FLUX FITTING WITH DUNE-PRISM

3RD DUNE NEAR DETECTOR WORKSHOP

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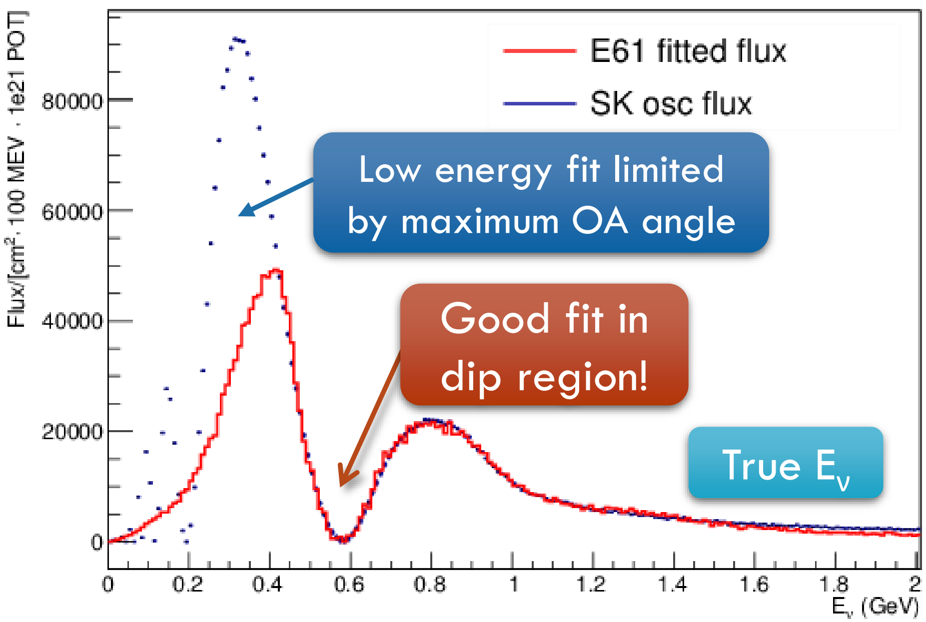
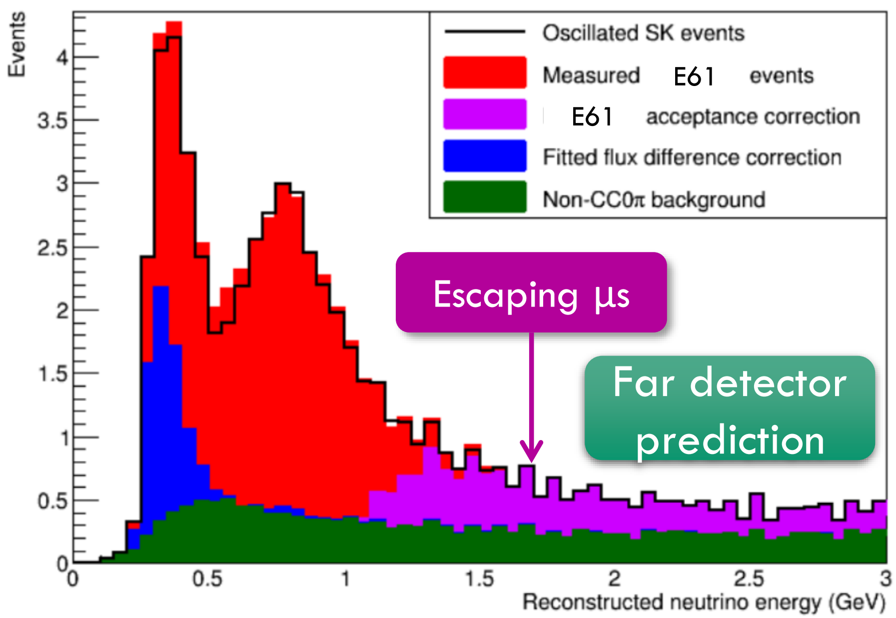
INTRODUCTION

- Exposing the same detector to a **range of angles** with respect to the beam centre allows for the **flux** and **interaction models** to be **decoupled**.
  - This **additional informatio**n can be used to better **constrain** interaction models (Guang's talk).
- For **oscillation** analyses, linear combinations of data taken at different angles can be used to produce **data-driven predictions** for **far detector observations.**
  - This technique has been extensively studied for T2K/T2HK and shown to give predictions that are **robust** against neutrino **interaction mis-modelling**.
- In this talk I will show initial studies of **linear combinations** using **DUNE** fluxes.
  - Focus on disappearance, for now…

FLUX FITTING WITH J-PARC E61 (NUPRISM)

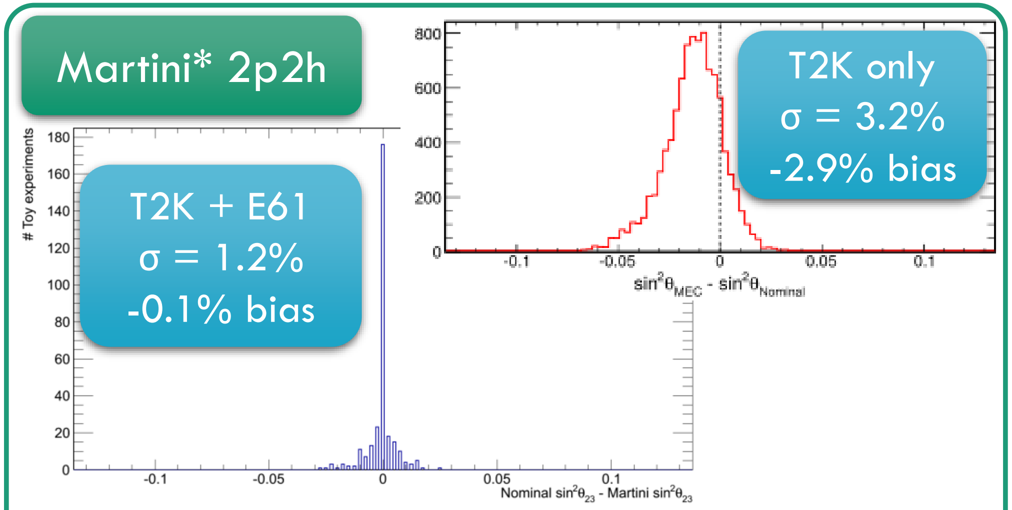
- Background, flux and acceptance corrections necessary for SK prediction.
  - Significant uncertainty cancellation in neutral-current background subtraction.
  - In oscillation dip region prediction is dominated by **E61 data**.
- Since the far detector is located off-axis, a moveable near detector can access fluxes that peak at energies higher than the oscillation maximum.
  - Useful for subtracting high energy tail.



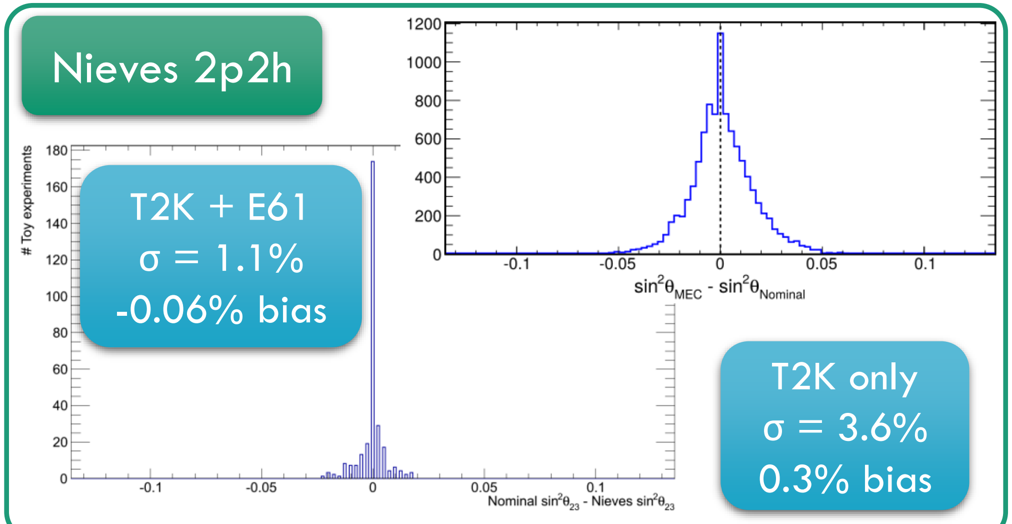


J-PARC E61 DATA-DRIVEN ANALYSIS

- Disappearance analysis using off-axis angles combinations is shown to be robust against interaction mismodelling.
    1. Produce fake data with throws of flux and cross-section uncertainties both with and without multi-nucleon effects.
    2. Fit the fake data using interaction model without multi-nucleon contributions.
    - E61 significantly reduces uncertainty and removes bias.
- This is a **data-driven** constraint, independent of model choice.



* “Hacked” model, with Nieves final states.

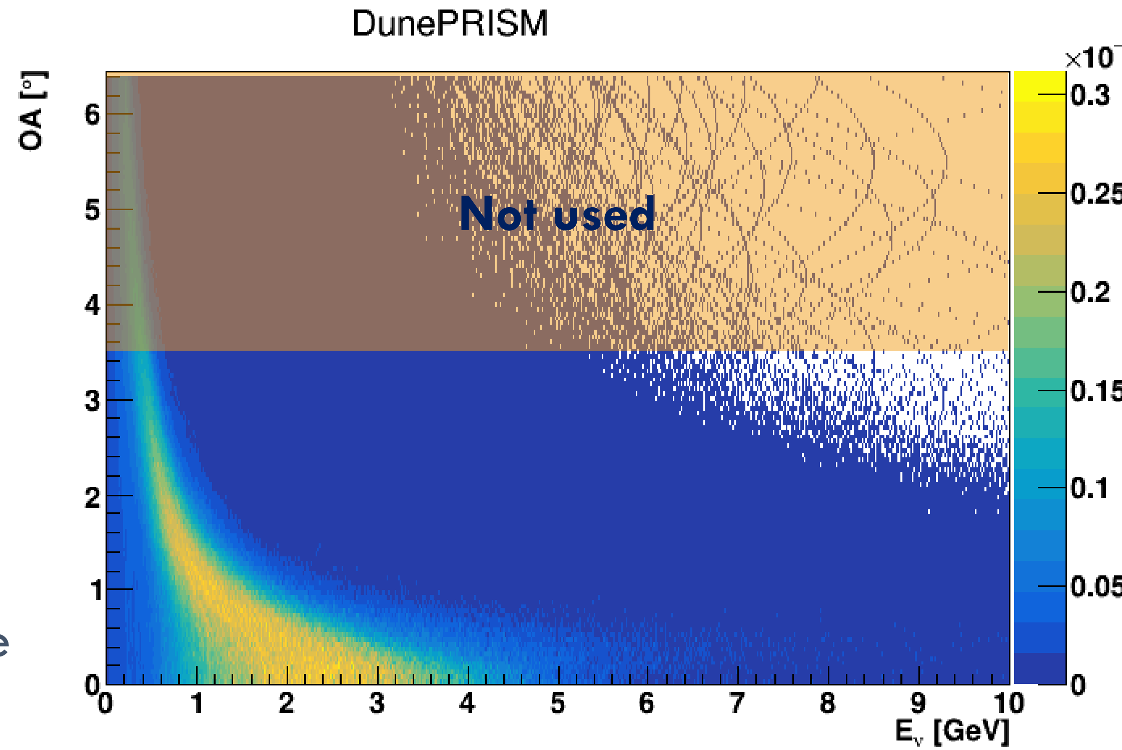


DOES THIS WORK FOR DUNE?

- The linear combinations technique has been **demonstrated** for an **off-axis** experiment in **detailed studies** including flux uncertainties, detector simulation and reconstruction, etc.
- However, the **DUNE** far detector will be positioned **on-axis,** leading to two important differences:
  - The flux is **broad**, spanning **two oscillation maxima.**
    - Linear combinations need to reproduce more complex structure.
  - It is not possible to expose the near detector to a flux peaking at higher energies than the far detector.
    - Can't go more on axis than on-axis…
- This is an initial study to understand how well this technique will work on DUNE.

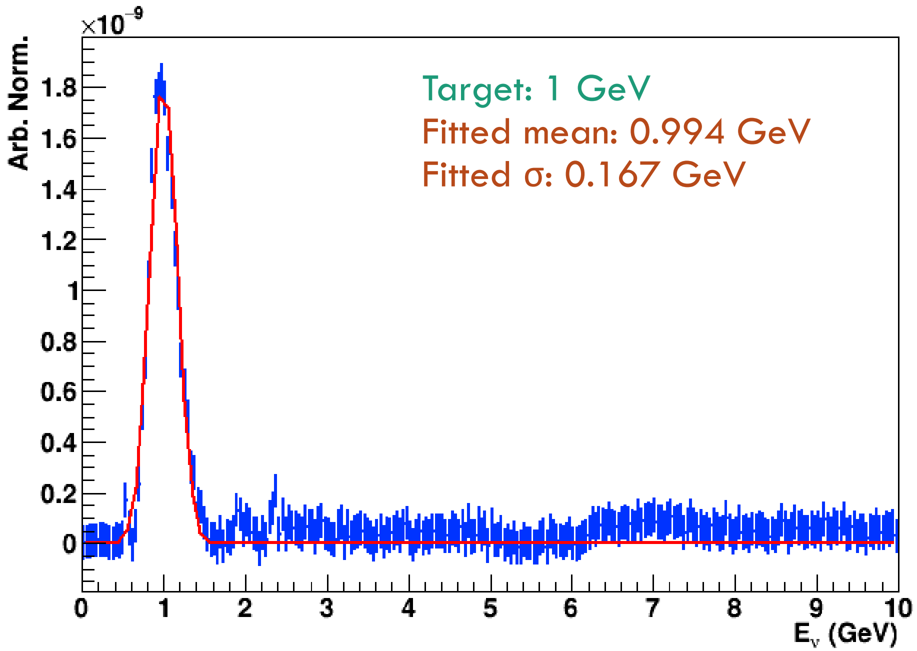
FLUX FITTING

- Produce ν_μ fluxes for off-axis angles from 0° to 3.5° in 0.05° steps.
  - Each step corresponds to a 50 cm slice in the detector, spanning a total of 35 m.
  - Caveat: I have a limited amount of beam simulation statistics, so the same files are used to produce the fluxes at different angles – non-trivial statistical dependence!
- Assign one coefficient to each off-axis slice.
  - 70 coefficients in total.
- Fit the coefficients with χ^2 minimisation so that linear combination reproduces desired spectrum.
- Regularise the fit by requiring that adjacent coefficients have similar values.

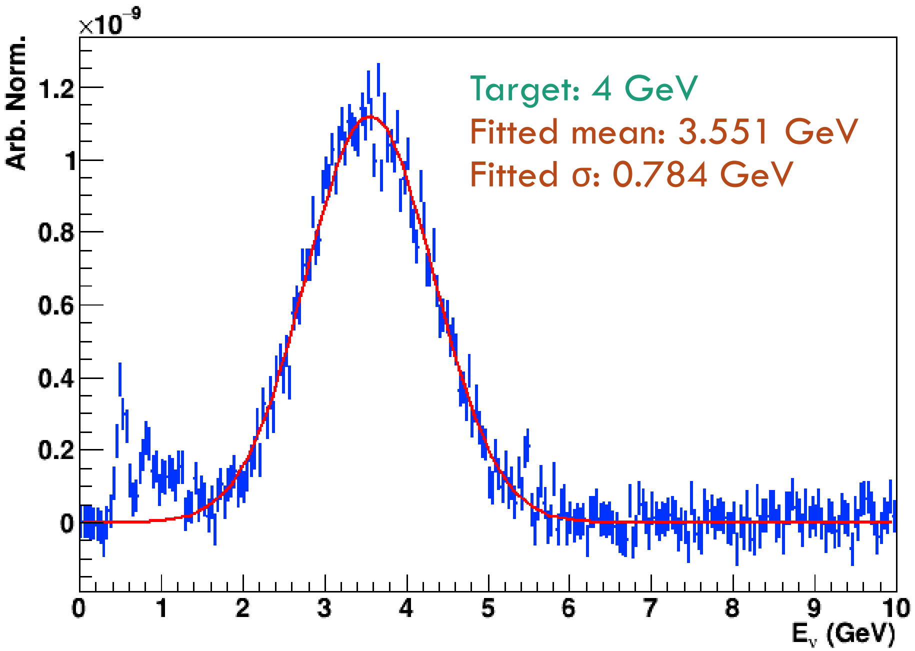


GAUSSIAN FITS

- Start by producing pseudo-monochromatic beams.
  - Linear combinations that add up to a Gaussian flux.
- Target Gaussian means ranging from 0.5 to 6 GeV with 10% σ.

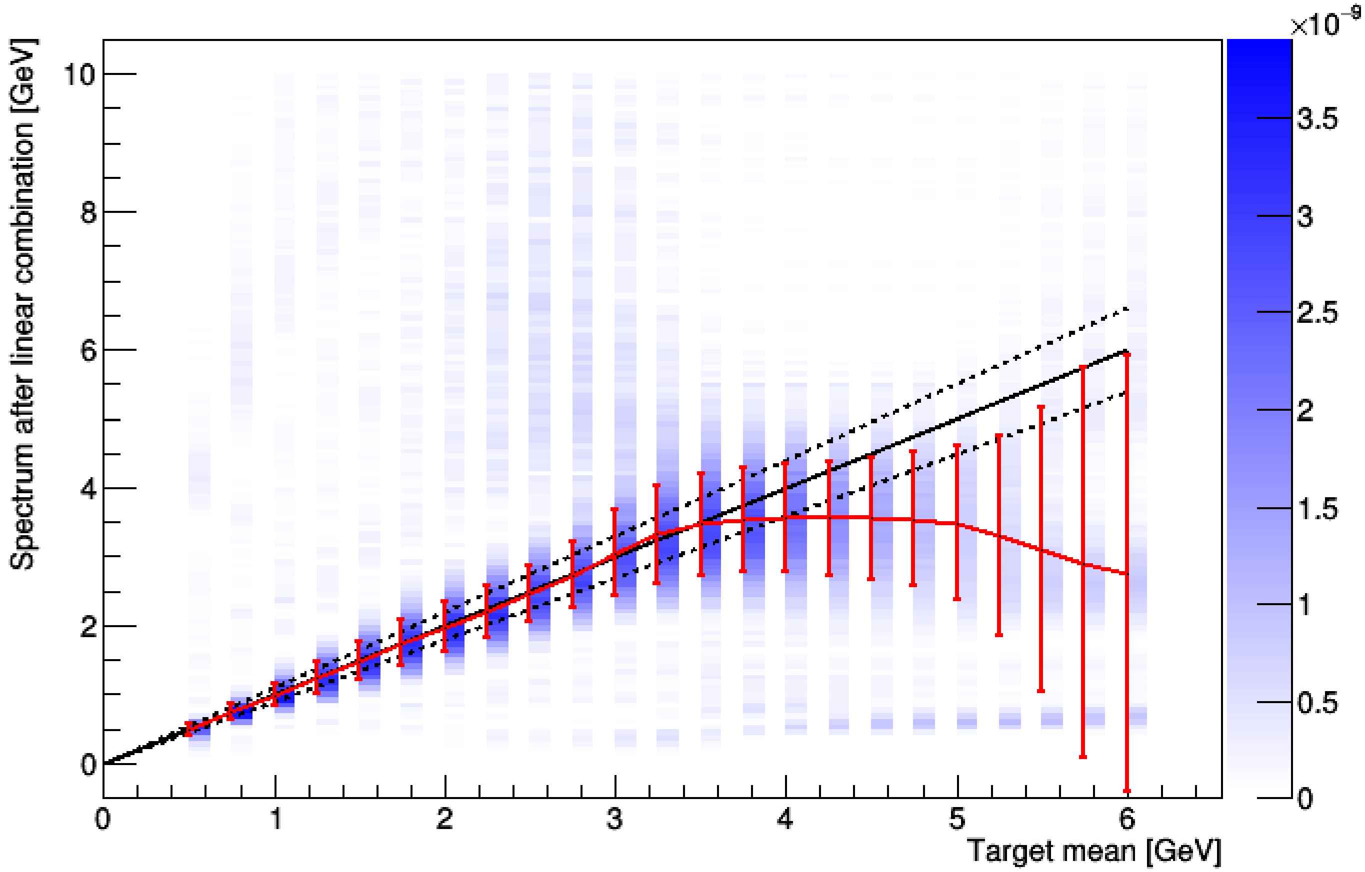


Very nice fits for low energies.



Fits start breaking down at ~3.5 GeV.
In this case flux still looks Gaussian,
but target mean is badly missed.

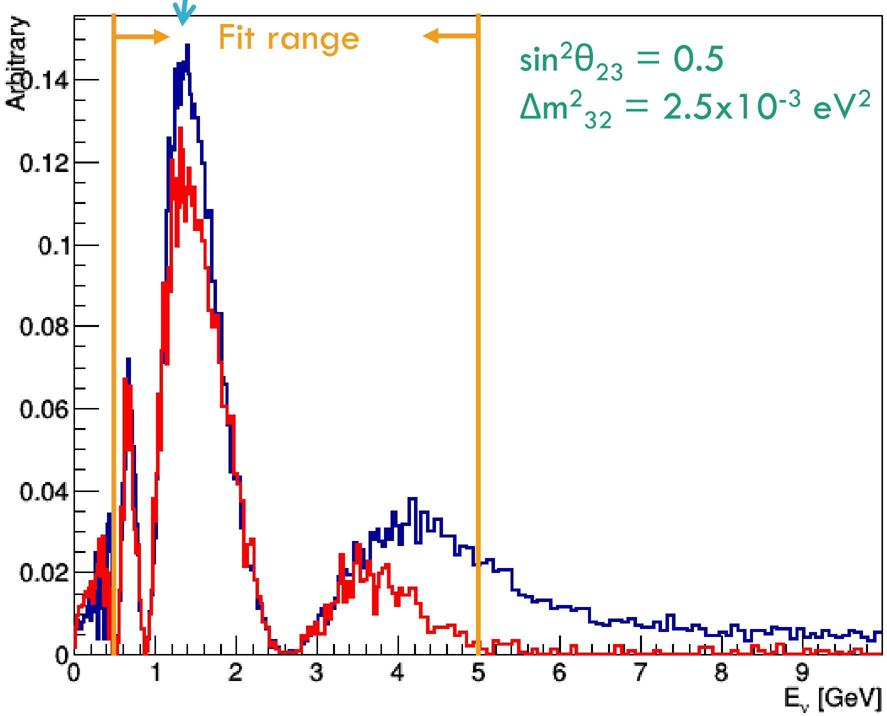
GAUSSIAN FITS

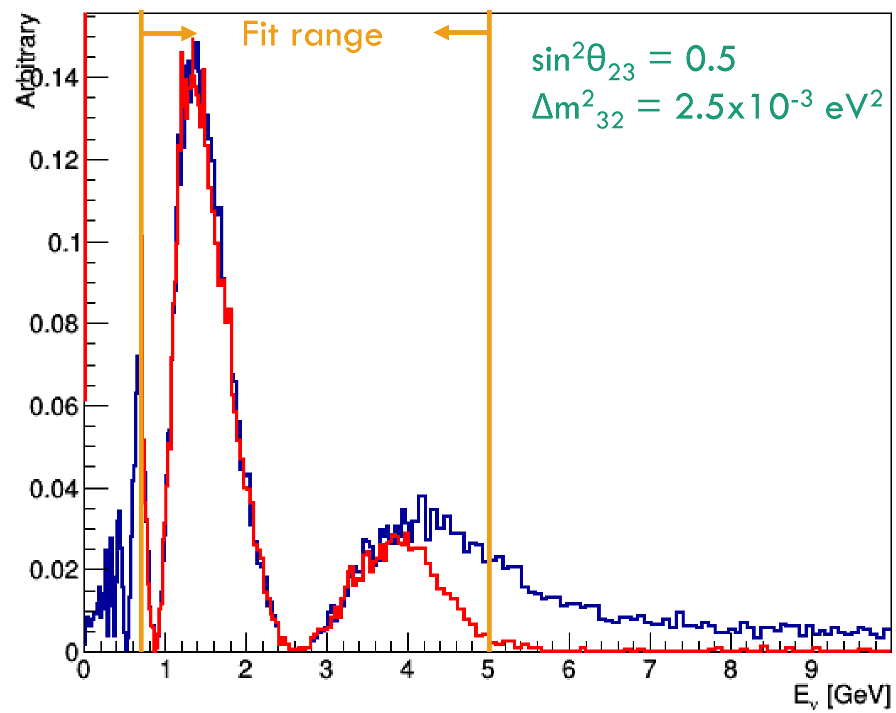


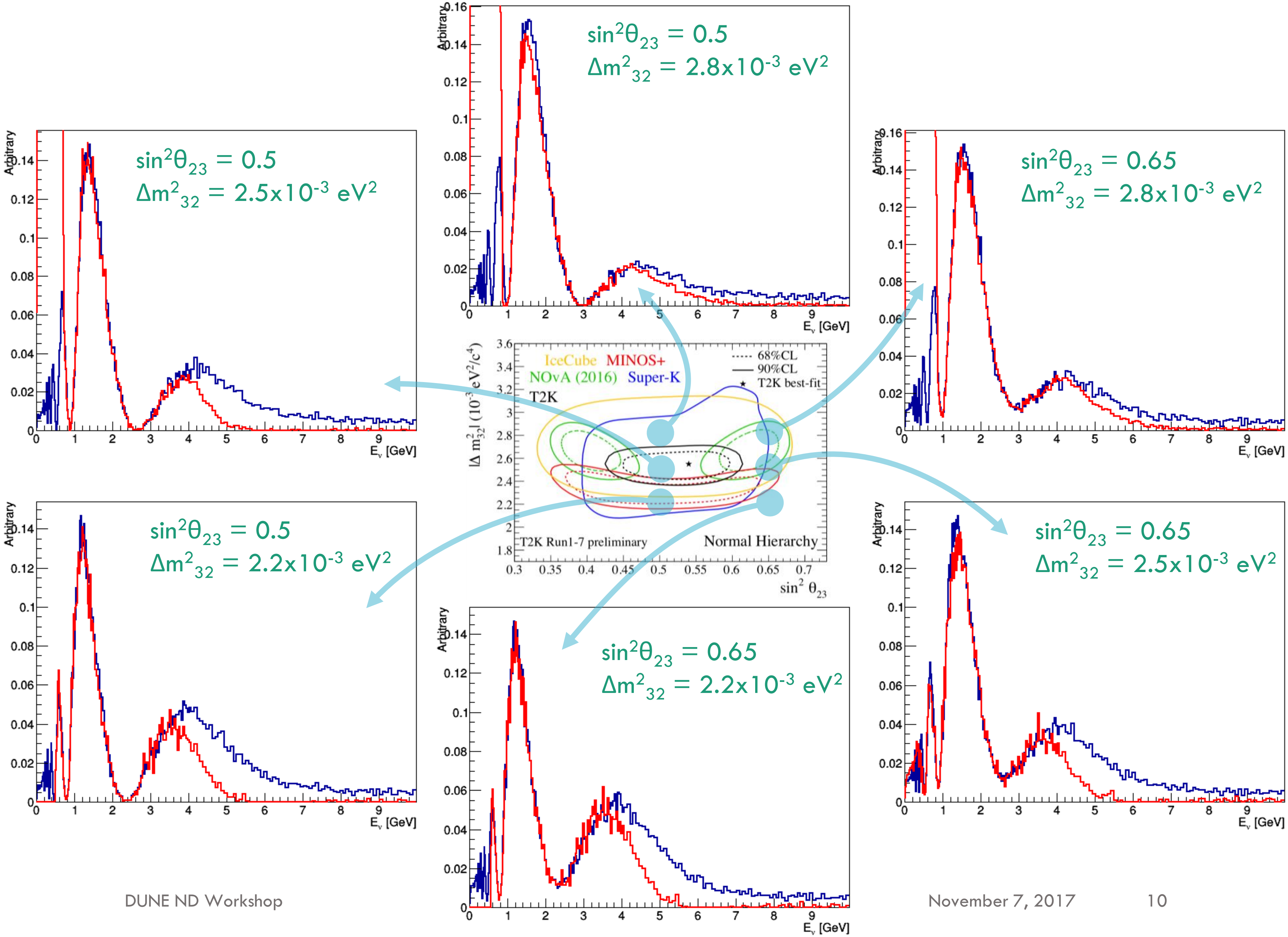
- Target Gaussian parameters in black, fitted in red.
- Indicates we might be able to resolve features up to ~3.5 GeV.

OSCILLATED SPECTRUM FITS

- Both oscillation minima can be fit simultaneously.
  - But there seems to be a trade-off between the peaks.
    - If the linear combination matches the low energy peak, it tends to undershoot the high energy peaks.
    - This can probably be taken care of with model dependent corrections.
      - Needs further study…







$\sin^2\theta_{23} = 0.5$
$\Delta m^2_{32} = 2.5\times10^{-3}\ eV^2$
$\sin^2\theta_{23} = 0.5$
$\Delta m^2_{32} = 2.8\times10^{-3}\ eV^2$
$\sin^2\theta_{23} = 0.65$
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$\sin^2\theta_{23} = 0.65$
$\Delta m^2_{32} = 2.5\times10^{-3}\ eV^2$
Arbitrary
E_ν [GeV]
IceCube MINOS+
NOvA (2016) Super-K
T2K
68%CL
90%CL
T2K best-fit
T2K Run1-7 preliminary
Normal Hierarchy
$|\Delta m^2_{32}|\ (10^{-3}\,eV^2/c^4)$
$\sin^2\theta_{23}$

CONCLUSIONS

- The technique of linearly **combining off-axis samples** developed at the J-PARC E61/NuPRISM greatly reduces **model dependence** in neutrino **oscillation analyses.**
- While the technique was originally developed for an off-axis far detector configuration, initial studies indicate that the method **works well** for the **DUNE on-axis configuration.**
- In particular:
  - Pseudo-**monochromatic** fluxes can be obtained up to ~3.5 GeV.
  - The two **oscillation maxima** can be **simultaneously fit** for a very wide range of ν_μ disappearance parameters.
- More work is needed to:
  - Understand in detail the **trade-off** between fitting different features in the spectrum;
  - Develop model-dependent **corrections** to make up for shortcomings in the flux combinations and detector acceptance – as done in J-PARC E61 analyses;
  - **Integrate** the data-driven predictions in **analysis frameworks.**
    - Including **appearance** channels…