

# Analyzing the Nuclear Recoil System in Neutrino-Nucleus Reactions

T.W. Donnelly<sup>1</sup>, K. Mahn<sup>2</sup>, J. Morrison<sup>2</sup>, J.W. Van Orden<sup>3</sup>

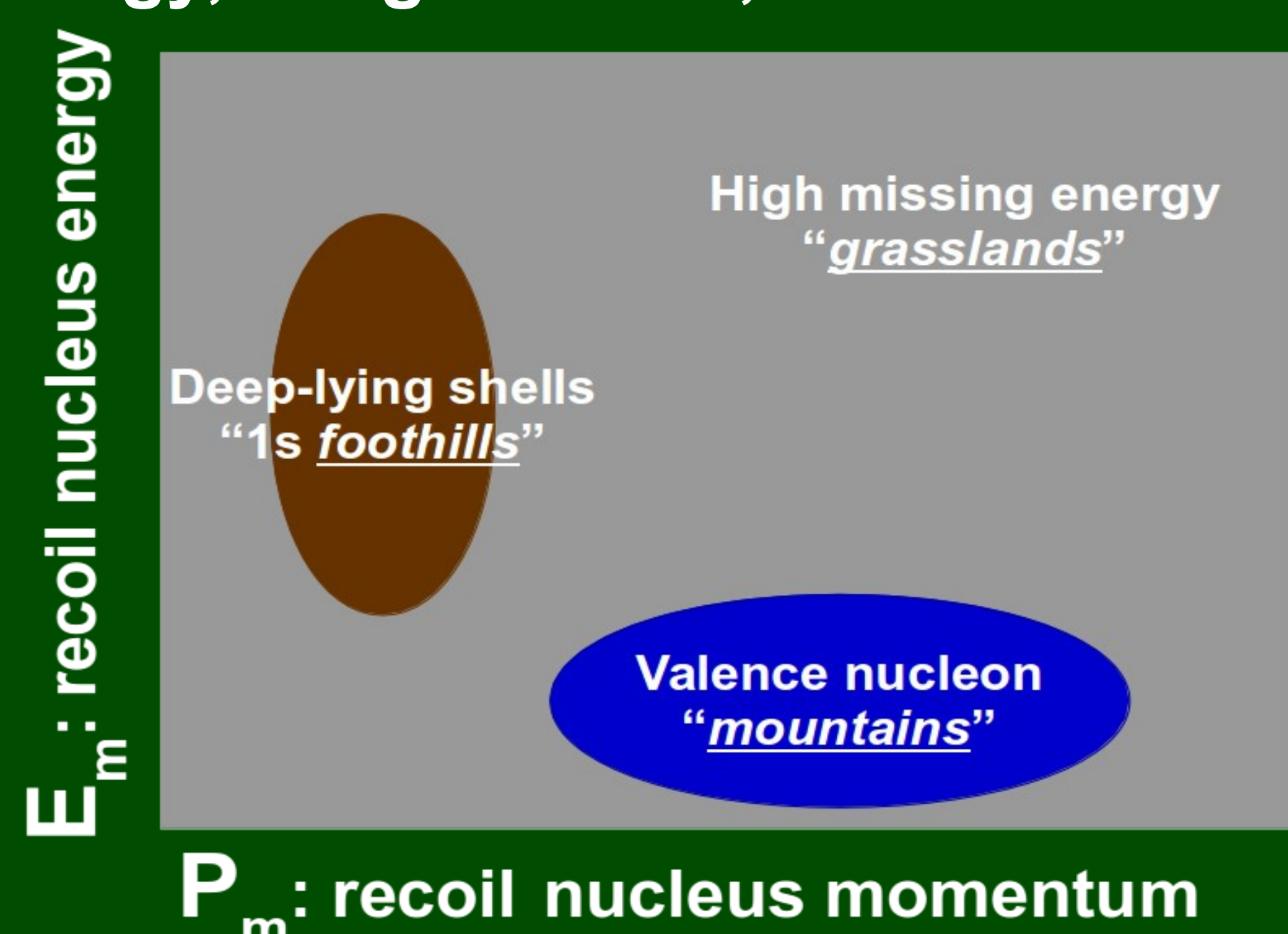
<sup>1</sup>Massachusetts Institute of Technology, <sup>2</sup>Michigan State University

<sup>3</sup>Old Dominion University



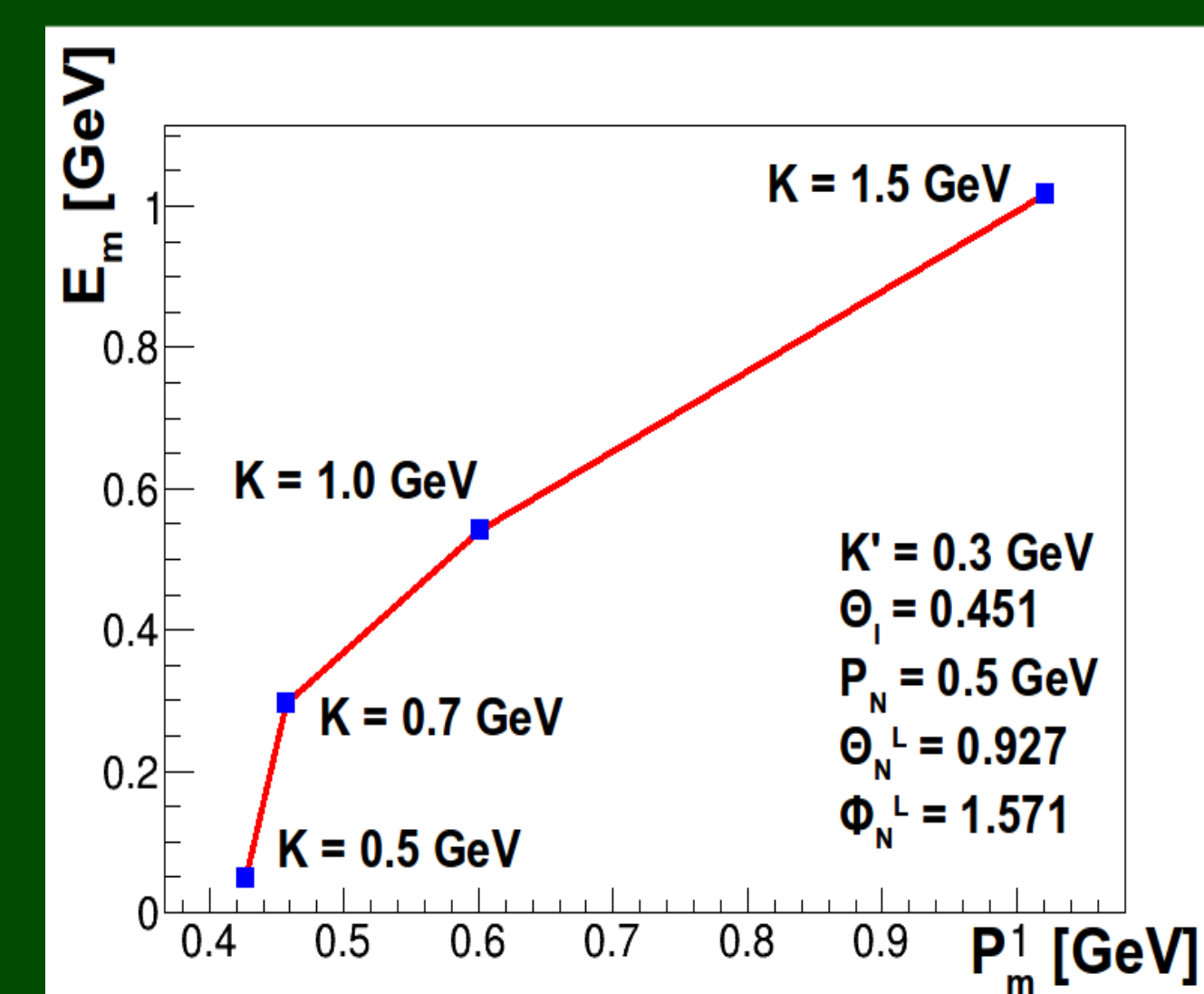
## Background

There are three main contributions to the neutrino-nucleus cross section. The valence “mountains” contribute about 40% of the cross section, while the deep-lying shells, or “1s foothills,” add about 30%. These regions are better understood from a nuclear theory standpoint. The rest is contributed by the high missing energy, or “grassland,” events.



## Phase Space “Rivers”

As you vary the incoming neutrino energy, but hold the muon and ejected nucleon kinematics fixed, tracks are traced out in the  $E_m$ - $p_m$  phase space.

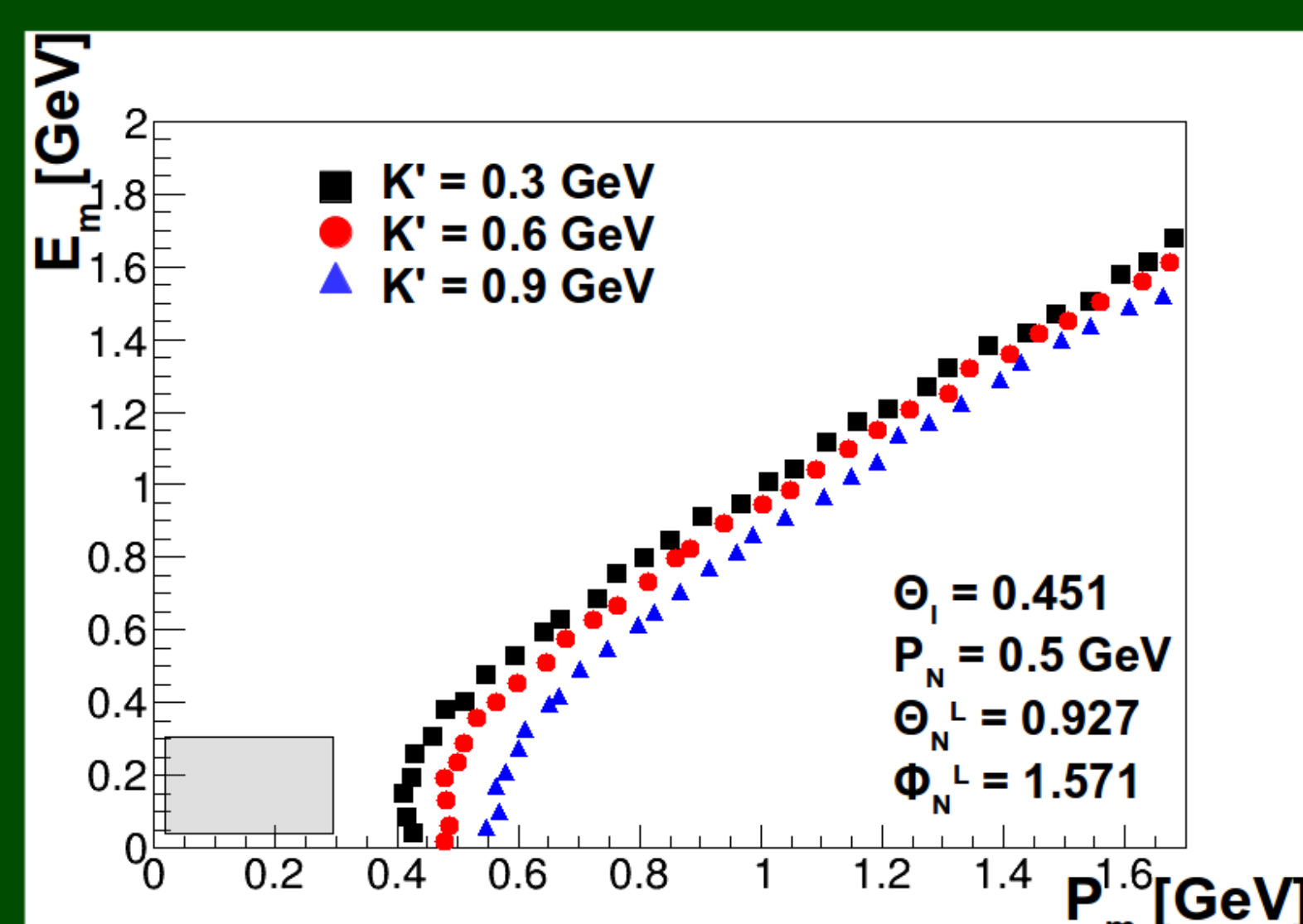


### Kinematic Variables:

- $K$  – neutrino momentum
- $K'$  – muon momentum
- $\Theta_i$  – muon polar angle
- $P_N$  – nucleon momentum
- $\Theta_N^L$  – nucleon polar angle
- $\Phi_N^L$  – nucleon azimuthal angle

Momentum in GeV  
Angles with respect to beam direction

## Muon Momentum



Regardless of what observable is being manipulated, as you increase the momentum of the neutrino, the rivers become more linear and quickly enter the grasslands region.

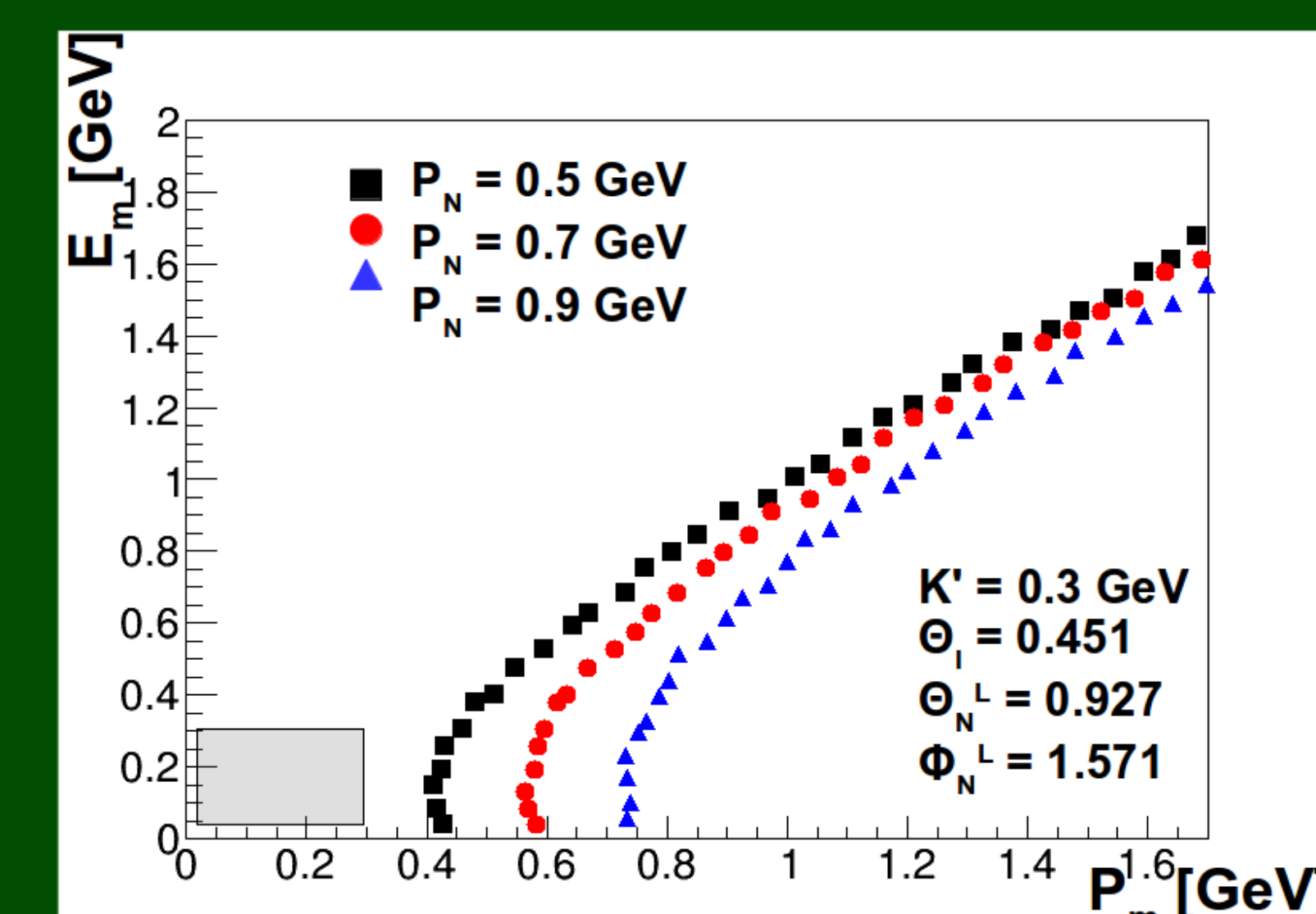
## General Remarks and Conclusions

The points represented by the black squares are the same for each plot. The grey box represents the mountains and foothills regions. The parameters that are fixed are listed in the corner of each plot.

More work will need to be done in order to better understand the nuclear physics of the grasslands region and how the neutrino-nucleus cross section is distributed across these interactions.

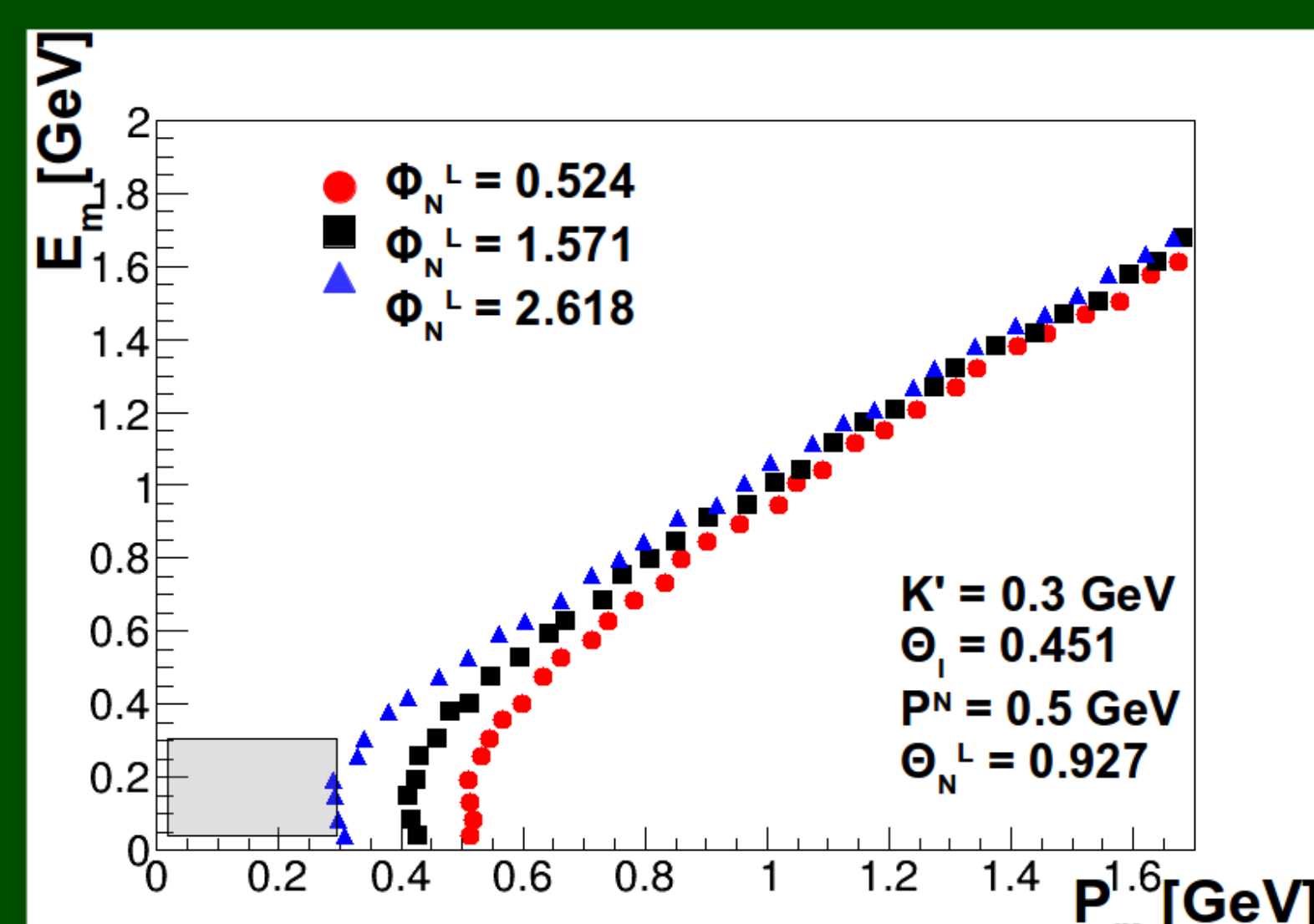
In order for experiments to probe the phase space covered by the valence mountains, energy sensitivities will likely need to be pushed lower. More studies will need to be performed to find how low the sensitivities must be.

## Proton Momentum



Even for low neutrino momentum, most of the rivers that have been calculated lie above the valence mountain region, where the bulk of the neutrino-nucleus cross section lives.

## Proton Azimuthal Angle



## Proton Polar Angle

