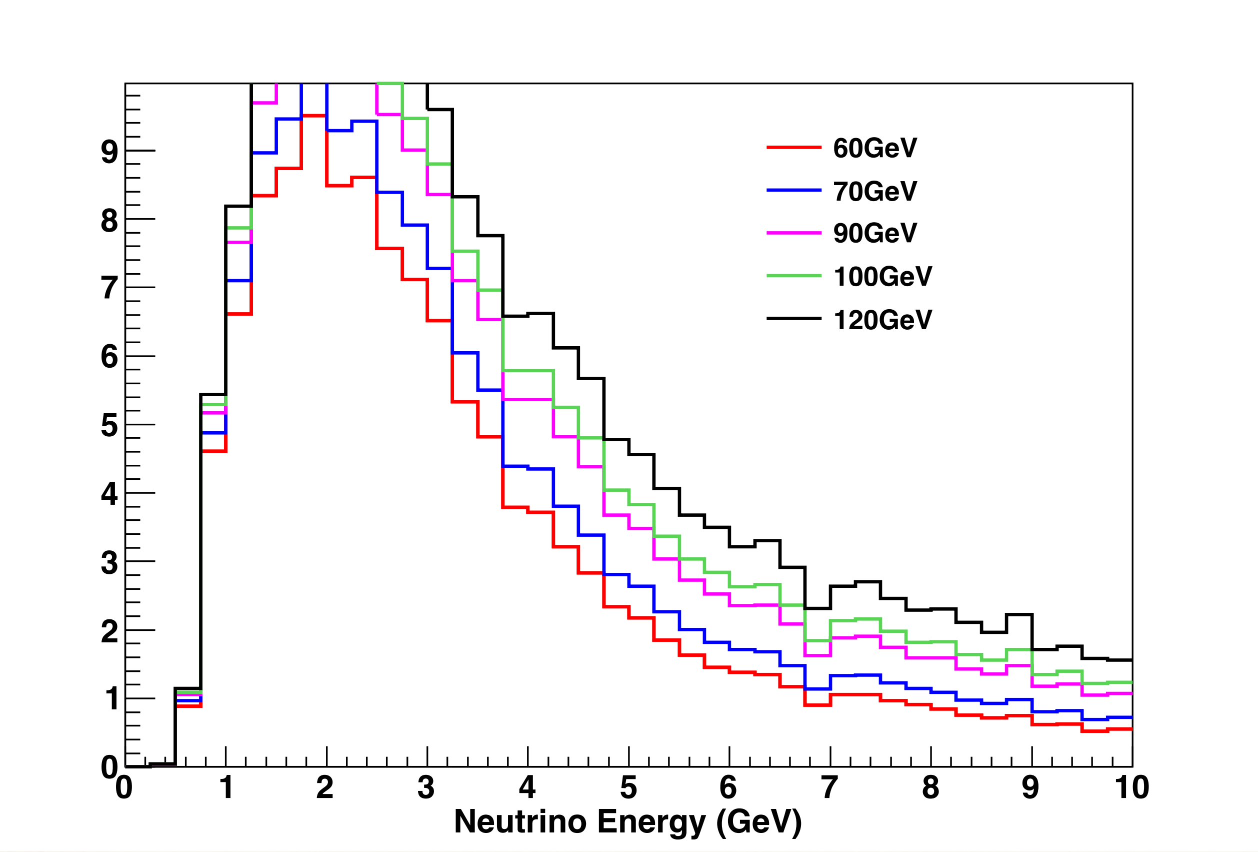
Signal Only Event Rates, nu_mu disappearance





Background Rates in Fast MC — Disappearance —FHC

Background Only Event Rates, nu_mu disappearance



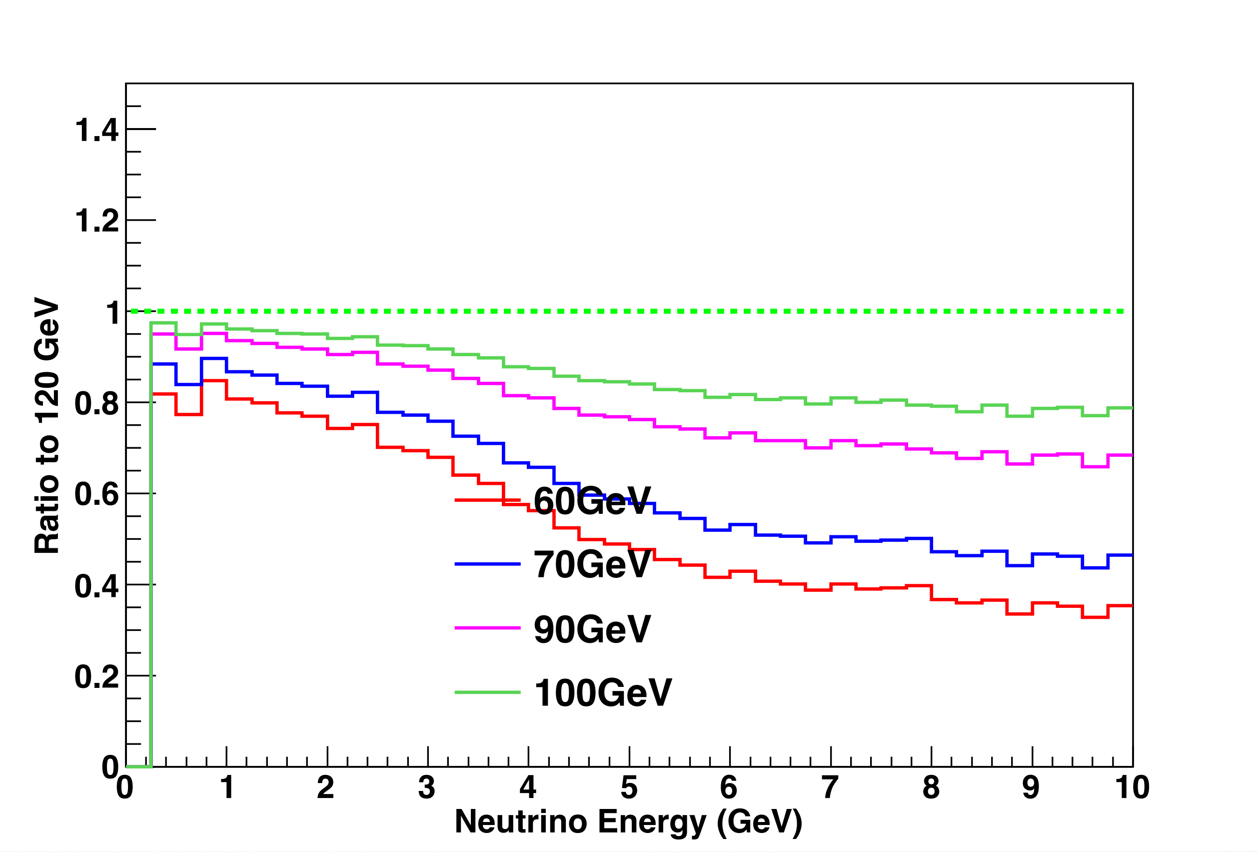
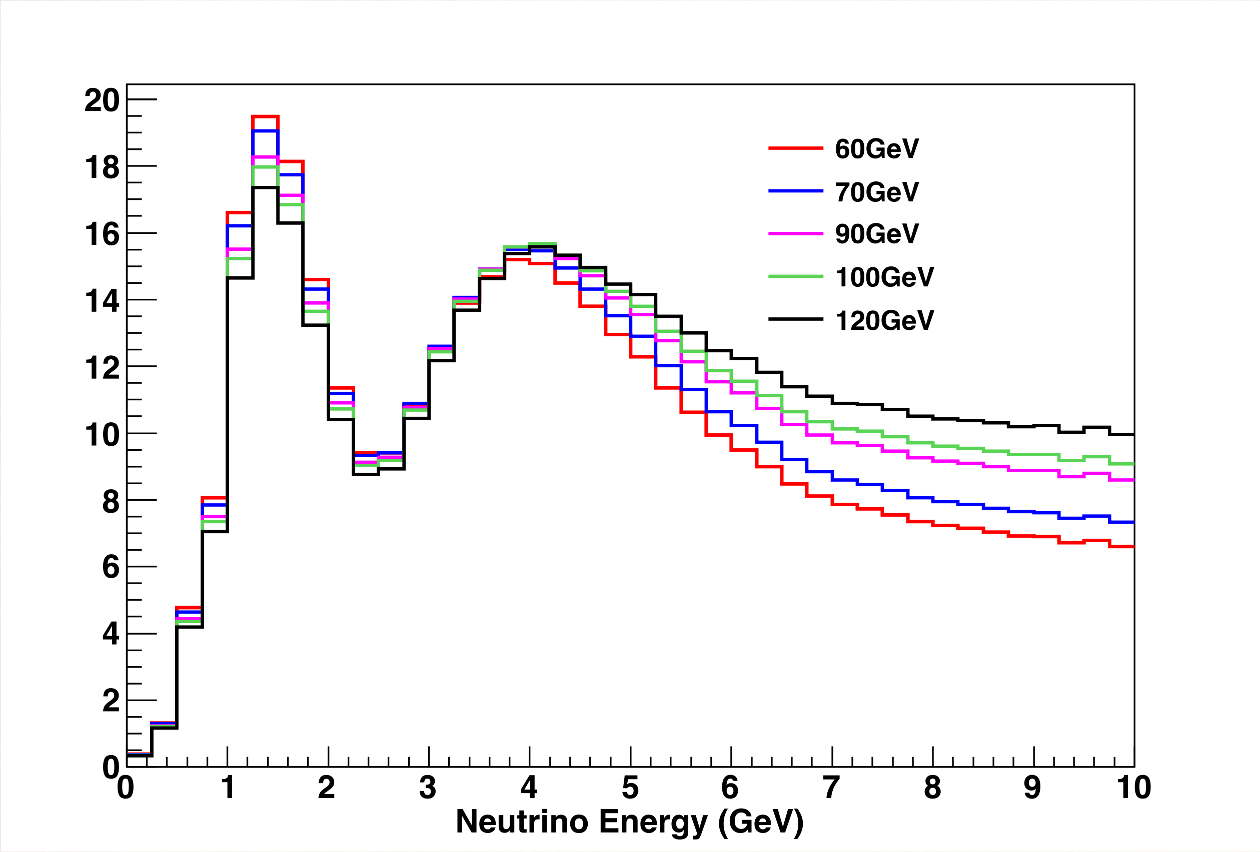


Figure of Merit from Fast MC — Disappearance — FHC

Signal/Sqrt(Signal+Background), nu_mu disappearance



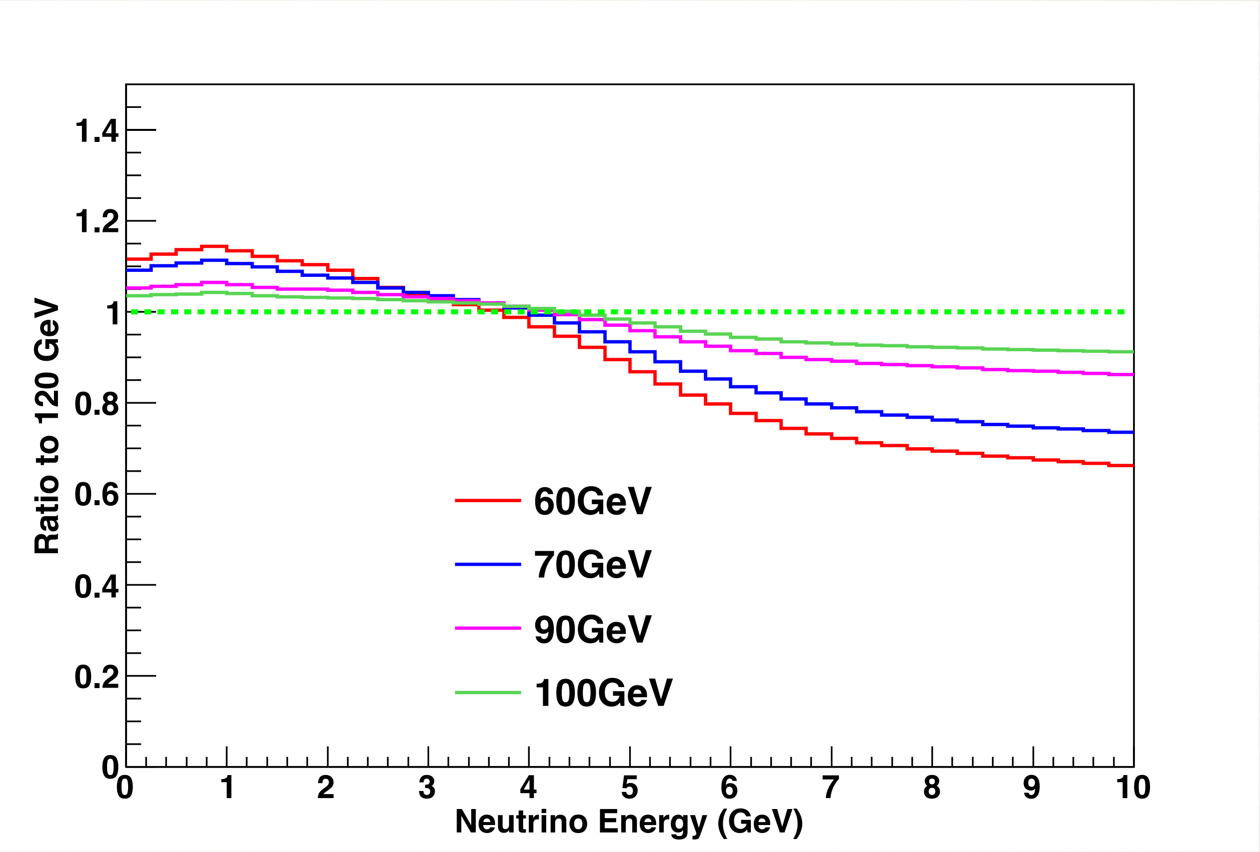
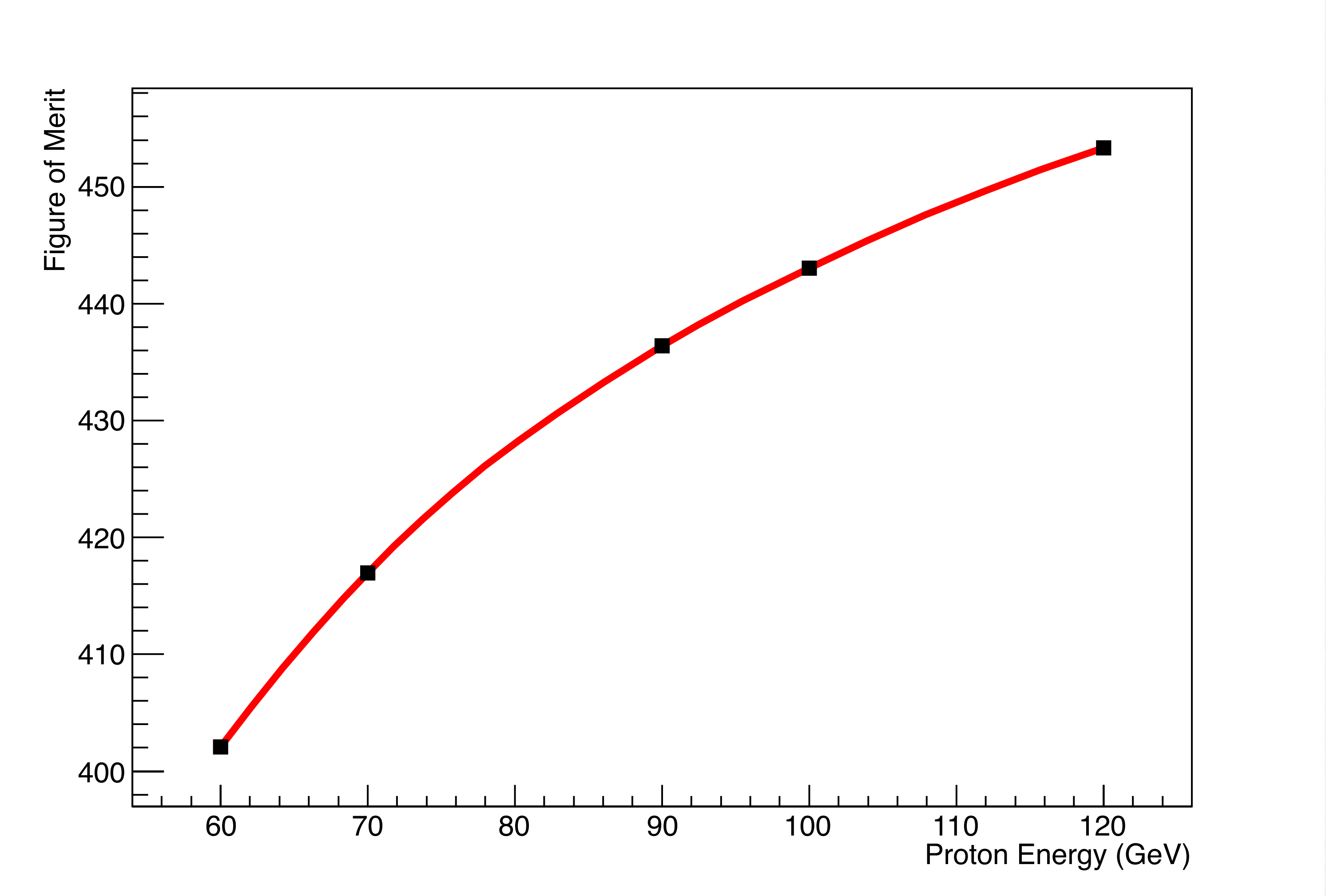


Figure of Merit vs Proton Energy — Disappearance —FHC

Integrated Figure of Merit - Disappearance



According to this metric, high proton energies are optimal for a muon neutrino disappearance measurement