



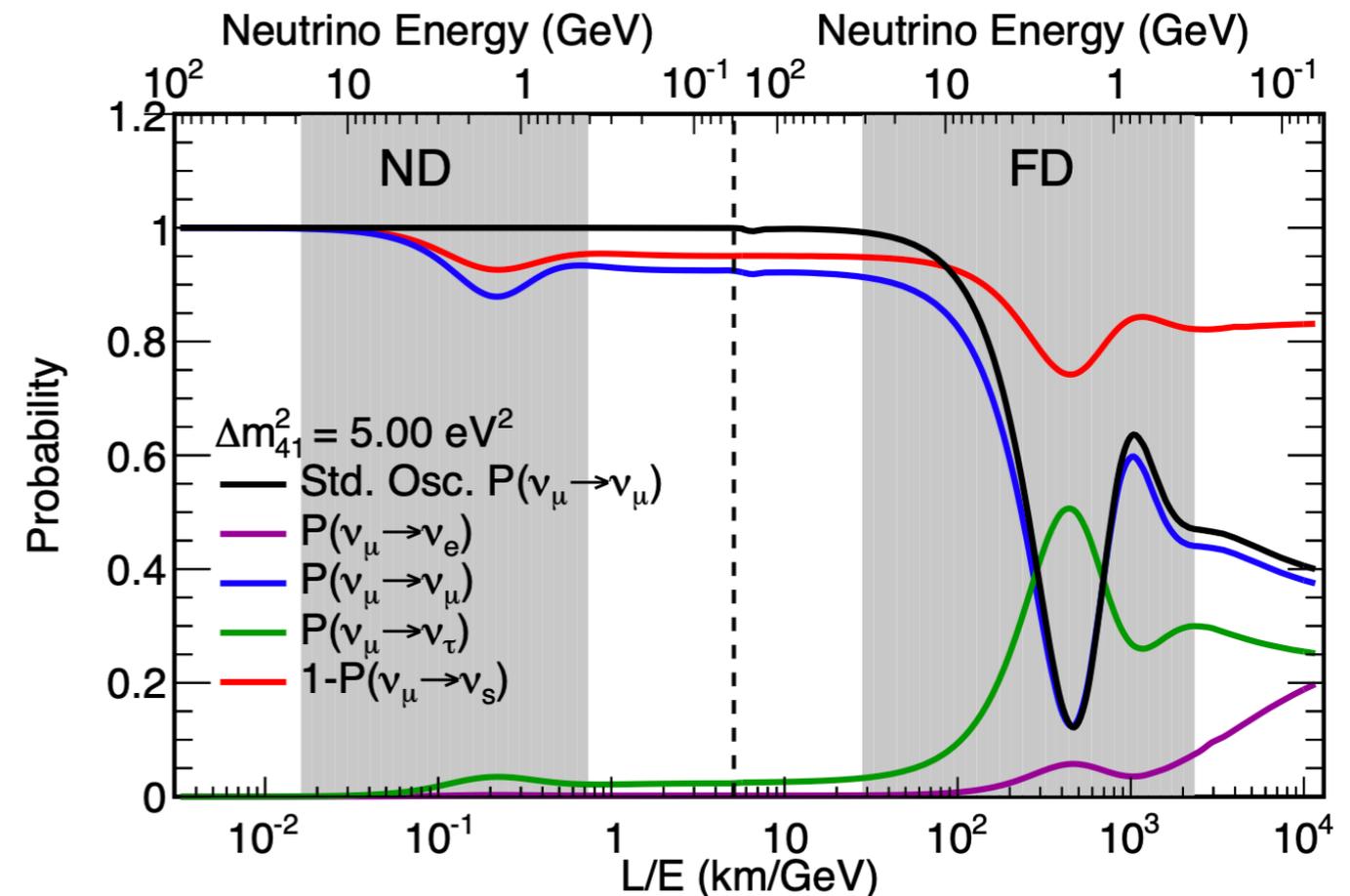
# **BSM ND Analyses: Simulation Files for SBL Oscillations**

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ND Software Integration Meeting  
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# Intro

<https://indico.fnal.gov/event/11417/#1-dune-1-over-e-plots-for-a-31>

- ‘Standard’ 3-flavor oscillations evolve over much longer distances than the DUNE ND, so we don’t need to consider oscillations over these short baselines.
- Some BSM models, such as a sterile neutrino with  $\Delta m^2 > O(0.1 \text{ eV}^2)$ , will have oscillations which may be observable at the ND.
- In order to understand these oscillations and develop analyses, we will require new simulation samples to correctly apply oscillations over ND baselines.



$\Delta m_{41}^2 = 5.00 \text{ eV}^2$   
— Std. Osc.  $P(\nu_\mu \rightarrow \nu_\mu)$   
—  $P(\nu_\mu \rightarrow \nu_e)$   
—  $P(\nu_\mu \rightarrow \nu_\mu)$   
—  $P(\nu_\mu \rightarrow \nu_\tau)$   
—  $1 - P(\nu_\mu \rightarrow \nu_s)$

$dm_{21} = 7.54e-05$   
 $dm_{32} = 2.43e-3$  //positive sign implies normal hierarchy  
 $th_{12} = 0.588$   
 $th_{13} = 0.154$   
 $th_{23} = 0.722$   
 $th_{14} = 0.16$   
 $th_{24} = 0.2$   
 $th_{34} = 0.6$   
 $\delta_{13} = 0$   
 $\delta_{14} = 0$   
 $\delta_{24} = 0$   
 $N_e = 1.4$  //matter effects

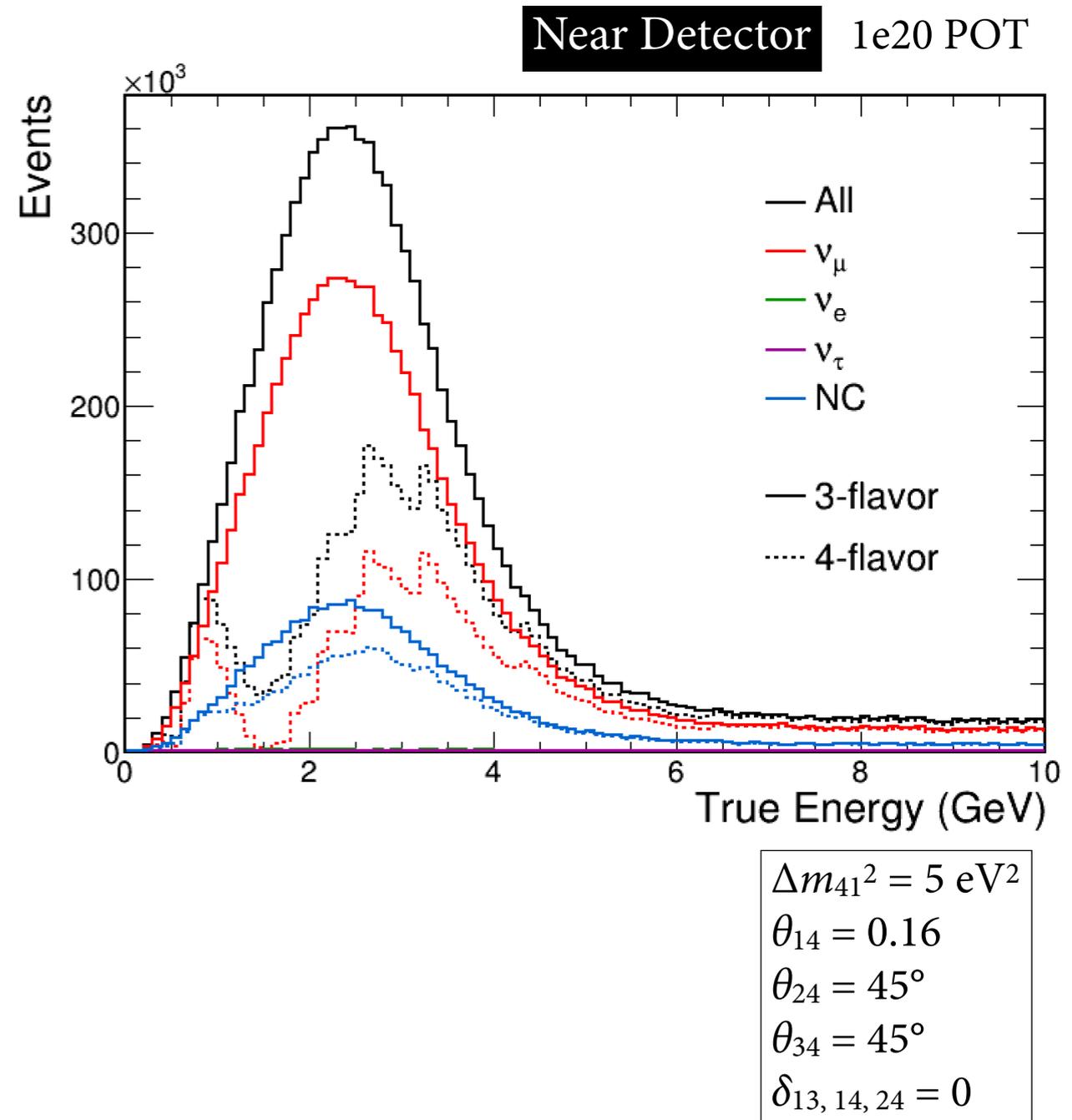
► Parameters used  
in 3+1 model

# CAFAna-Based Analysis

- The current DUNE sterile/LED analysis uses the GLOBES framework.
  - Inclusion of shape systematics in GLOBES is challenging.
- In parallel, we are developing a sterile analysis in the CAFAna framework.
  - CAFAna was developed for NOvA analyses and used by the LBL group for the DUNE TDR studies.
  - Designed, among other things, to allow a simpler implementation of systematics uncertainties and to be a unified framework for all analyses.
  - Utilizes a standard data format, CAF (Common Analysis Format/File).
- See update at the January Collaboration Meeting:  
<https://indico.fnal.gov/event/46502/timetable/#178-sterileled-status-report>

# ND Oscillations

- I have developed the oscillation machinery to include ND oscillations in CAFAna.
- Using the simulation files produced by the LBL group for 3-flavor oscillation studies in the TDR, produced oscillated ND spectra.
  - Example spectra show very large sterile oscillations to demonstrate the effect of altering the parameters.
- Can currently only apply SBL disappearance, since we don't have the required 'appeared' ND files.



# Required Samples

- In order to apply full ND oscillations, we need files of ‘appeared’  $\nu_e/\nu_\tau$ s in the ND, which the framework can then use when applying oscillations in the analysis.
- We are still working out exactly what we will need, and any discussion at this meeting will be very useful in understanding what is possible.
- Two ways of potentially generating the required simulation:
  - swap beam  $\nu_\mu$ s for neutrinos of different flavors, but the exact same properties (energy, momentum etc);
    - this is how the LBL oscillations are applied, but pile-up isn’t an issue at the FD;
    - probably just a subset (likely one per bunch) would be swapped at the ND.
  - simulate single neutrinos of the new flavors and overlay onto the existing  $\nu_\mu$  interactions in the simulation.
- Ideally at least 1 year of ND running for each sample would be required.

# Required Detectors

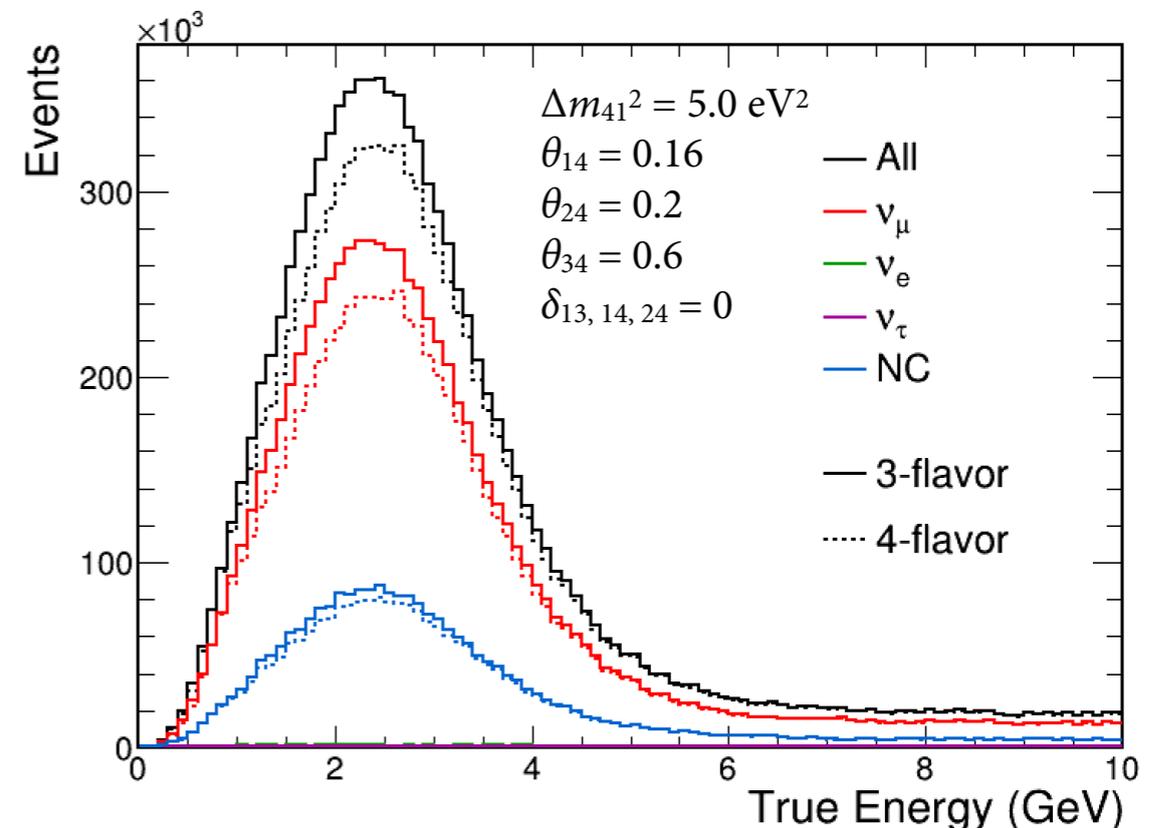
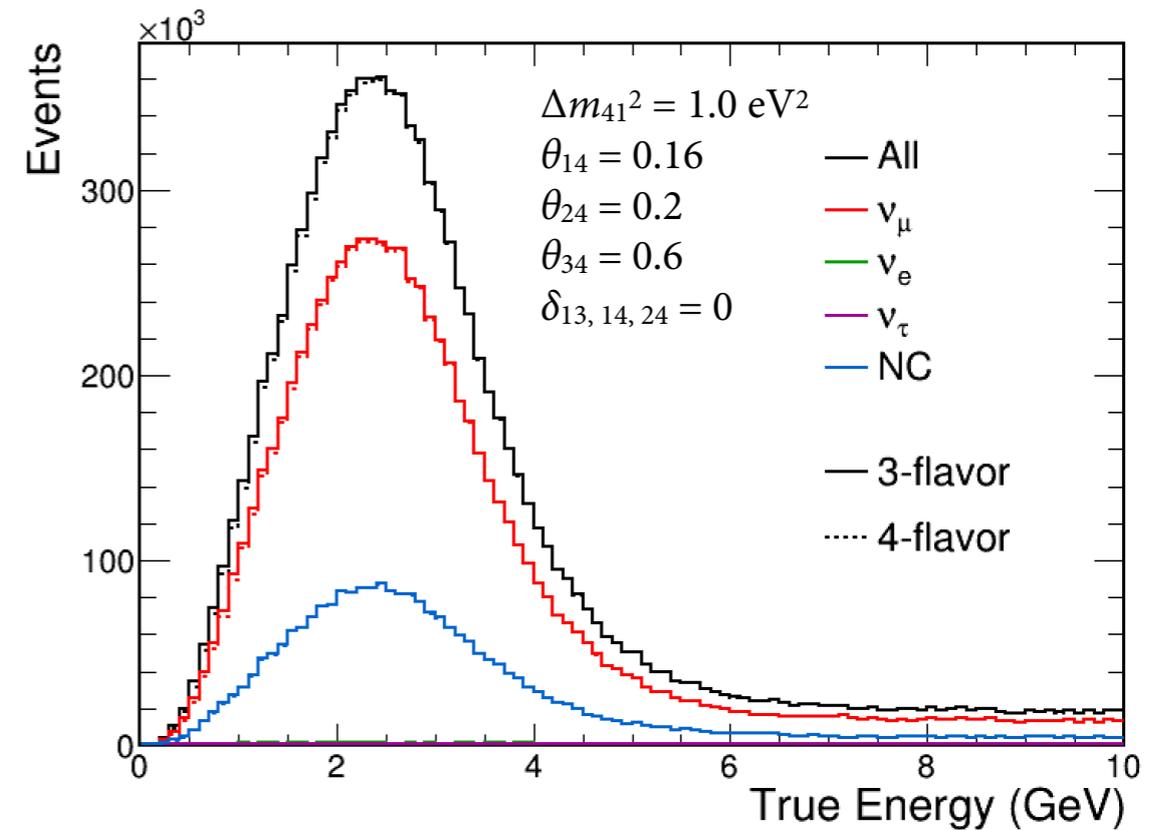
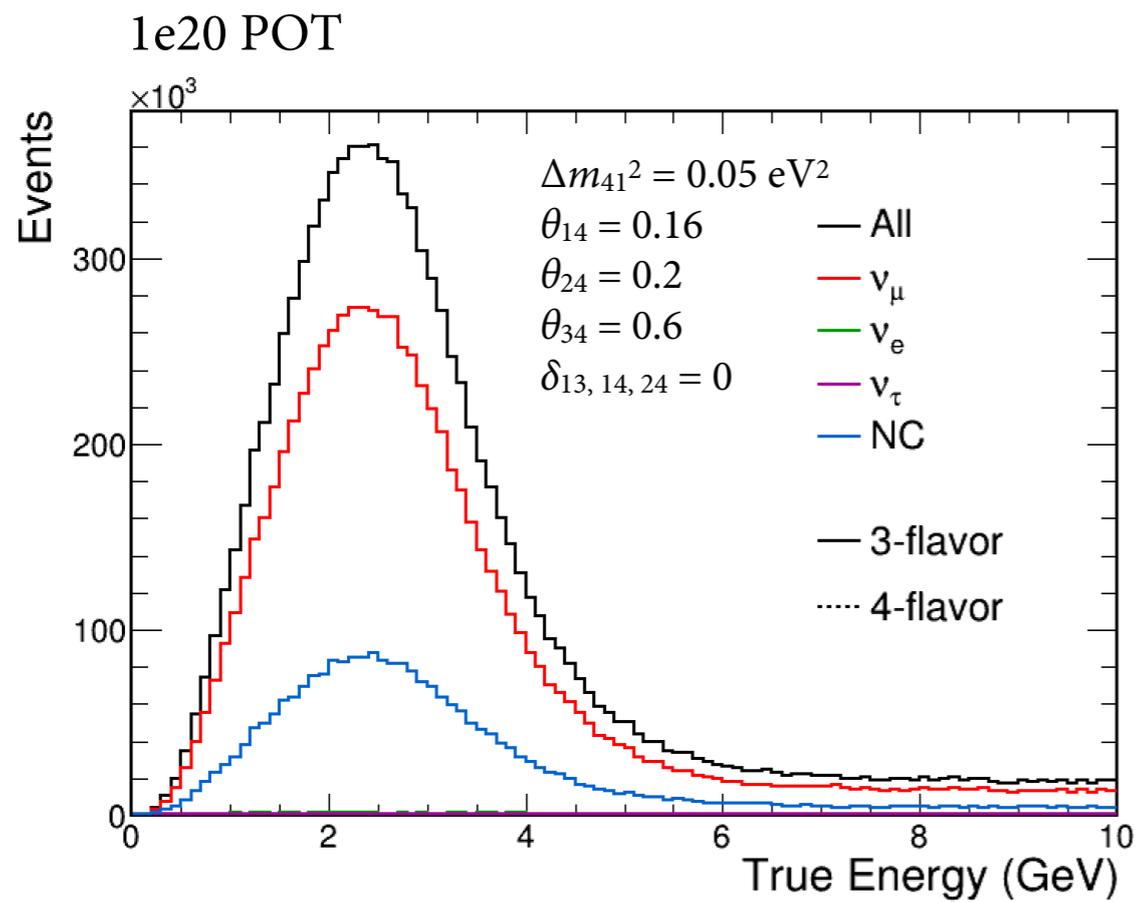
- In addition to the generated neutrinos, if possible we'd like to have the detector simulation for some of the subsystems, depending on what is available and how the simulation is typically made.
- At least the ND-LAr would be a good start. If we could also have any other current simulation (e.g. ND-GAr and/or/SAND) we would definitely take it!

# Discussion

- Are there any other groups who may be interested in these samples, to ensure we're making the most versatile data?
- What is the preferred way of including these oscillated neutrinos at the ND?
  - Is there machinery available for overlaying the neutrinos on top of the  $\nu_\mu$  interactions?
- What sample sizes are typical in these productions? What would be available?
- Which detector simulations are available and typically included?

# More!

# Oscillations Validation — ND



- Oscillator spectra (all events) for different values of the new sterile mass splitting.
- Near Detector.