

# Ongoing Sensitivity Studies with the Upgraded ND280

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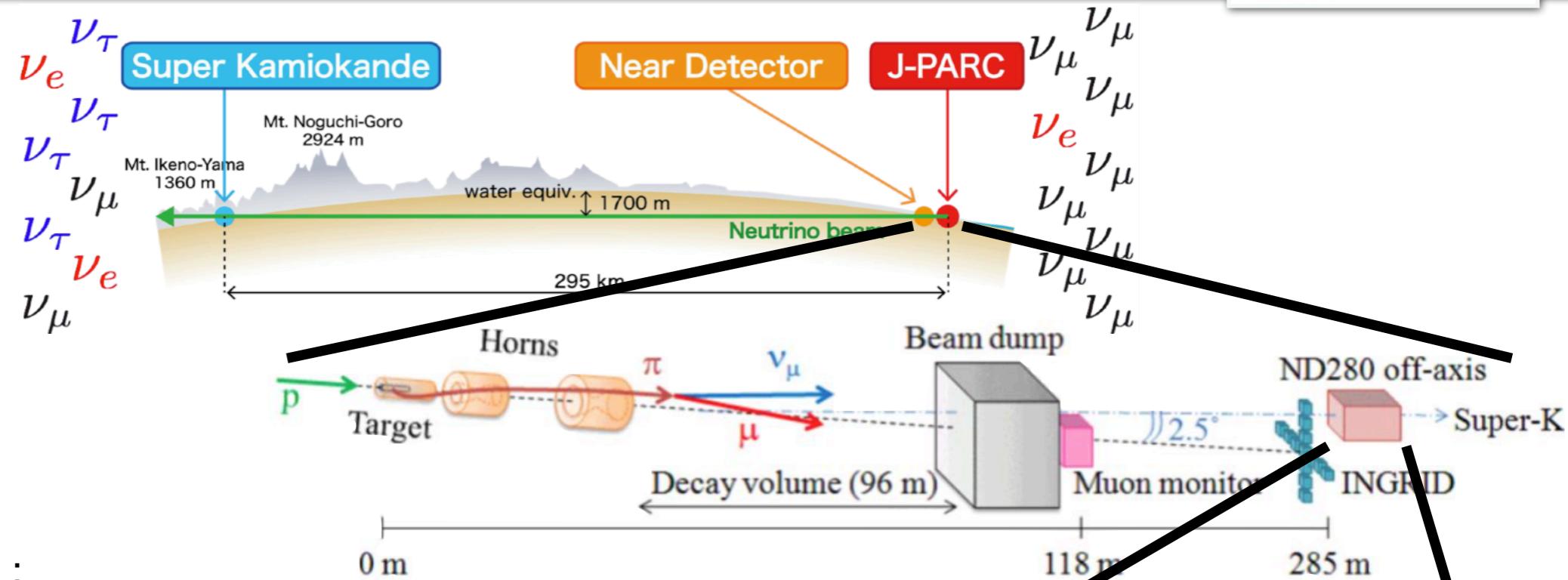
**Adrien Blanchet**  
*LPNHE - (Paris)*

The 31th of March 2020

# The ND280 Upgrade

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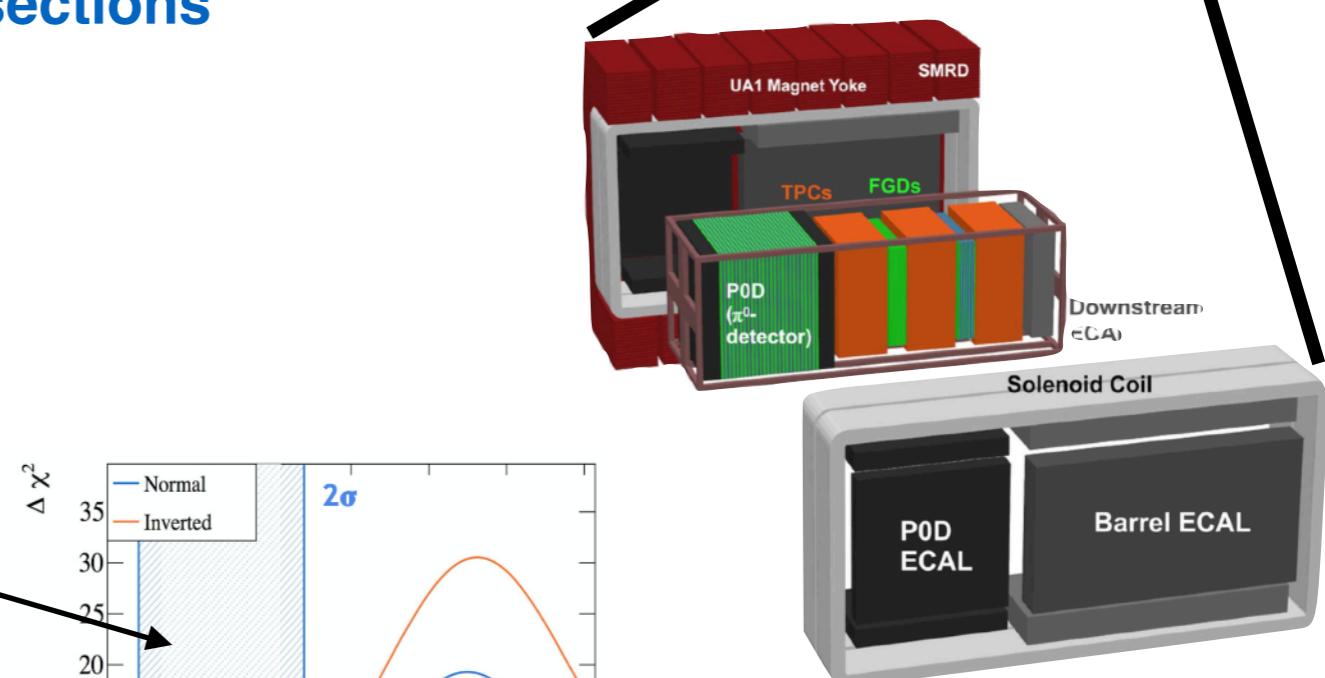
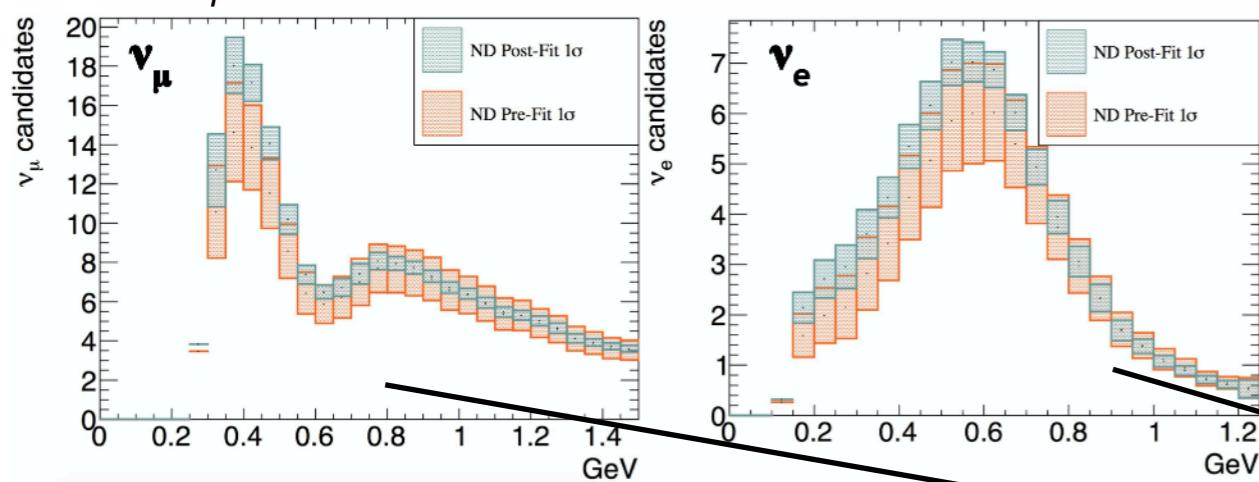
# The Current ND280



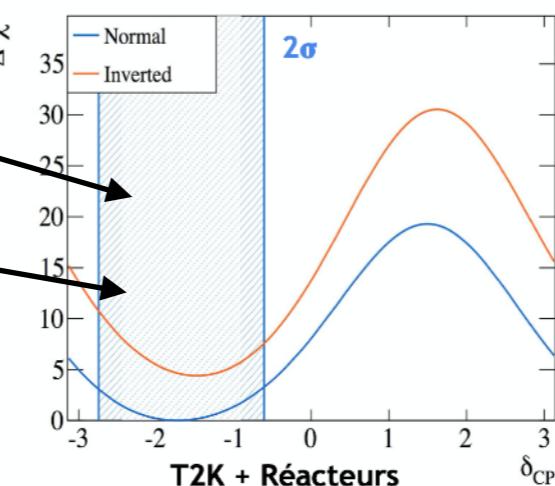
## Goal of the near detector :

# **Bring constraints on the parameter flux / X-sections for oscillation analysis at SK**

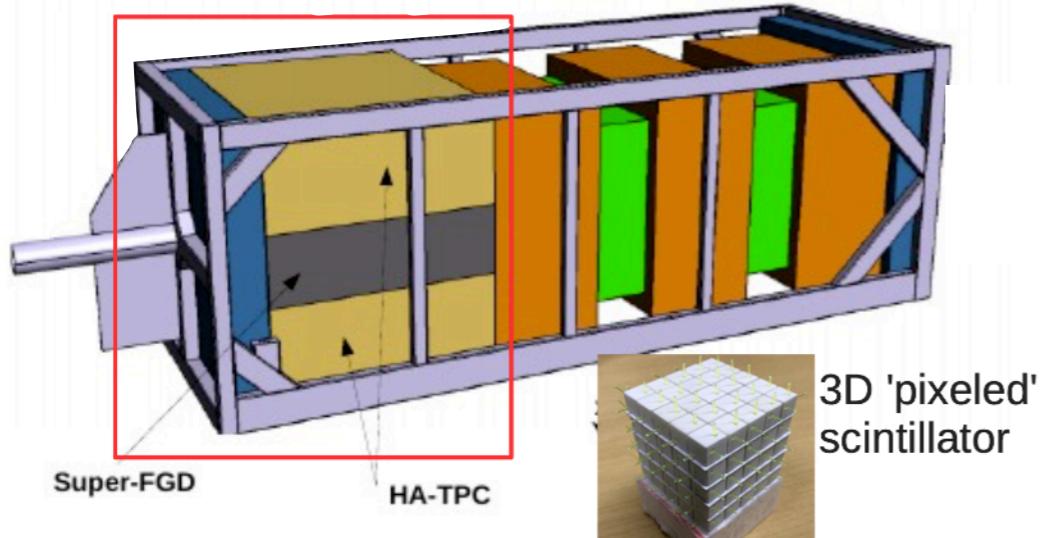
### *Measured spectra at SK :*



ND280 reduced the systematic errors sufficiently to provide the ability to measure the neutrino violation phase :



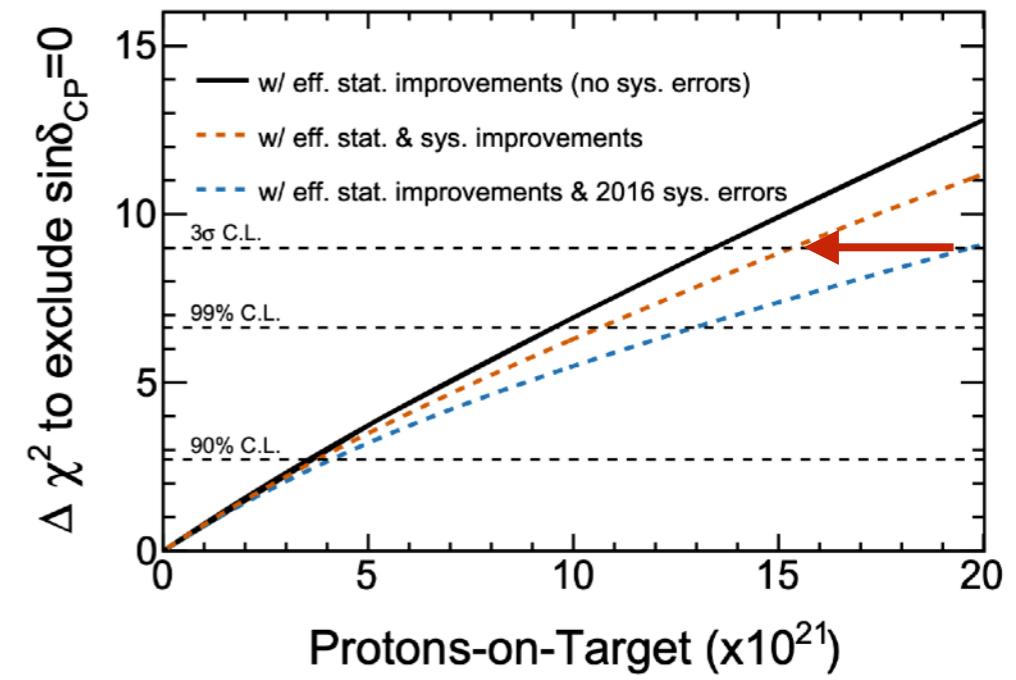
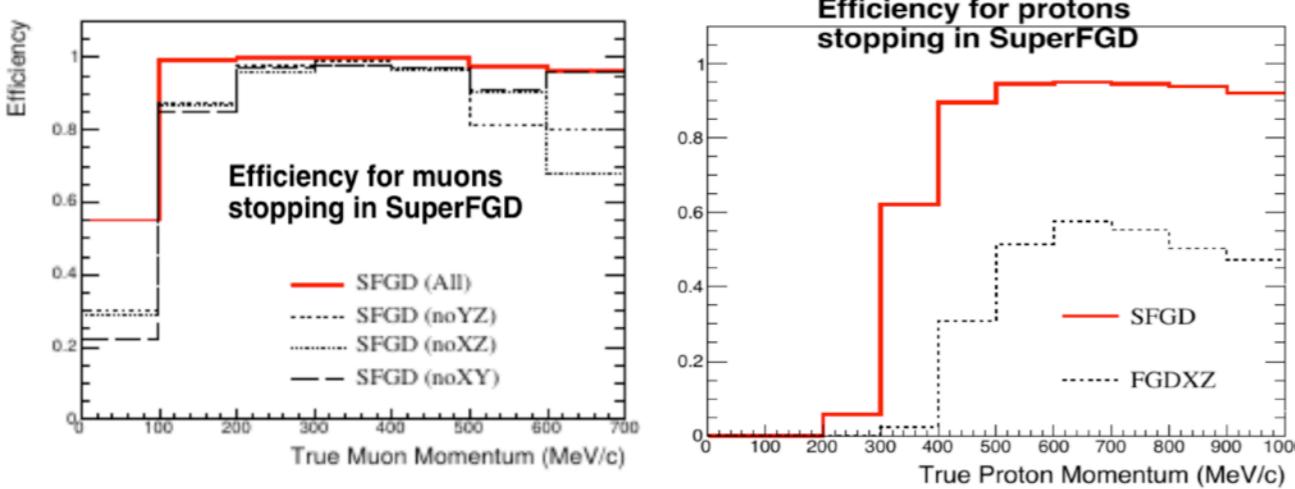
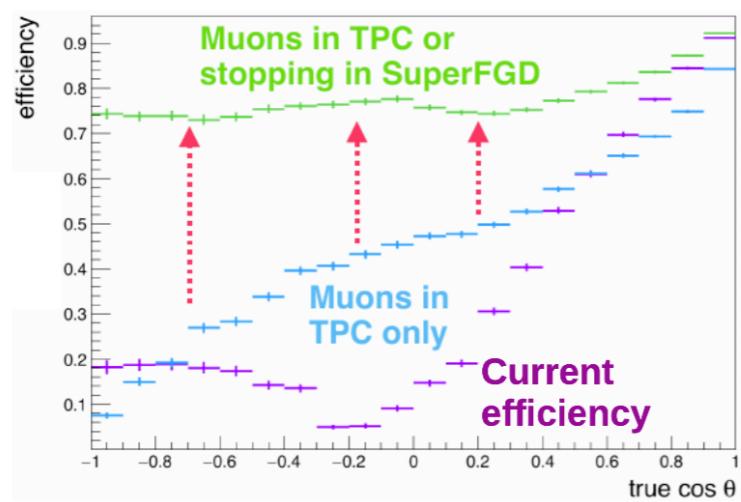
# The Upgraded ND280



## Upgrade of the **detection efficiency**

- Increased acceptance for high angle muons (match SK acceptance)
- Lower momentum threshold for muons and protons

→ *Thinner binning, new observables = better constrains on the systematics*



# **Principle of the ND280 Fit**

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# Principle of the ND280 Fit

- Based on a likelihood fit :

$$\chi^2 = \sum_s^{samples} \sum_{p,t} 2 \left( M_{pt}^s - D_{pt}^s + D_{pt}^s \times \log \left( \frac{D_{pt}^s}{M_{pt}^s} \right) \right) \\ + \sum_c^{syst-cat.} \left( \sum_n \sum_{n'} \left( \alpha_n - \alpha_n^{prior} \right) V_{nn'}^{-1} \left( \alpha_{n'} - \alpha_{n'}^{prior} \right) \right)$$

  
 $p_\mu, \cos\theta_\mu$

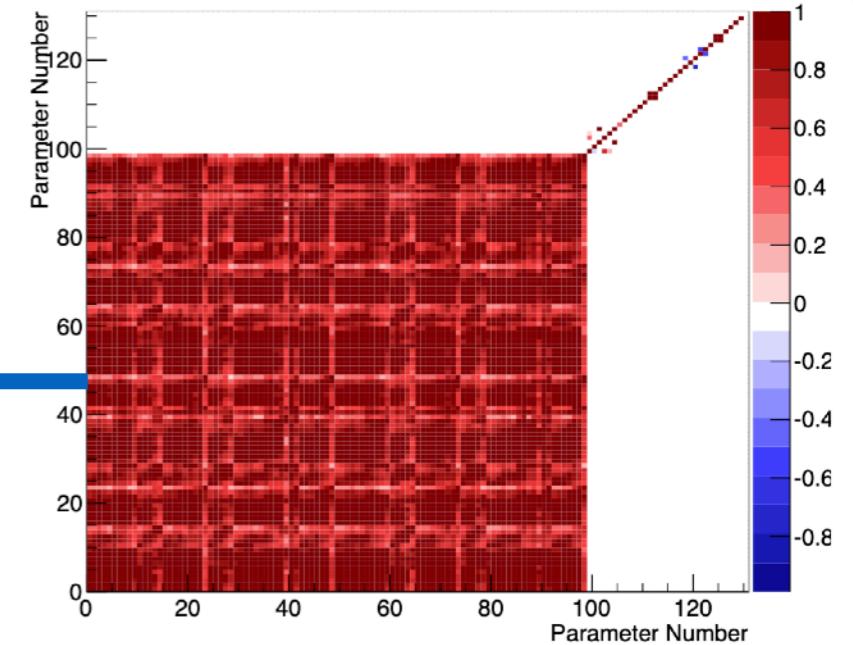
For the ND280 upgrade physics :

- Samples = ["CC-0Pi", "CC-1Pi", "CC-Other"]
- Syst. Categories = [flux, detector, cross-section, Eb, ...]

# Principle of the ND280 Fit

(The BANFF is in charge of this)

- Take the **covariance matrix of the flux/cross-section** we got from **other measurements**

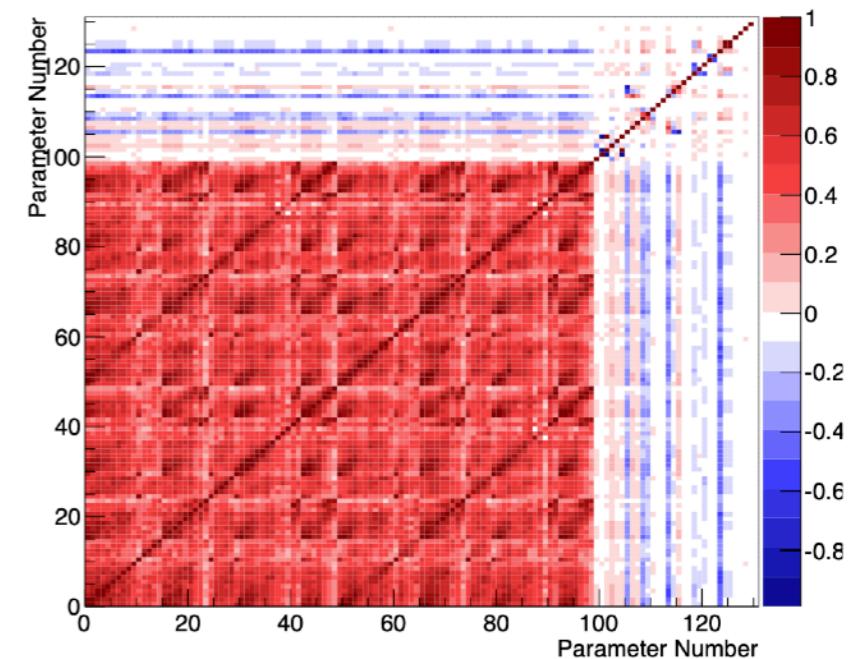


- **Plug the matrix in the Chi2**

$$\chi^2 = \dots + \sum_c^{syst-cat.} \left( \sum_n \sum_{n'} \left( \alpha_n - \alpha_n^{prior} \right) V_{nn'}^{-1} \left( \alpha_{n'} - \alpha_{n'}^{prior} \right) \right)$$

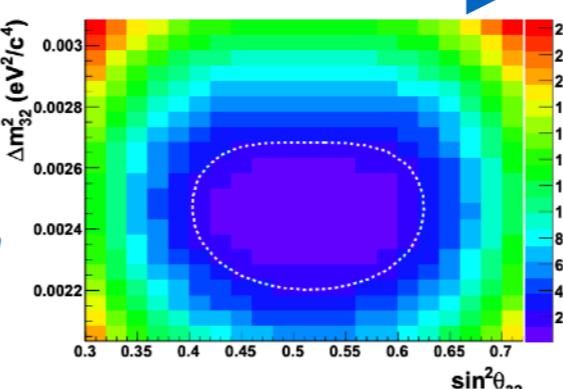
- **Fit the nuisance parameters**

- Vary each nuisance parameter around the best-fit and **compute the new covariance matrix**



- Plug the new matrix into SK oscillation analysis

*Ex: Use of P-Theta*



# Using xsLLhFitter for Upgrade Physics



- ND280 Upgrade will allow much **improved access to outgoing hadron kinematics**
- For example, could fit the data with transverse variables in addition to muon momentum / cos theta

$$(p_\mu, \cos\theta_\mu) \rightarrow (\delta p_T, \delta\alpha_T, p_n \dots)$$

- Add extra systematics

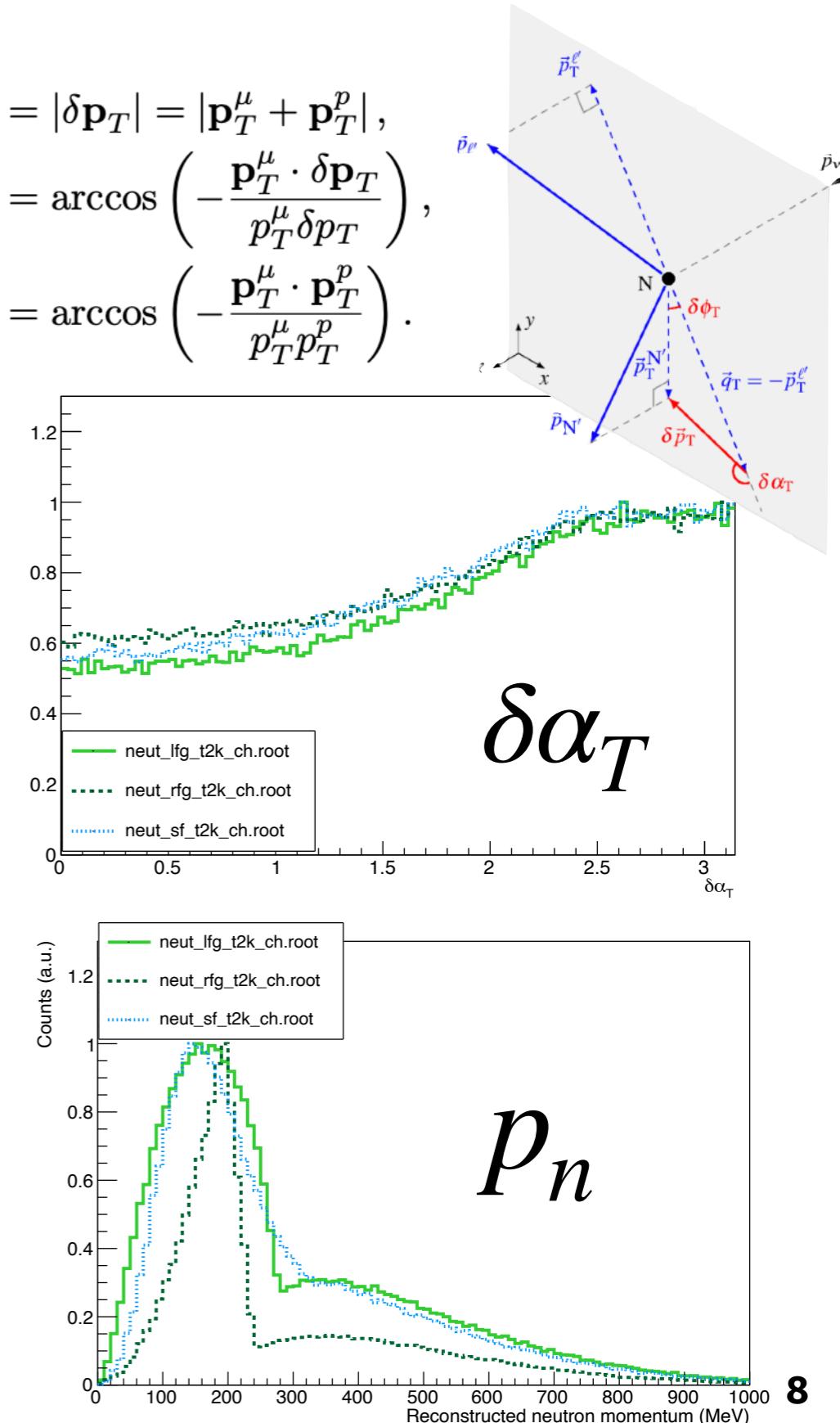
$[E_b, FSI, \dots]$

- See if the upgraded ND280 will be able to discriminate between nuclear models

- See the performance gain on the systematics and the physics parameters

**First Step : Reproducing the BANFF Fit with xsLLhFitter (the cross-section fitter)**

$$\begin{aligned}\delta p_T &= |\delta \mathbf{p}_T| = |\mathbf{p}_T^\mu + \mathbf{p}_T^p|, \\ \delta\alpha_T &= \arccos \left( -\frac{\mathbf{p}_T^\mu \cdot \delta \mathbf{p}_T}{p_T^\mu \delta p_T} \right), \\ \delta\phi_T &= \arccos \left( -\frac{\mathbf{p}_T^\mu \cdot \mathbf{p}_T^p}{p_T^\mu p_T^p} \right).\end{aligned}$$



# First Attempt to Reproduce the BANFF Fit

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# Building the Prediction M\_{pt}

$$\chi^2 = \sum_s^{samples} \sum_{p,t} 2 \left( M_{pt}^s - D_{pt}^s + D_{pt}^s \times \log \left( \frac{D_{pt}^s}{M_{pt}^s} \right) \right) + \sum_c^{syst-cat.} \left( \sum_n \sum_{n'} \left( \alpha_n - \alpha_n^{prior} \right) V_{nn'}^{-1} \left( \alpha_{n'} - \alpha_{n'}^{prior} \right) \right)$$

Flat trees were taken from iRODS path :

/QMULZone1/home/asg/asg2019oa/ND280/Highlandv2r41\_TestFlatTrees\_FGDHitInfo\_26Nov2019/

drwxr-s--- 3 ablanche t2k 14122 Mar 2 11:33 run2a
drwxr-sr-x 3 ablanche t2k 10127 Mar 2 11:33 run2w
drwxr-sr-x 3 ablanche t2k 52451 Mar 2 11:33 run3
drwxr-sr-x 3 ablanche t2k 55343 Mar 2 17:56 run4a
drwxr-sr-x 3 ablanche t2k 20731 Mar 3 07:44 run4w
drwxr-sr-x 3 ablanche t2k 12662 Mar 3 10:05 run5
drwxr-sr-x 3 ablanche t2k 19298 Mar 3 15:12 run6
drwxr-sr-x 3 ablanche t2k 18824 Mar 3 21:13 run7

- BANFF is working directly with these flat trees
- The same event selection process can also be done by Highland2

## Install notes and hot fixes - link

- 3 different analyses have to be performed :

Nu\_mu candidates :

**RunNumuCCMultiPiAnalysis.exe**

Anti Nu\_mu candidates :

**RunAntiNumuCCMultiPiAnalysis.exe**  
**RunNumuBkgInAntiNuModeAnalysis.exe**

# Building the Prediction M\_{pt}

## Getting the BANFF binning

- The binning in BANFF is hard coded :  
<https://github.com/t2k-software/BANFF/blob/OA2020/src/BinningDefinition.cxx>
- In xsllhFit, the binning is specified in a text file where the lower/higher bounds of each bin is specified on each line : { cos(theta) min ; cos(theta) max ; p\_mu min ; p\_mu max }

```
26 //FHCNumuCC0Pi
27 int FHCNumuCC0Pi_Mom_NBin = 29;
28 double FHCNumuCC0Pi_Mom_Bin[30] = {0., 200., 300., 400., 450., 500., 550.
29                                     650., 700., 750., 800., 850., 900., 950.
30                                     1050., 1100., 1200., 1300., 1400., 1500., 1600
31                                     1800., 2000., 2500., 3000., 5000., 30000.};
32 int FHCNumuCC0Pi_Det_Mom_NBin = 8;
33 double FHCNumuCC0Pi_Det_Mom_Bin[9] = {0., 300., 1000., 1250., 1500., 2000., 3000., 5000.};
34
35 int FHCNumuCC0Pi_Cos_NBin = 29;
36 double FHCNumuCC0Pi_Cos_Bin[30];
37 int FHCNumuCC0Pi_Det_Cos_NBin = 8;
38 double FHCNumuCC0Pi_Det_Cos_Bin[9] = {-1.0, 0.6, 0.8, 0.85, 0.9, 0.92, 0.98, 0.99, 1.0};
39 if(!Do4PiFHC){ //FHC Multi Pi
40     FHCNumuCC0Pi_Cos_NBin = 29;
41     FHCNumuCC0Pi_Cos_Bin[ 0] = -1.0 ;
42     FHCNumuCC0Pi_Cos_Bin[ 1] =  0.5 ;
43     FHCNumuCC0Pi_Cos_Bin[ 2] =  0.6 ;
```



	-1	0.5	300	400
4	-1	0.5	300	400
5	-1	0.5	400	450
6	-1	0.5	450	500
7	-1	0.5	500	550
8	-1	0.5	550	600

# Covariance Matrices

$$\chi^2 = \sum_s^{samples} \sum_{p,t} 2 \left( M_{pt}^s - D_{pt}^s + D_{pt}^s \times \log \left( \frac{D_{pt}^s}{M_{pt}^s} \right) \right) + \sum_c^{syst-cat.} \left( \sum_n \sum_{n'} \left( \alpha_n - \alpha_n^{prior} \right) V_{nn'}^{-1} \left( \alpha_{n'} - \alpha_{n'}^{prior} \right) \right)$$

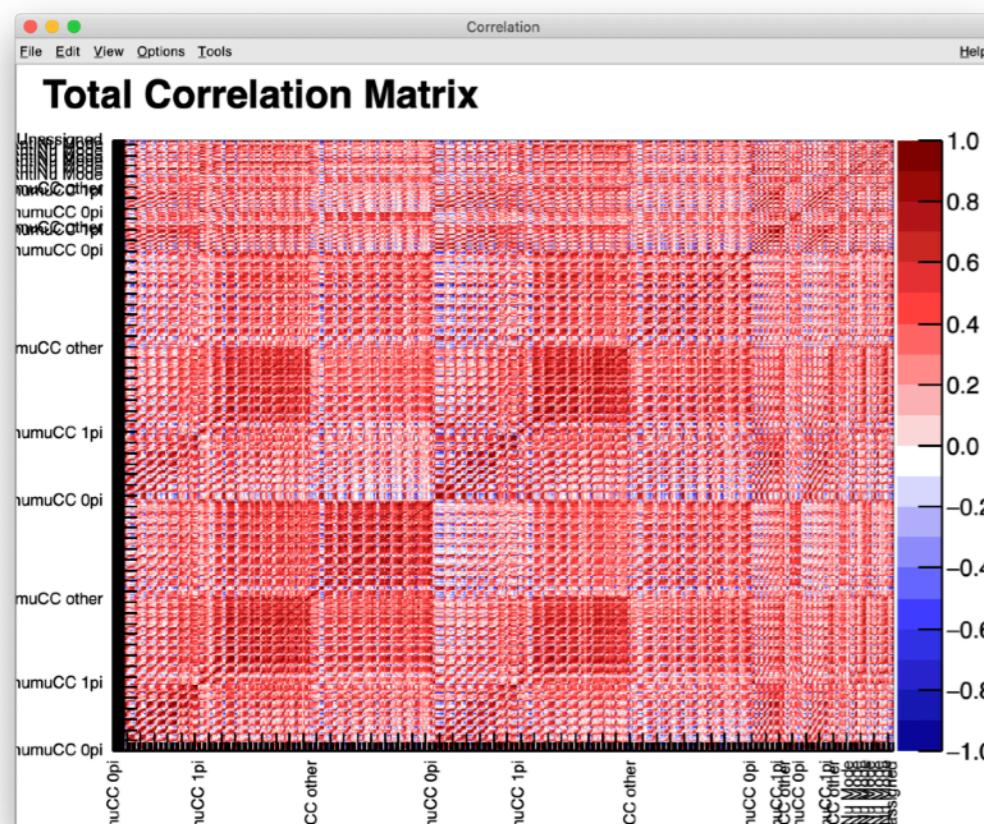
# Detector covariance matrix (January 2020)

<http://www.hep.ph.ic.ac.uk/~wparker/T2K/NDCovs/>

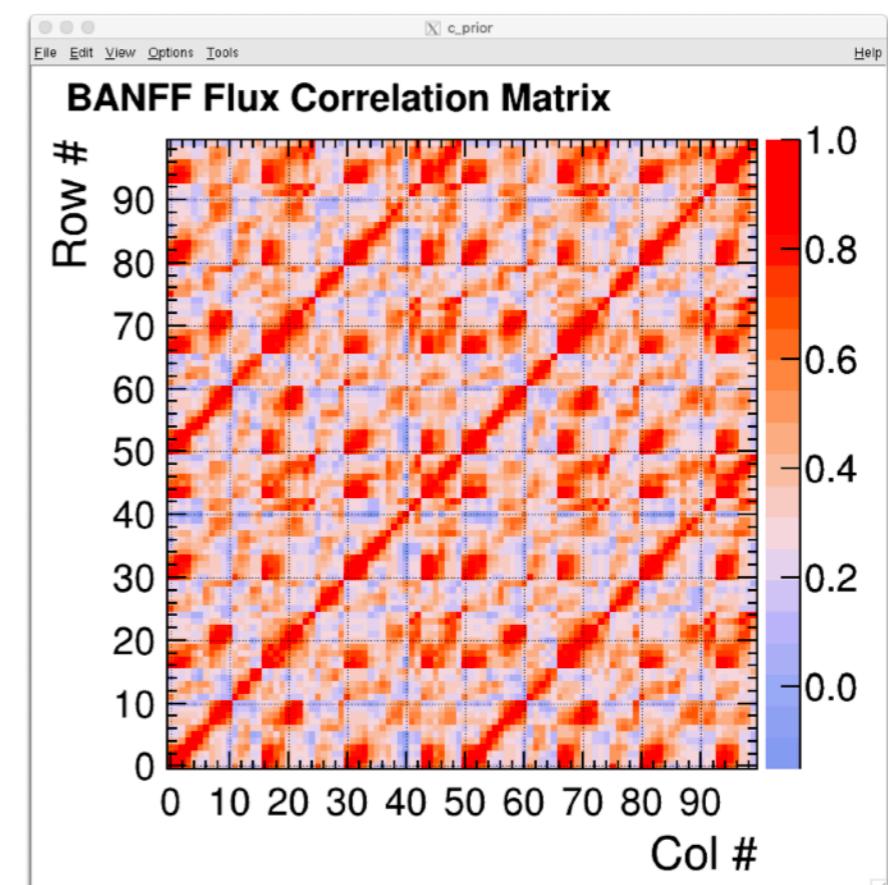
# Flux covariance matrix (December 2019)

<https://t2k.org/beam/NuFlux/FluxRelease/13areplica/13av6/13av6-flux-uncertainty>

## Detector covariance matrix



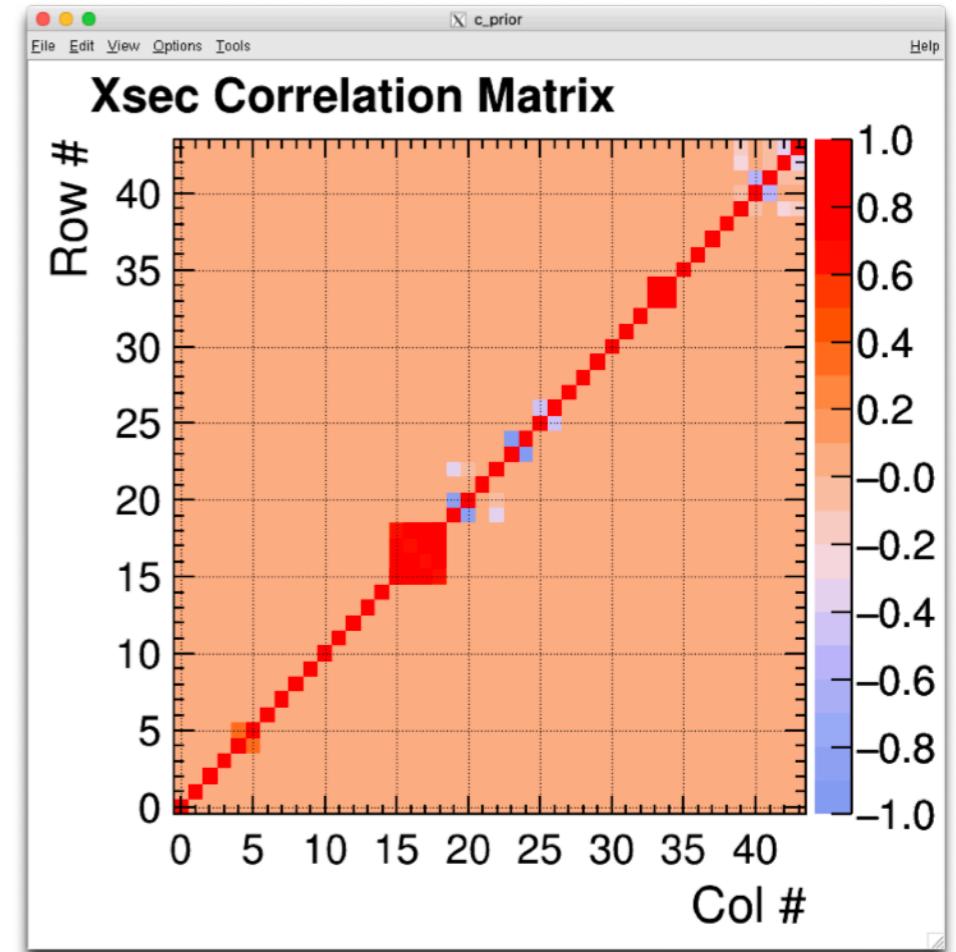
## Flux covariance matrix



# Covariance Matrices

**Xsec covariance matrix (on iRODS)**

[/QMULZone1/home/asg/asg2019oa/xseccovs](file:///QMULZone1/home/asg/asg2019oa/xseccovs)

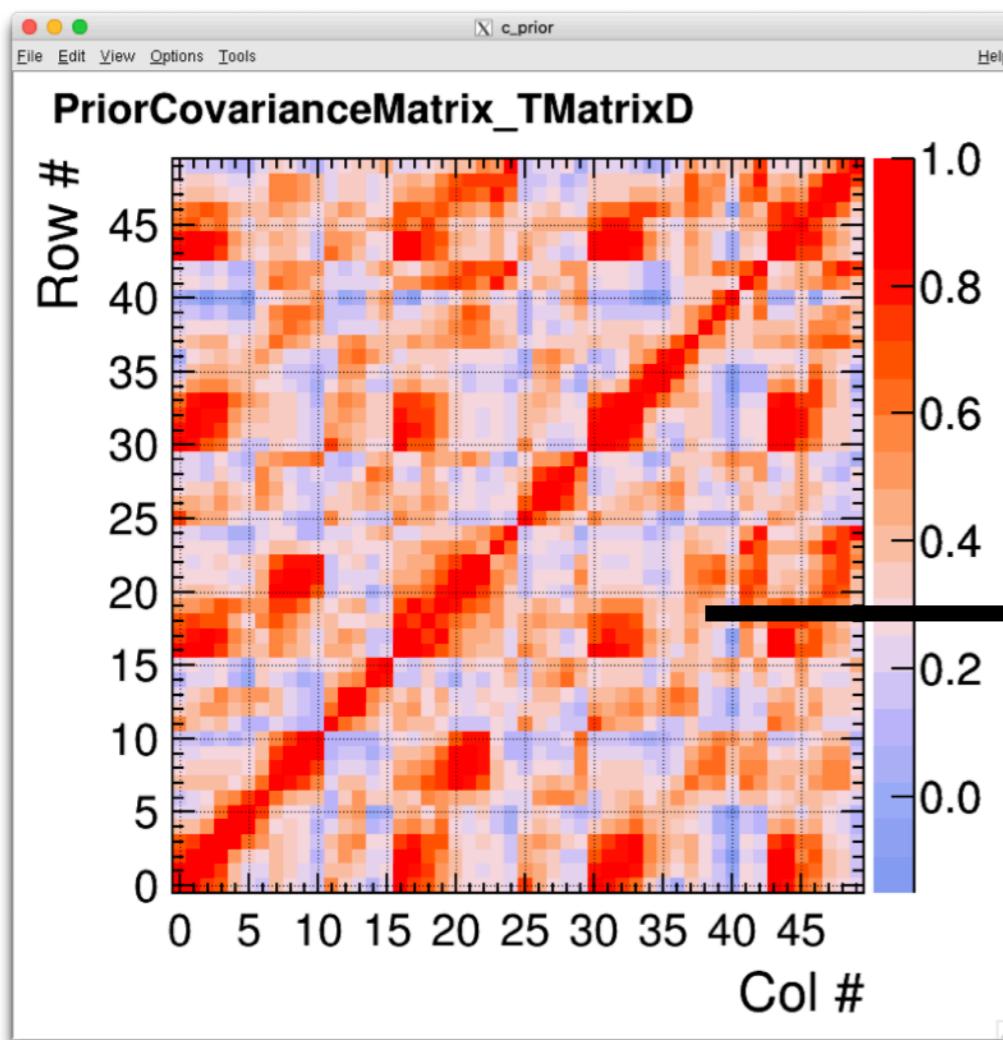


**Need to generate splines to propagate the effect of the cross-section uncertainties**

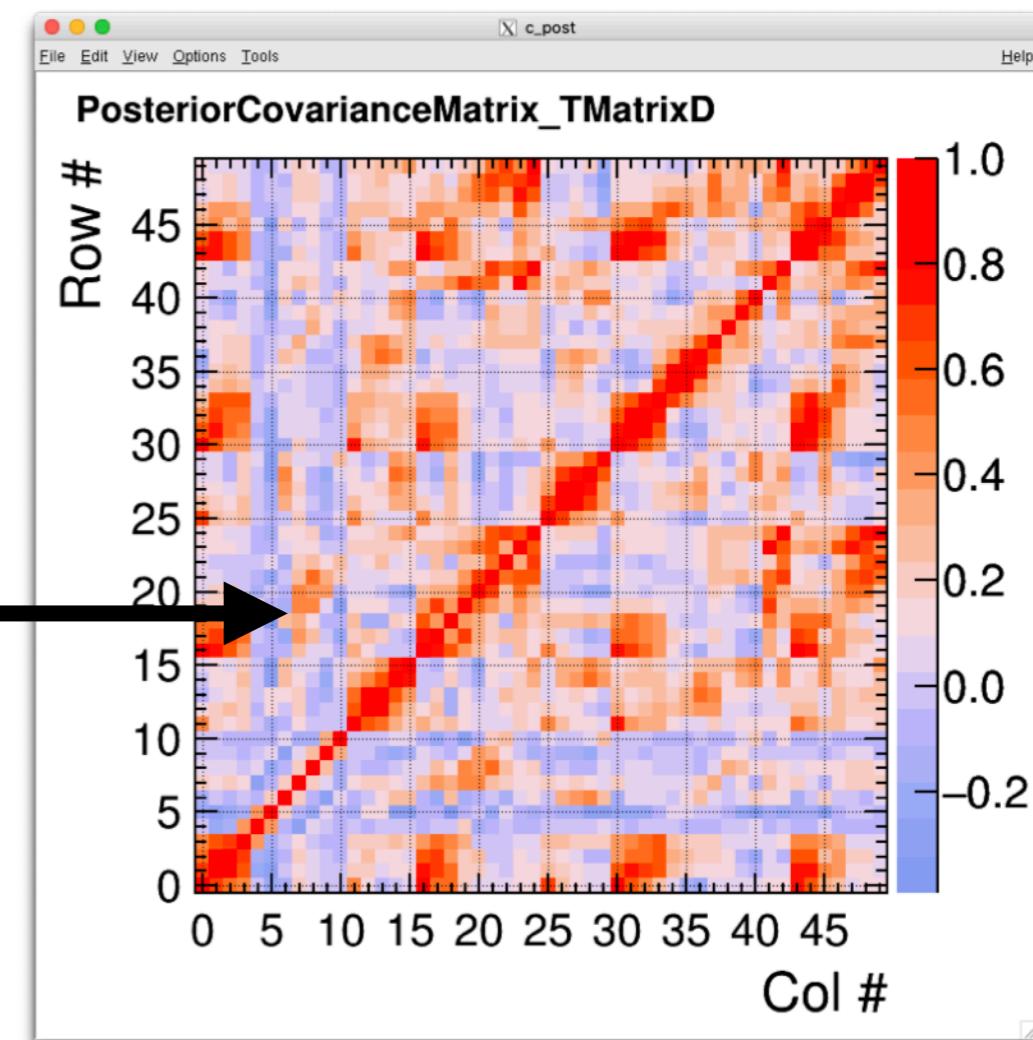
# First Fit Attempt With Flux Covariance

## Ingredients :

- Using MC files from run2a
- BANFF binning in p\_mu, cos\_theta
- Using 3 Samples (not 9 yet)
  - Numu + CC0Pi selection cuts
  - Numu + CC1Pi selection cuts
  - Numu + CCOther selection cuts
- BANFF flux covariance matrix (only ND280 part)
- Approx. 10 mins of computing



*Fit*



A photograph of a vast field of small, light-blue flowers, likely nemophila, covering a hillside. A single, tall pine tree stands prominently on the crest of the hill. In the background, several tall power transmission towers with multiple cross-arms are visible against a clear blue sky with a few wispy clouds.

# Thanks for Listening

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