Flux Uncertainty Studies for Hyper-K LBL

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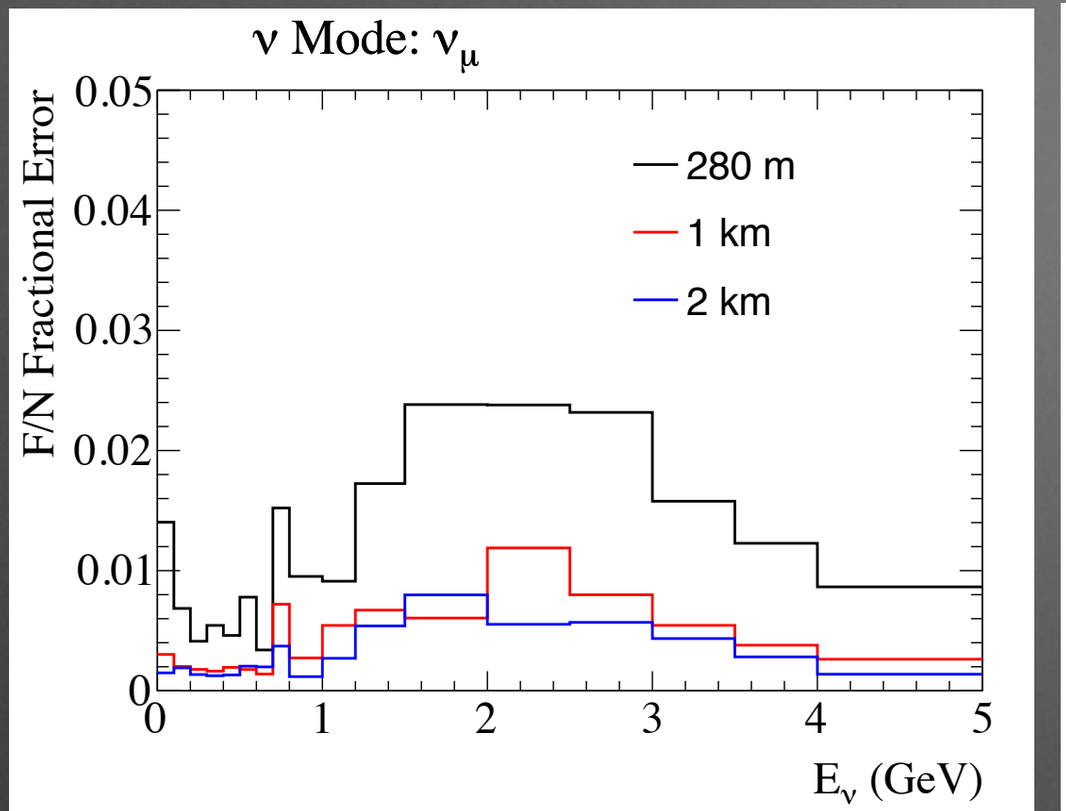
Outline

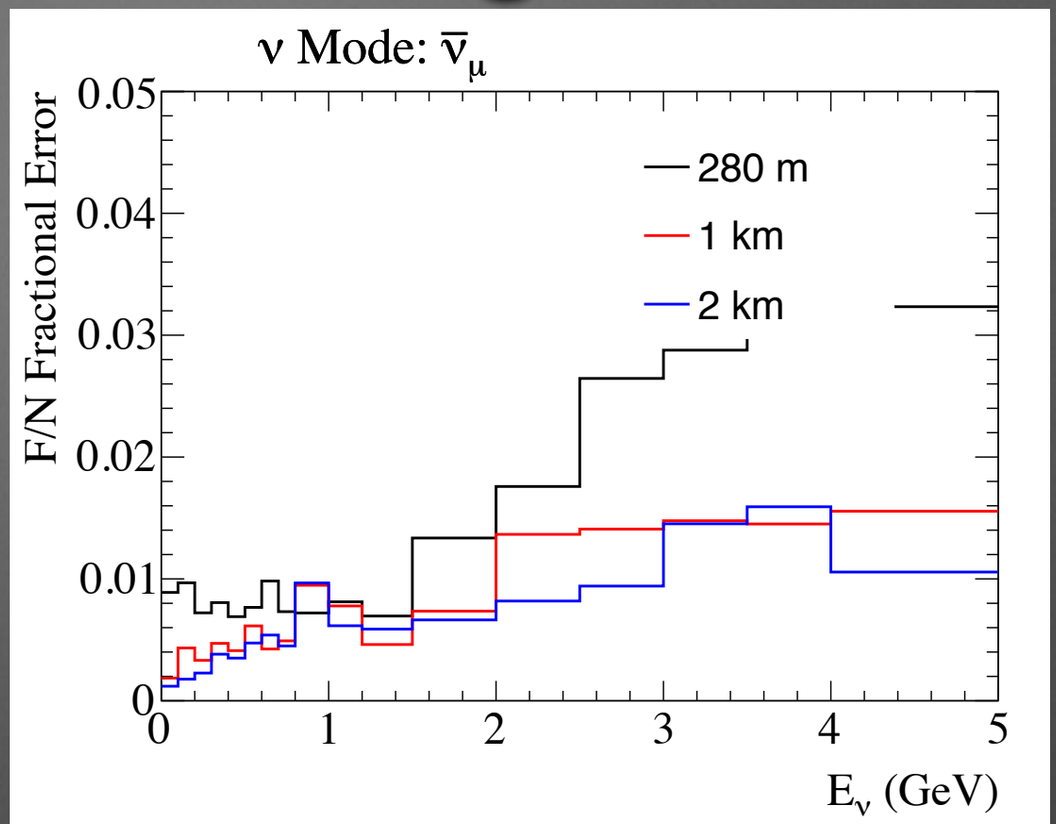
- Study of far-to-near ratio uncertainties
- Baseline to near detectors
- Beam direction uncertainties and near detector position

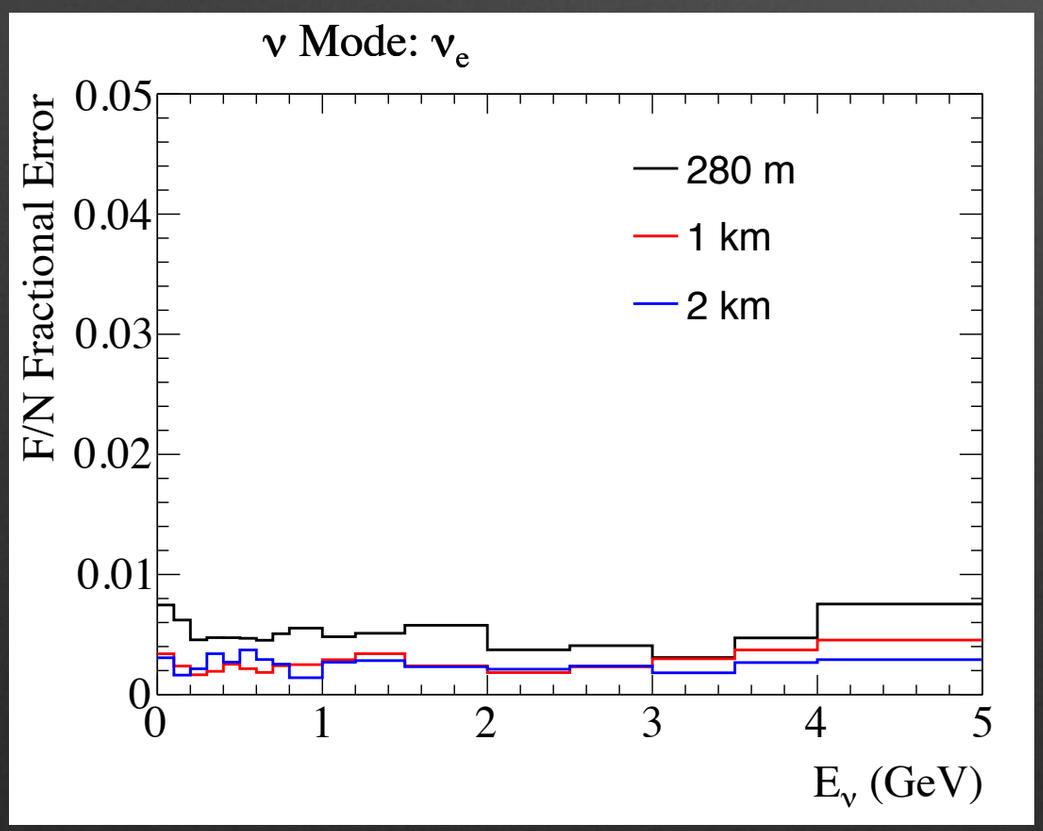
Far-to-Near Ratio Uncertainties

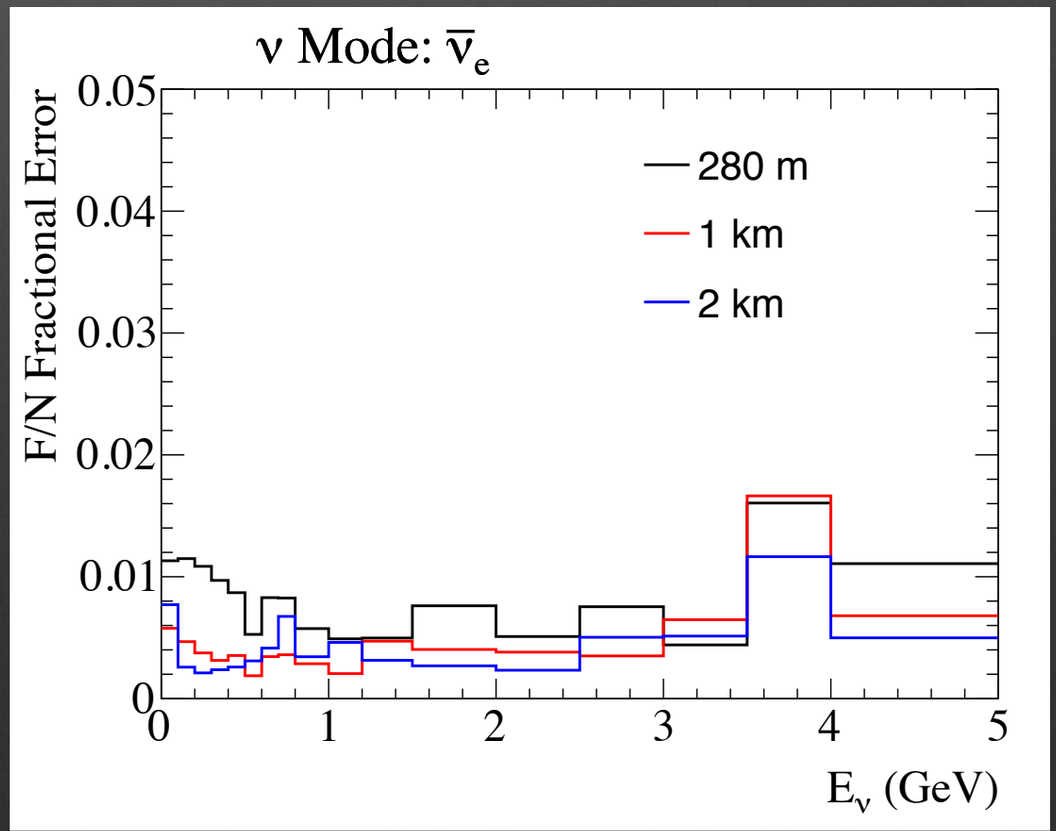
- We have evaluated uncertainties on the far-to-near ratios based on the T2K flux model
  - Hadron production errors are updated assuming replica target data will be available
- Can evaluate the error dependence on baseline to the near detector
- Will show errors split between
  - Errors that are evaluate with reweighting - hadron production, proton beam uncertainty, off-axis angle uncertainty
  - Errors that are evaluated with regeneration fo the flux - horn alignment, target alignment, horn currents

Neutrino Mode Reweighted Errors



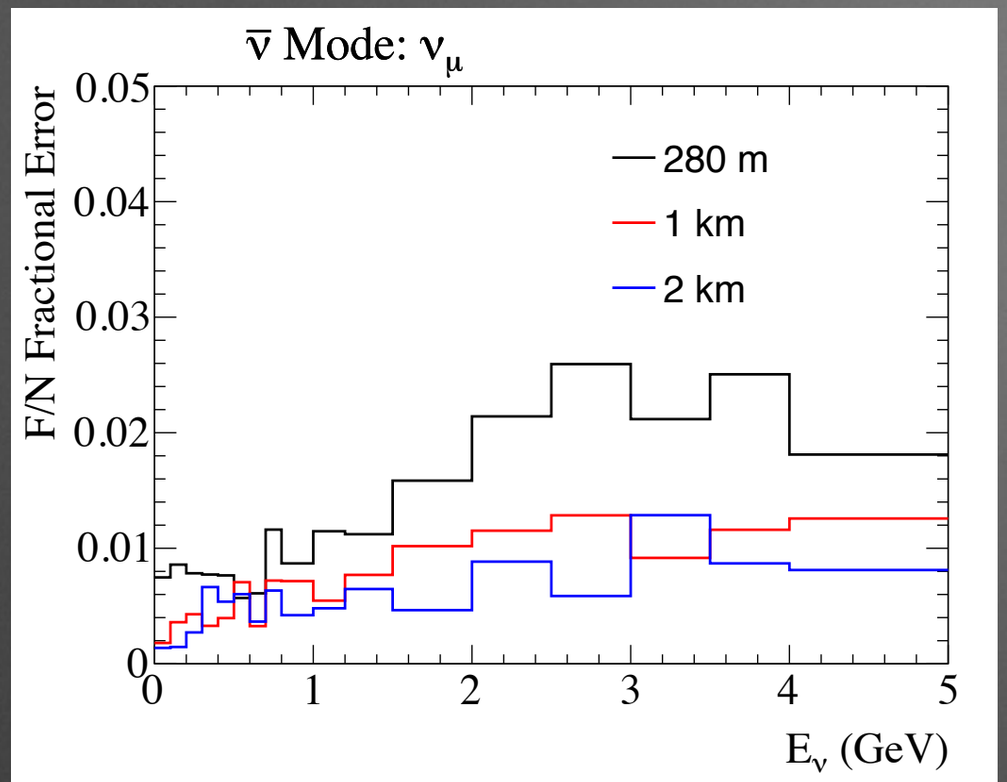


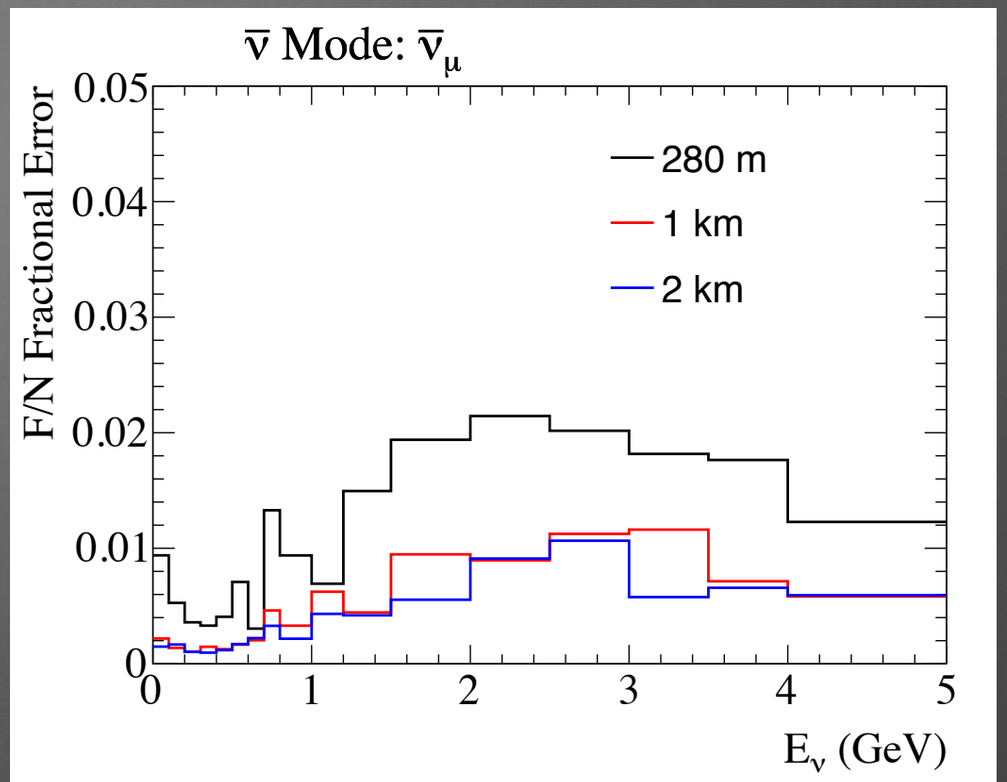


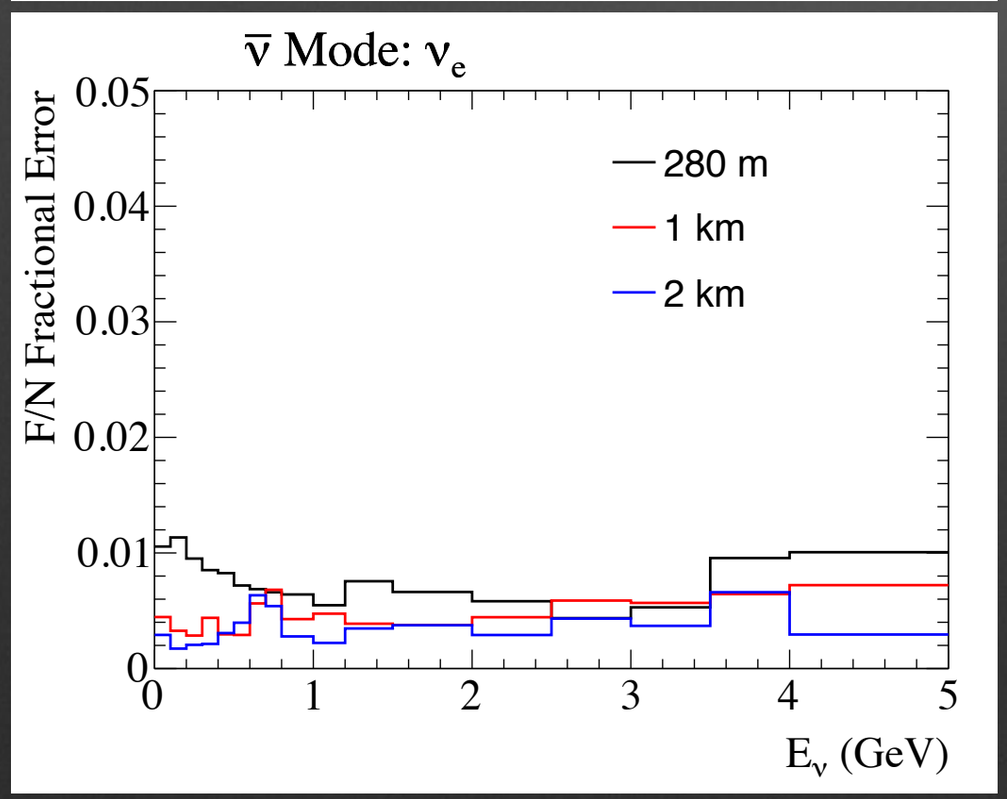


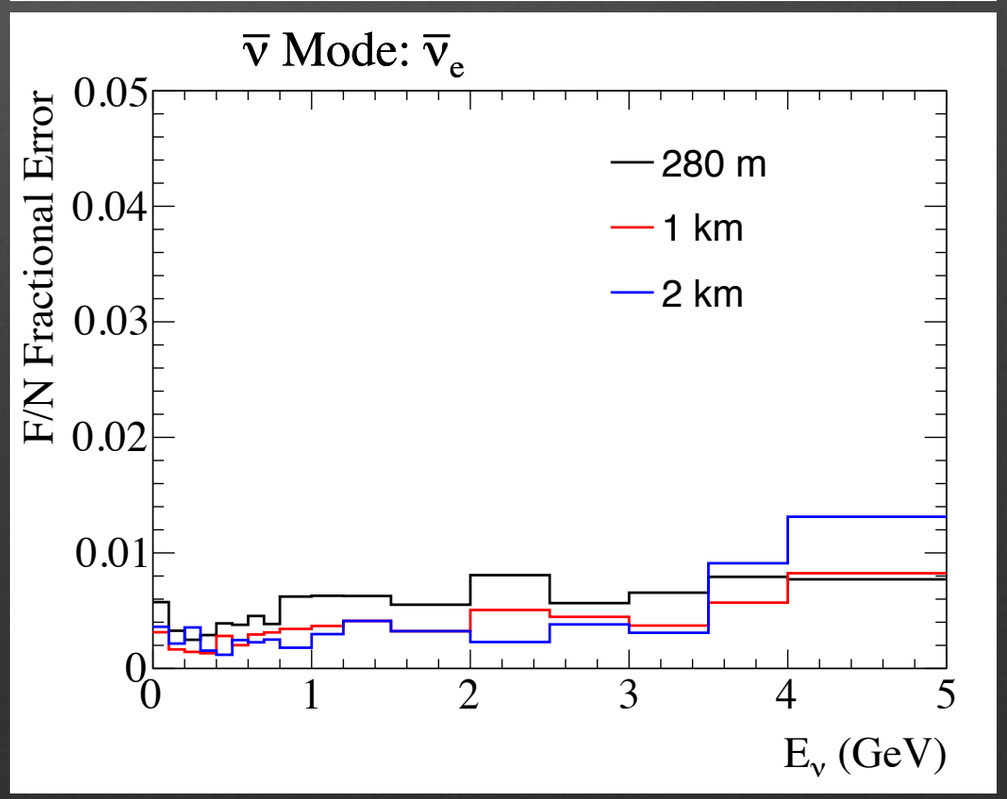
See reduction in errors at longer baseline

Antineutrino Mode Reweighted Errors



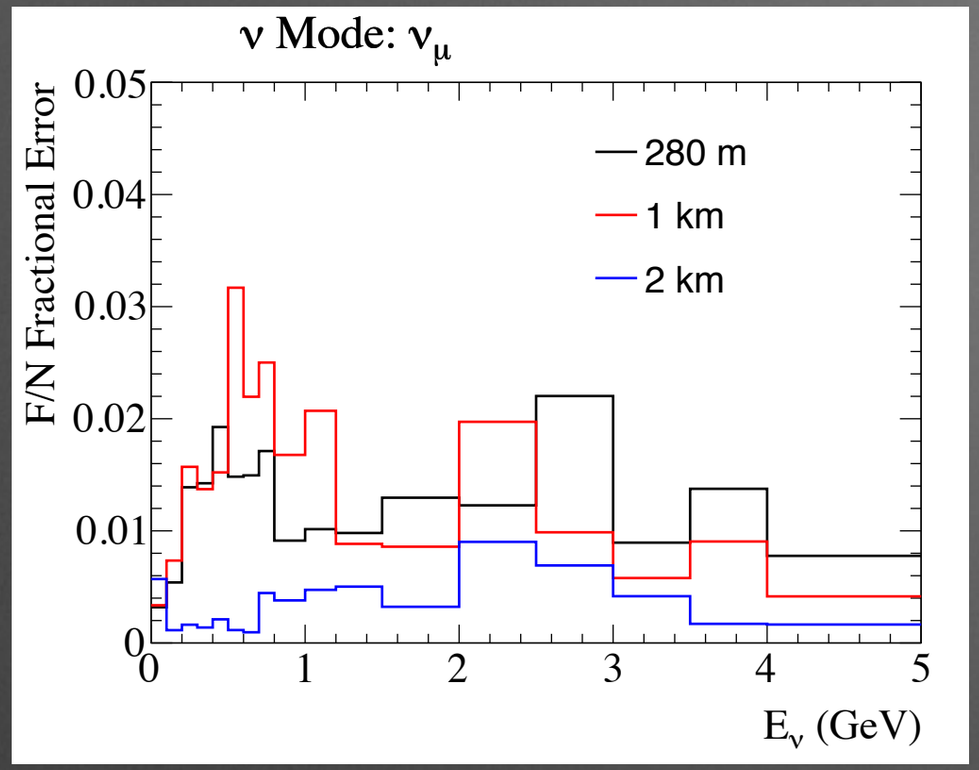


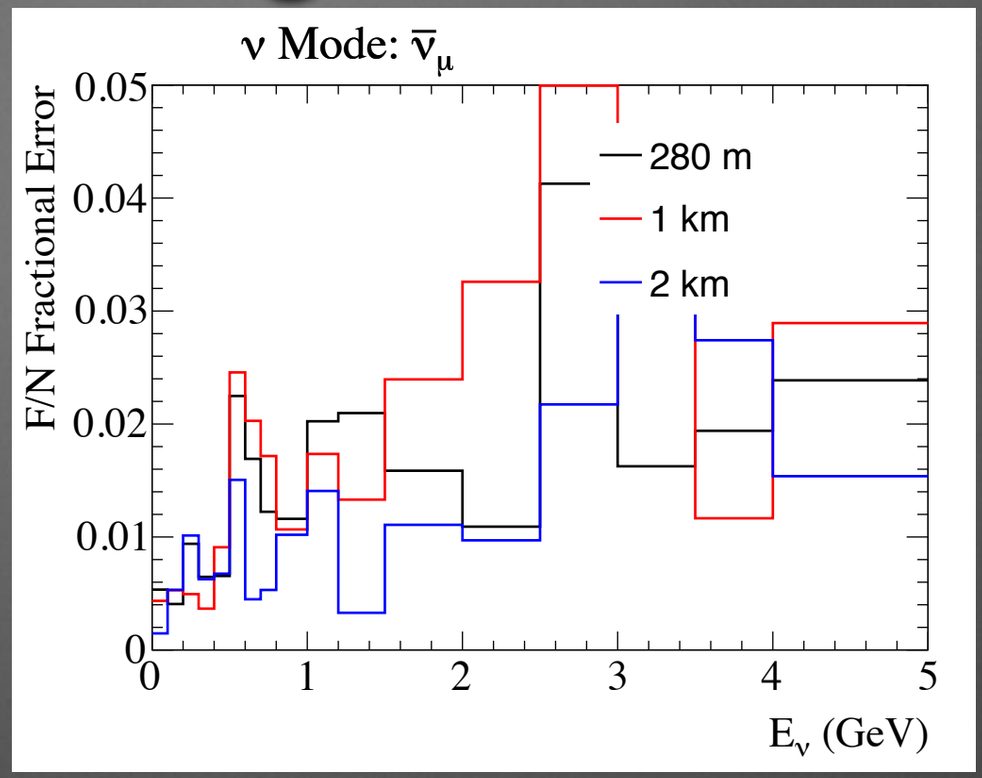


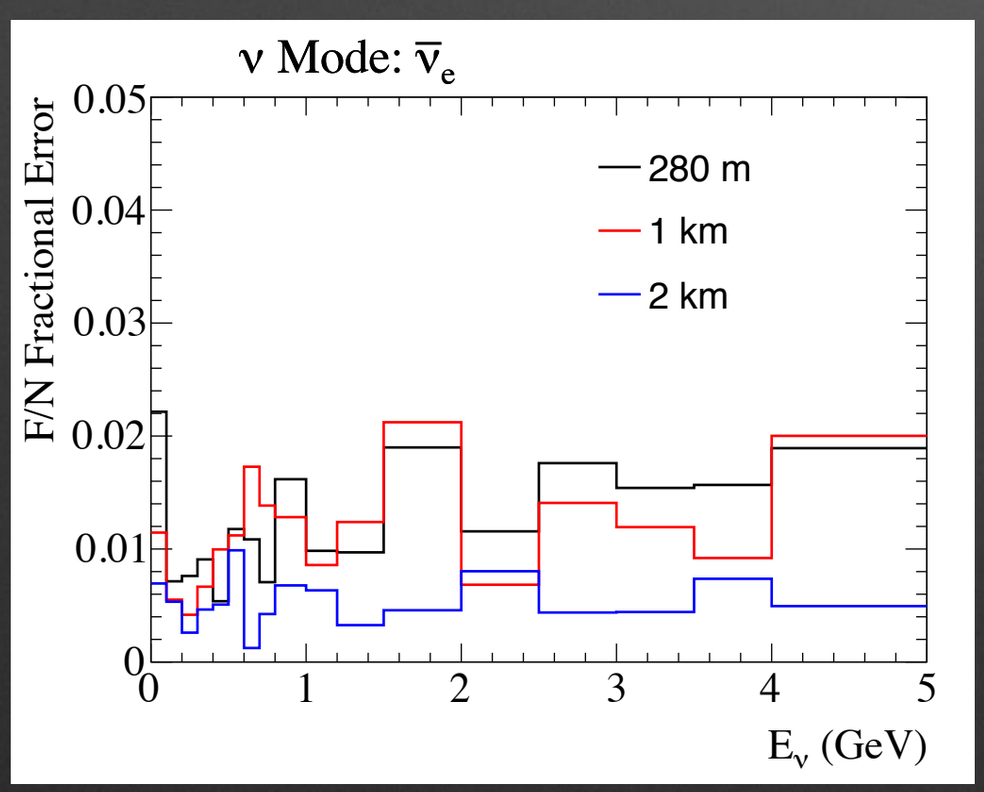


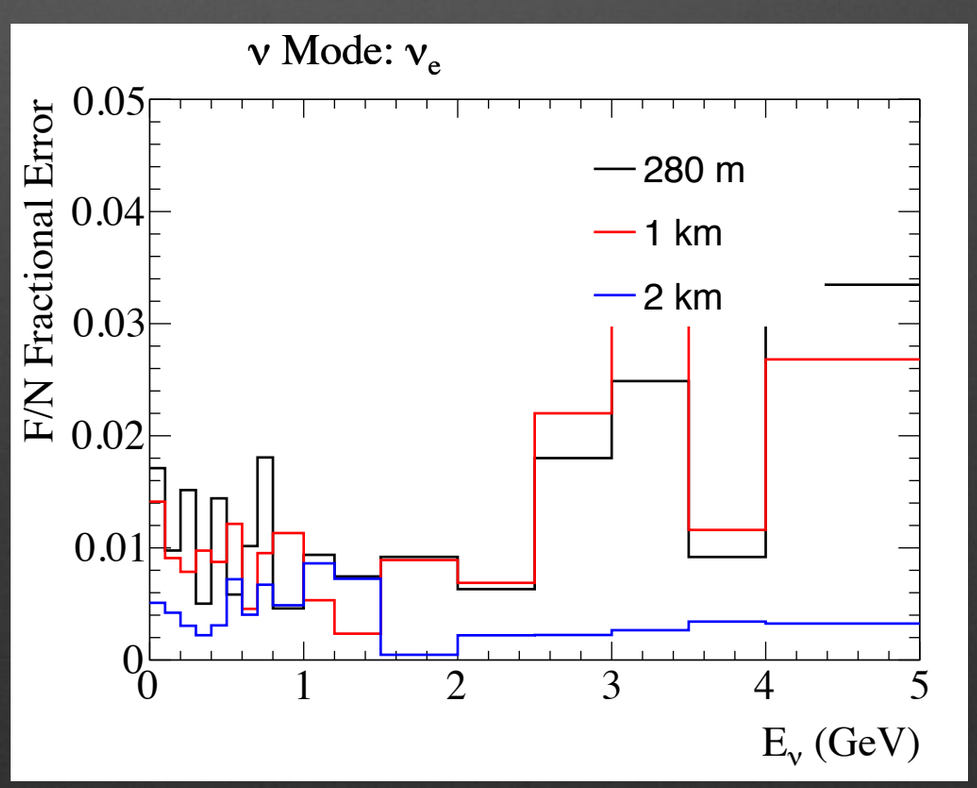
Neutrino Mode Regenerated Errors

R. Terri







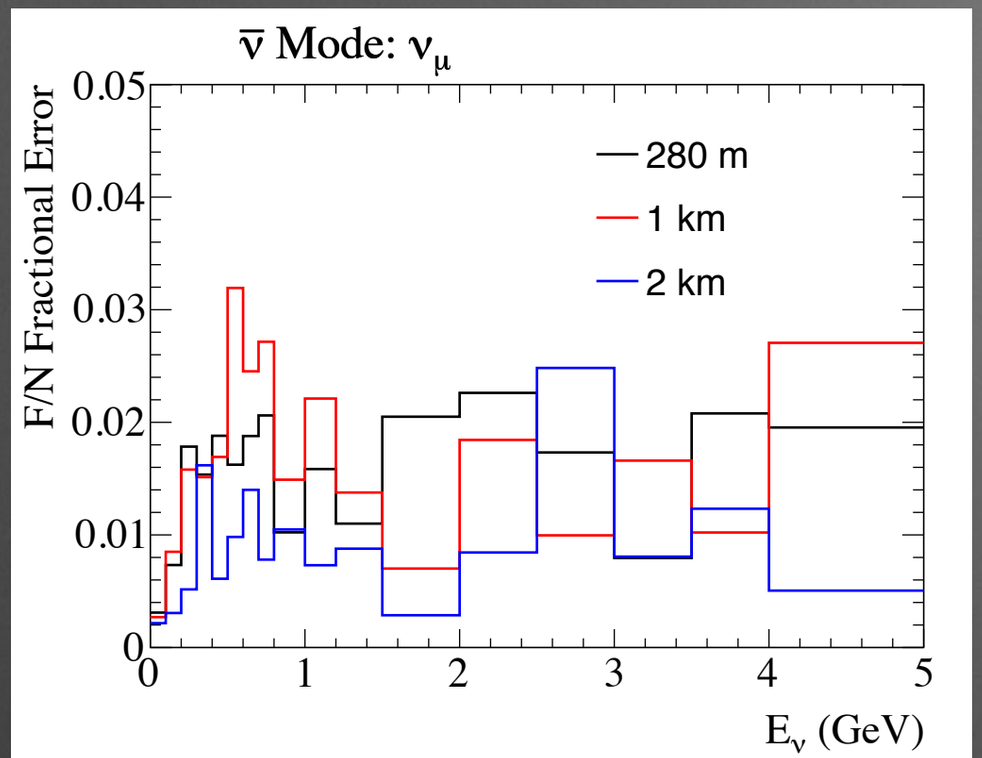


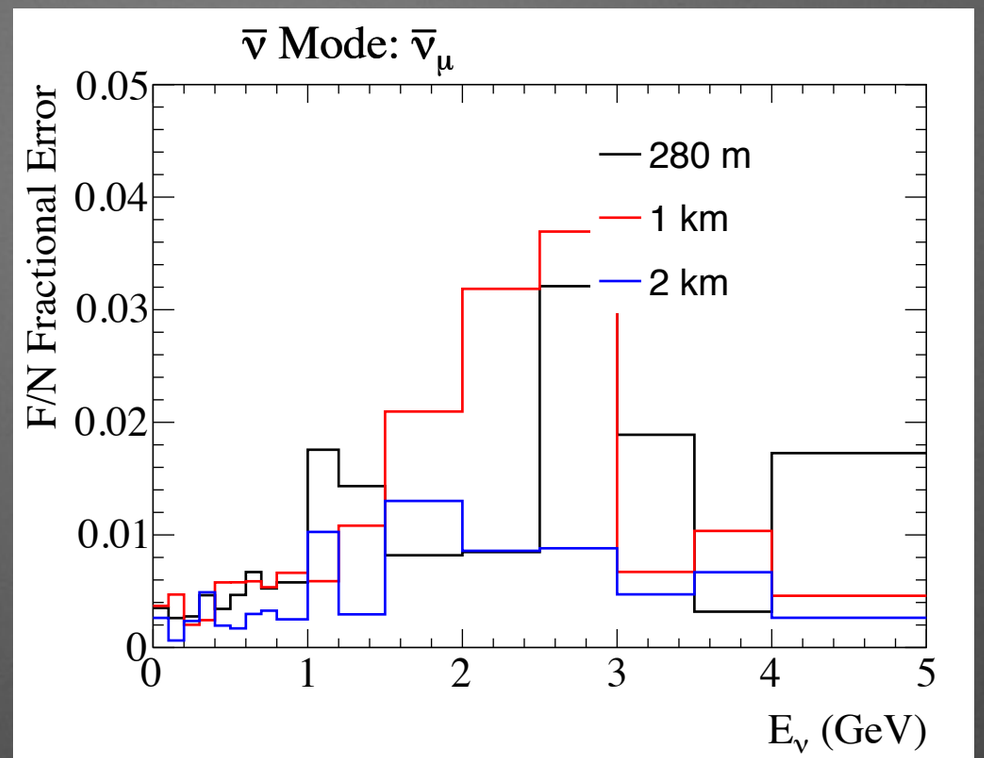
Statistical errors are significant.

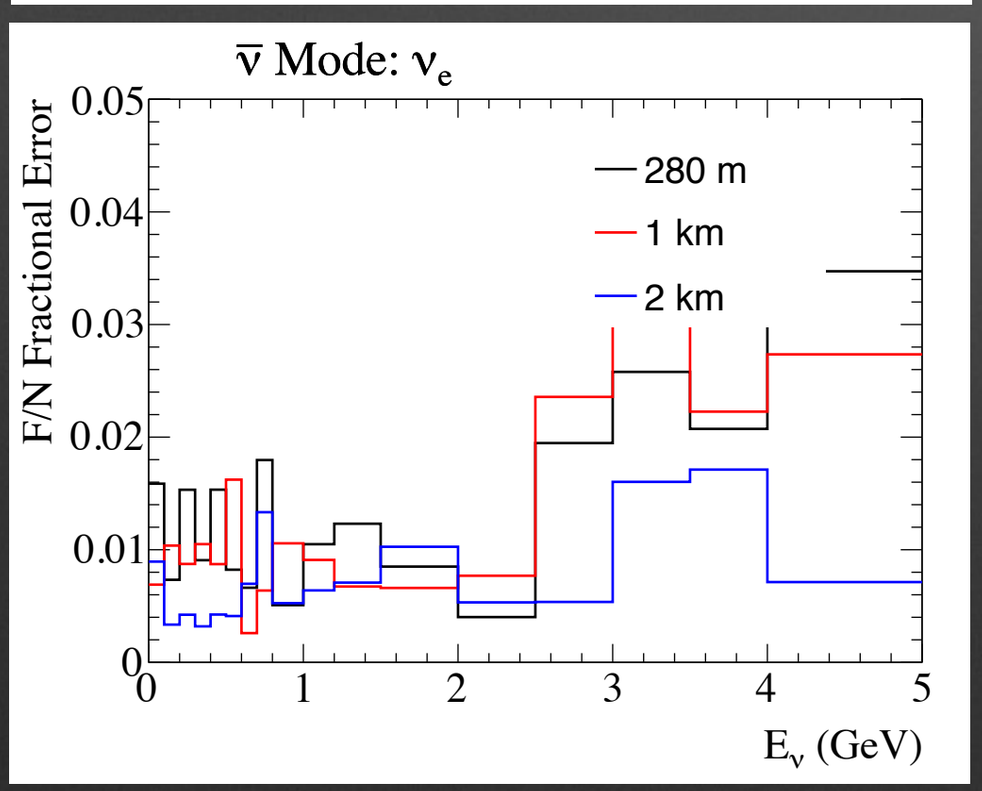
Higher statistics 2 km samples show alignment errors reduced to <1% for the right sign flux

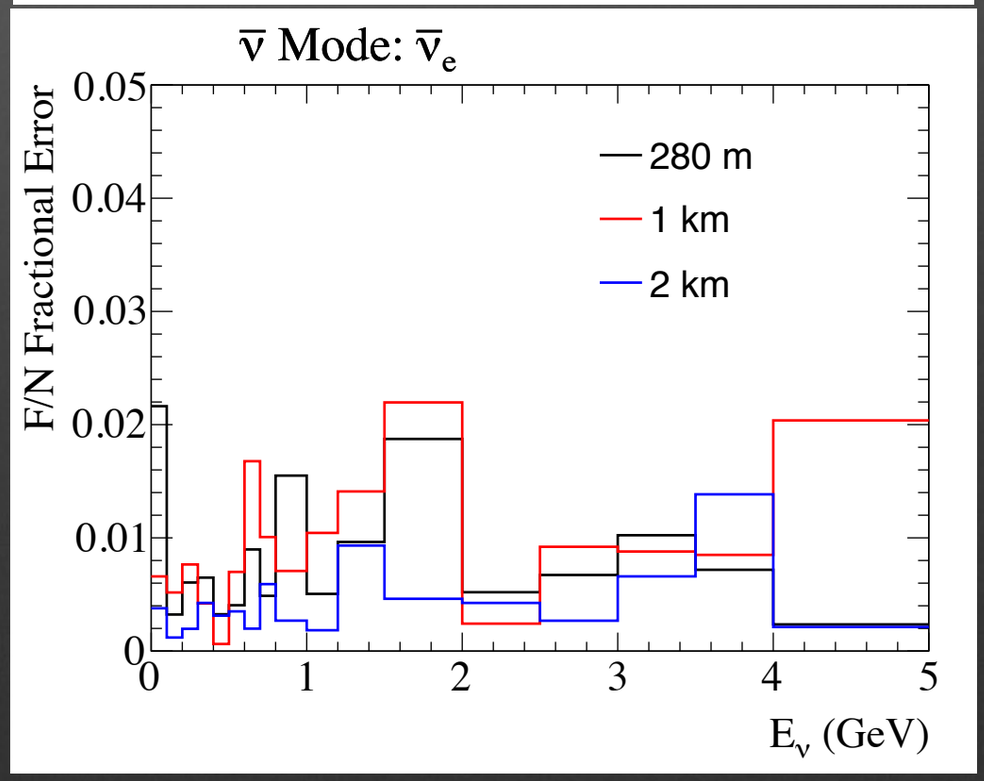
Antineutrino Mode Regenerated Errors

R. Terri









Conclusion on Far-to-Near Ratio Uncertainties

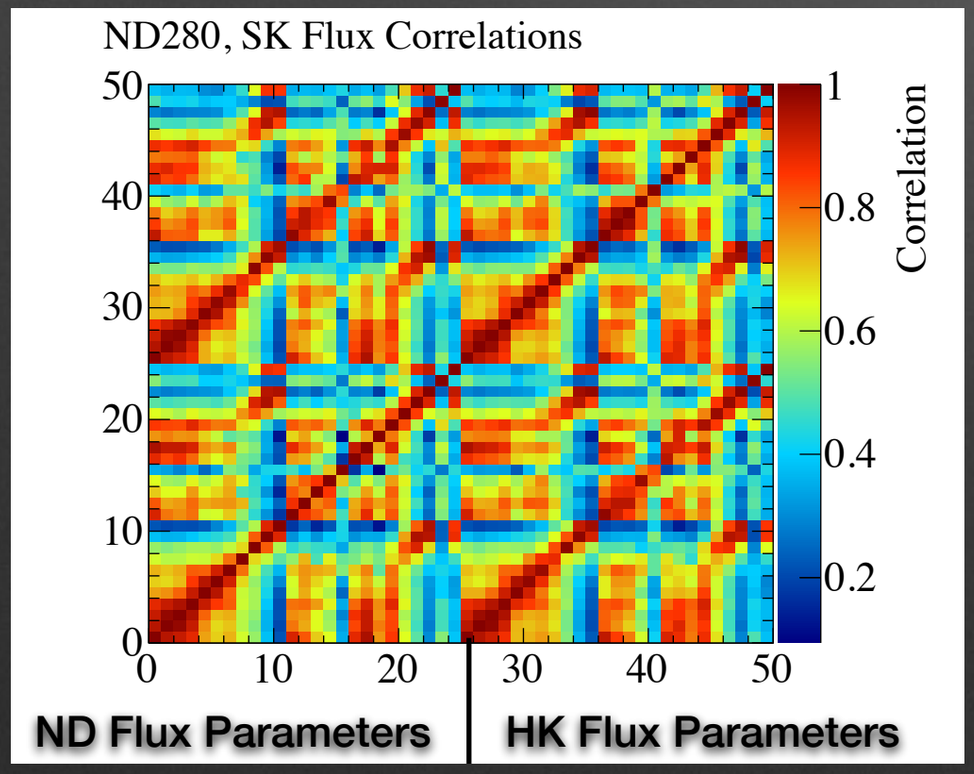
- We see the F/N ratio error does depend on the baseline, but event 280 m flux has <1% errors near the flux peak for reweightable systematic variations

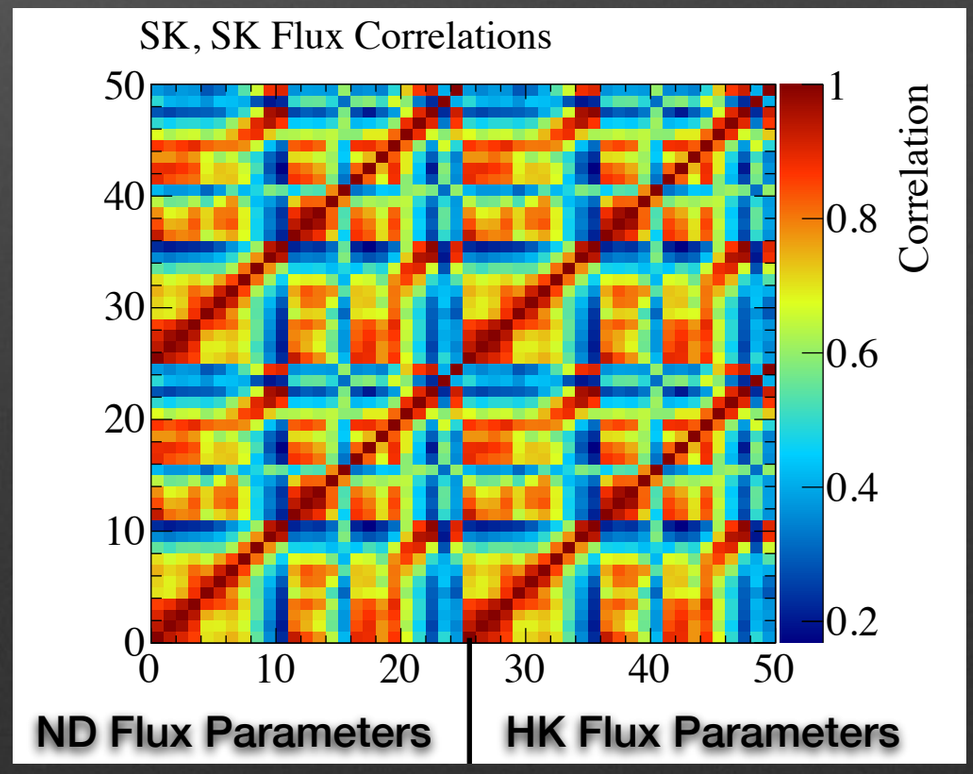
- Would need to generate many more stats to evaluate all of the alignment errors to the <1% level

- Can we study an extreme case of F/N ratio errors to determine if baseline is important and this need further study?

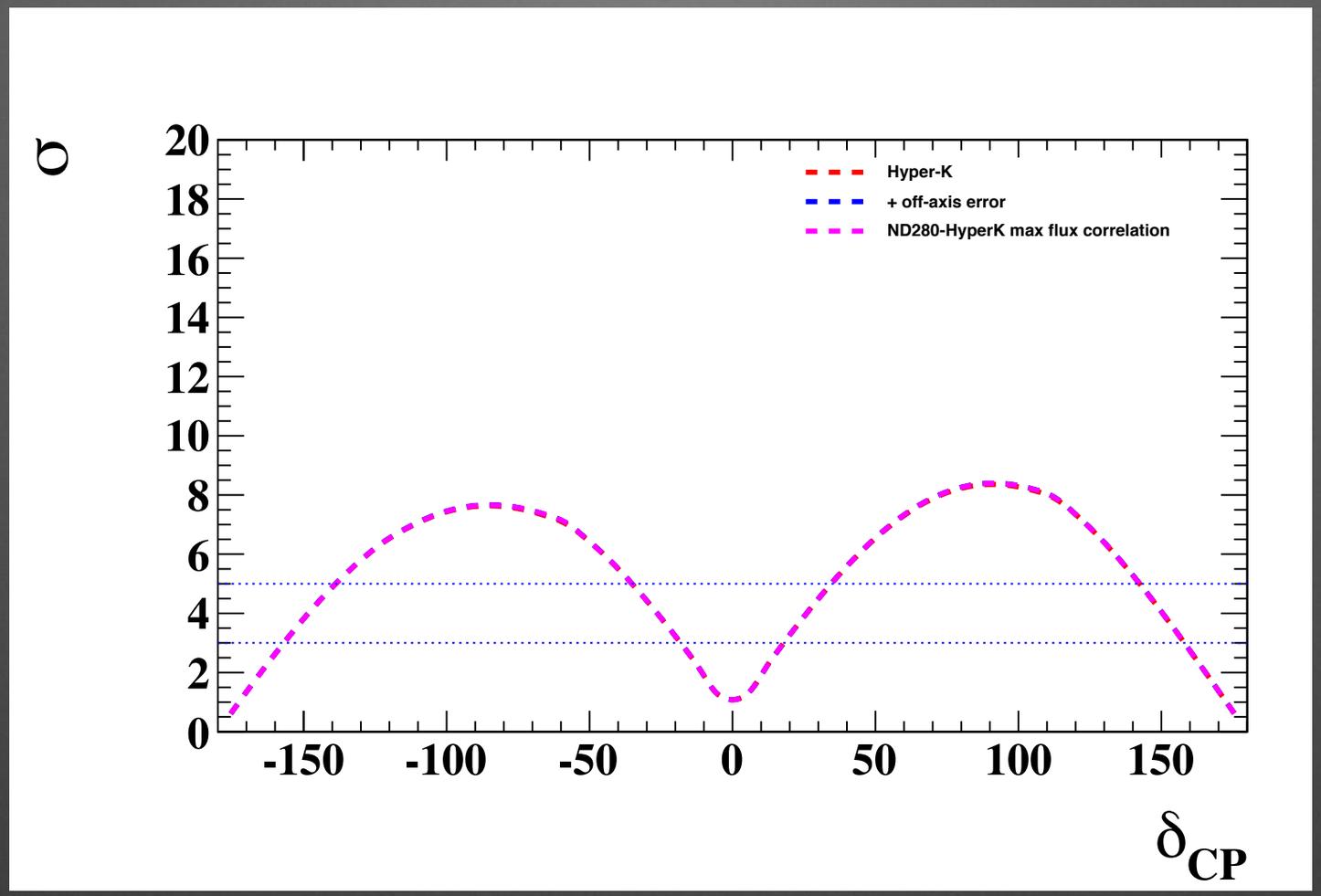
Near Detector Baseline

- Is it important to have a near detector at a longer baseline so the flux is more similar to the far detector flux?
- We can check the extreme case: assume the flux uncertainties are identical at the near and far detector
  - Rerun the near detector fit and compare to the case where the 280 m flux uncertainties are used
  - Evaluate in the HK sensitivity framework





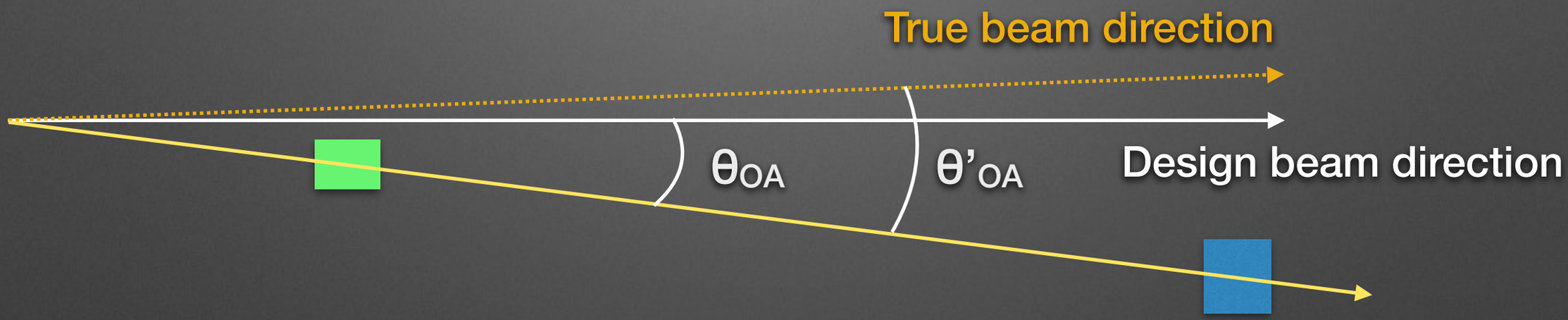
Perfect Flux Correlation Sensitivity



- The CP violation sensitivity is not significantly improved by moving to perfect correlations for the near and far flux parameters
- In current sensitivity framework, ND baseline is not too important

Beam Direction Uncertainty

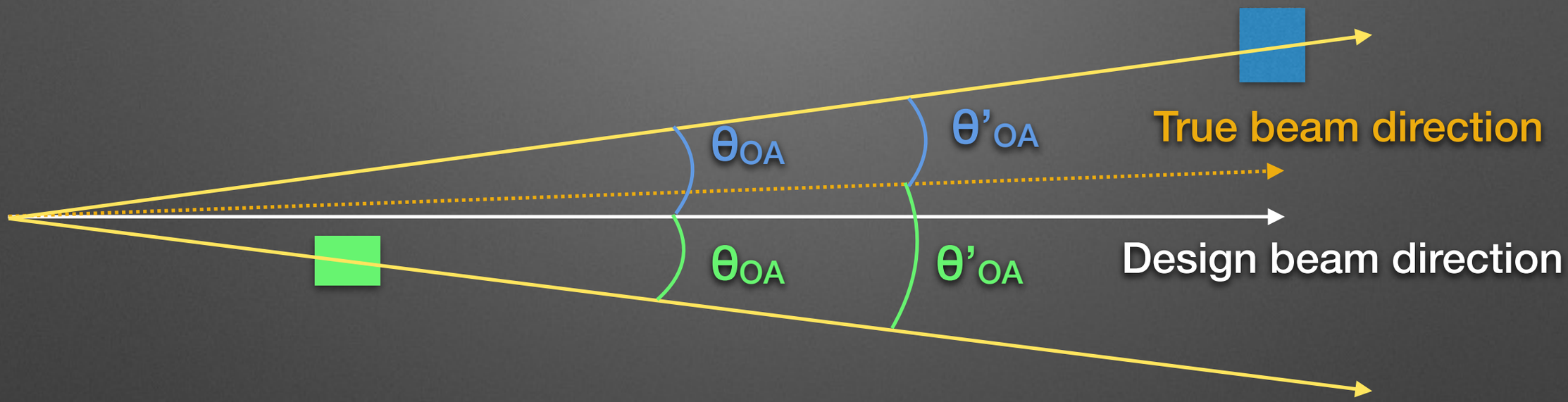
- If the near detector and far detector are in the same direction (ND280 and SK), then any change to the beam angle affects the near and far flux in the same way:



- The change in the flux is detected at the near detector and can be applied to the far detector prediction

Near and Far Detectors, Different Direction

- However, near detector and far detector may have the same design off-axis angle but not be in the same direction (ND280 and Tochibora)

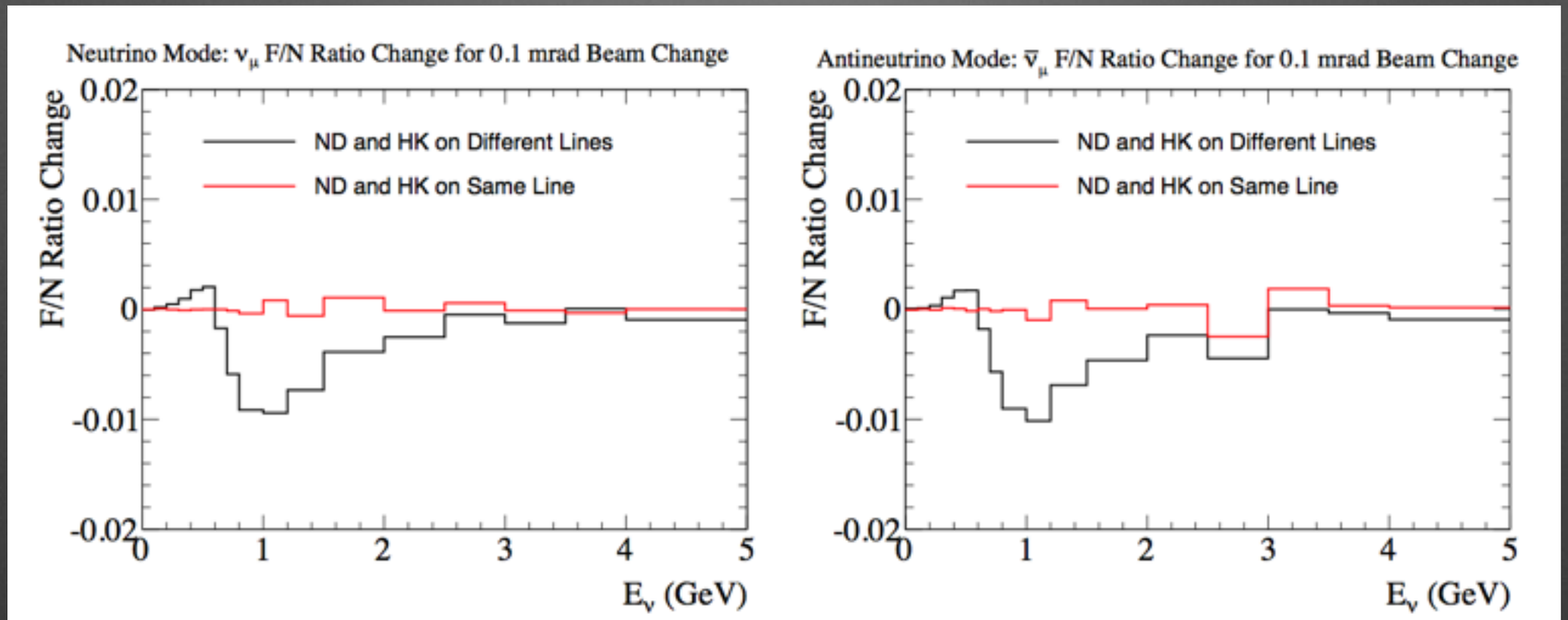


$$\theta'_{OA} \neq \theta'_{OA}$$

- Can't we say $\theta'_{OA} = 2\theta_{OA} - \theta'_{OA}$?
  - Doesn't work since an x shift of the beam affects the near and far detectors in the opposite direction while a y shift affects them in the same way - there is ambiguity

Error Treatment in LOI

- In the LOI, we assigned and uncertainty equal to the difference between a +1 and -1 sigma shift of the beam x direction assuming a 1 sigma constraint of 0.1 mrad (2.5 cm) from INGRID:

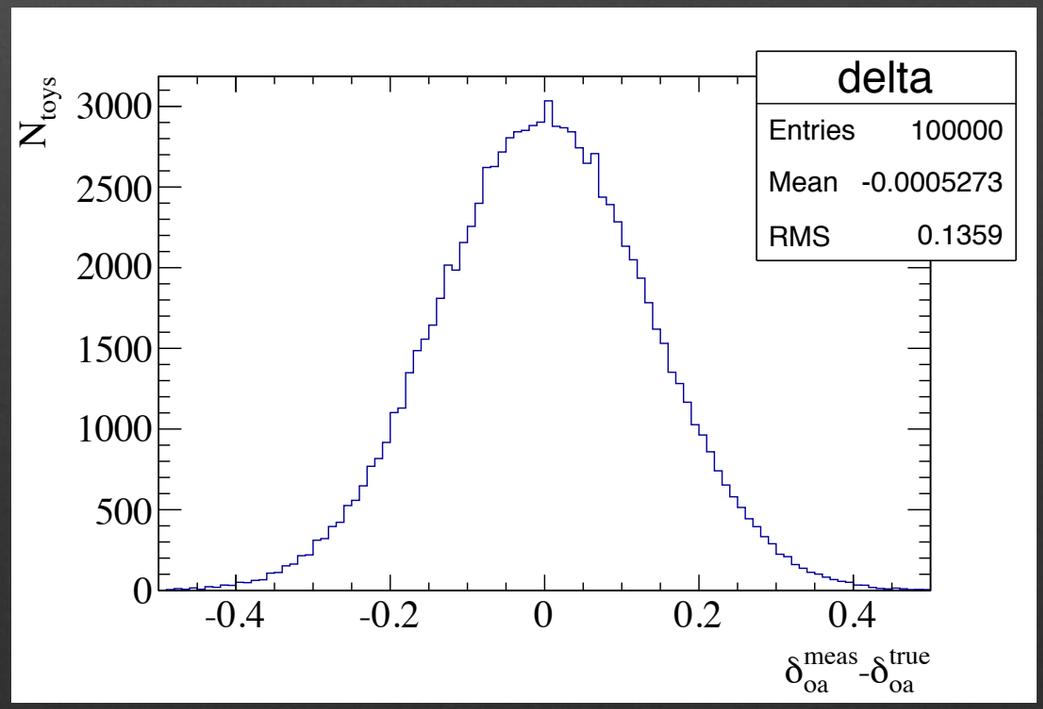


- Introduces equivalent of a ~0.08 mrad uncertainty on the off-axis angle
- This may be underestimating the error because INGRID constraint is too tight
- Should better motivate assignment of 2x the x shift as uncertainty

Updated Beam Direction Uncertainty

- Assume INGRID uncertainties on the beam center position are ~5 cm. Uncertainty from y has larger effect because most of off-axis effect comes from the vertical inclination
  - δ_y = 0.2 mrad
  - δ_x = 0.08 mrad
- If we assume any shift is completely in the y direction, then we introduce a systematic error of ~0.14 mrad in the far detector off-axis angle measurement

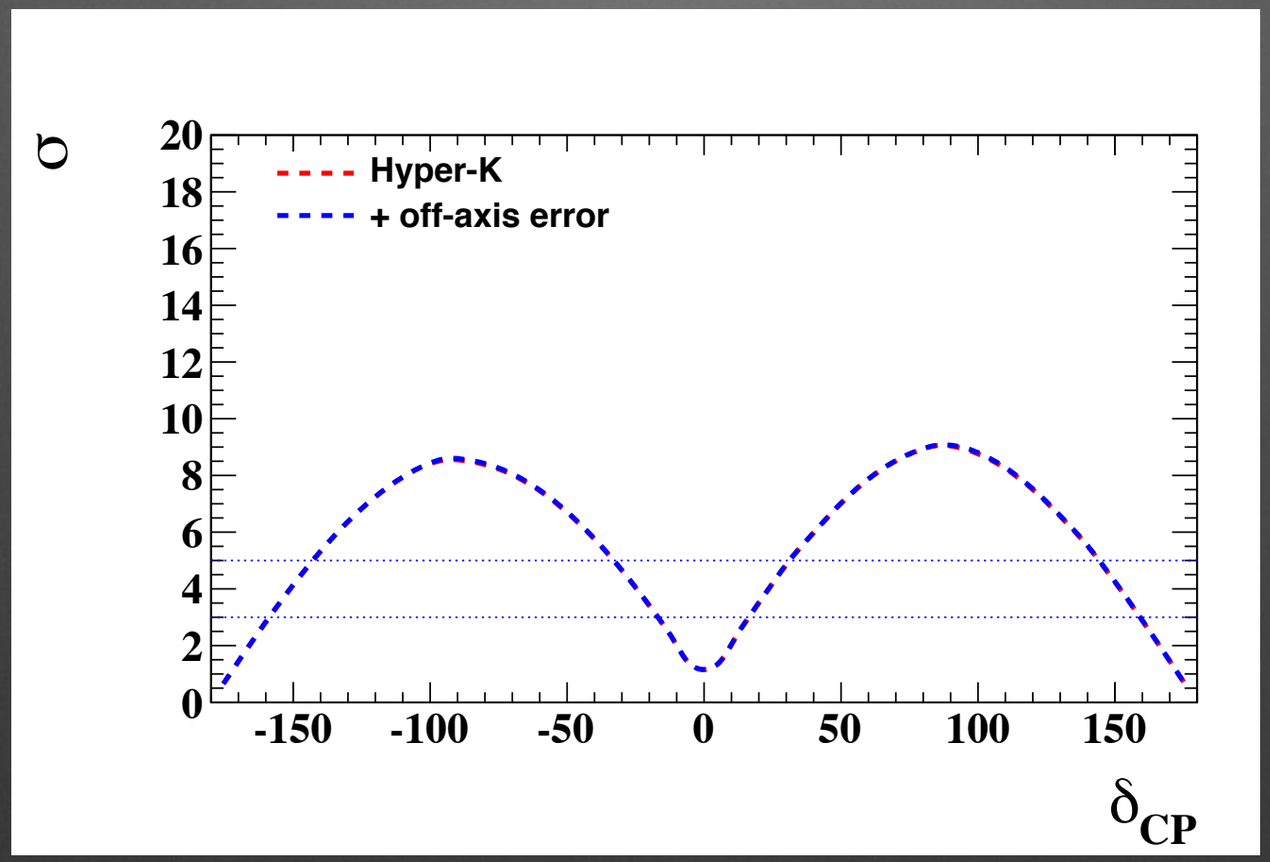
ND280 at
3.22, 9.63 m
relative to beam



Effect on Sensitivity Results on Sensitivities

- We add the additional off-axis angle uncertainty to BANFF fit output and rerun the sensitivity studies

  - Currently using 0.05 mrad uncertainty. Will update to 0.14 mrad later.



- Don’t see a significant change to the sensitivity due to the off-axis angle error.