Ongoing Activities Report April 2020

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LPNHE - (Paris)

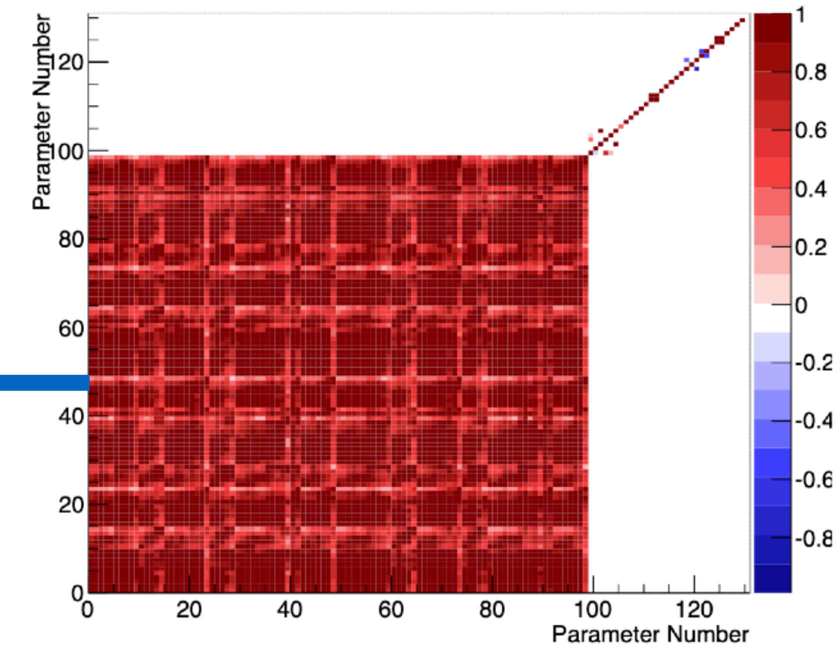
The 28th of April 2020

Ikenoyama (Autumn)

ND280 Upgrade

Principle of the ND280 Fit

(The BANFF is in charge of this)



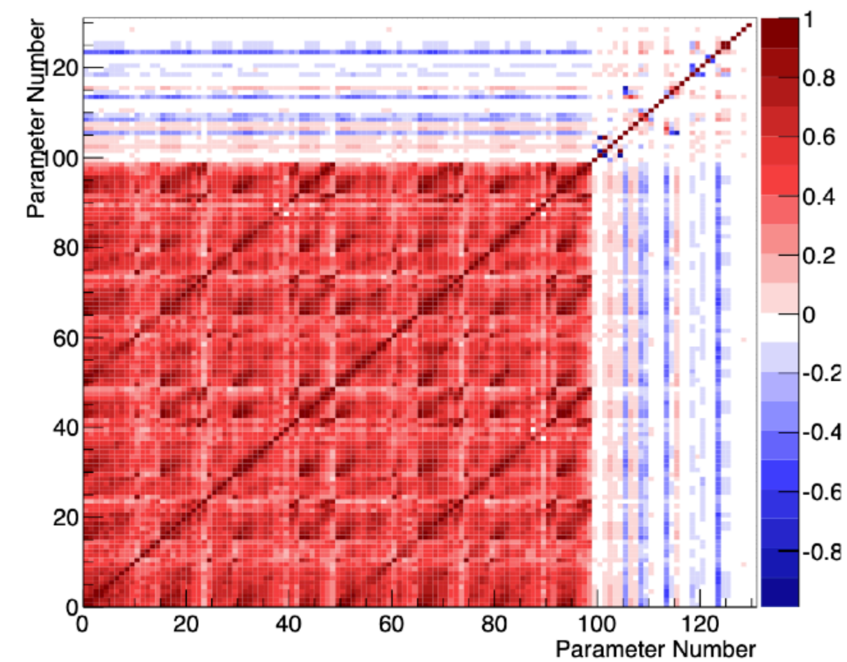
- Take the **covariance matrix of the flux/cross-section** we got from **other measurements**

- **Plug** the matrix **in the Chi2**

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

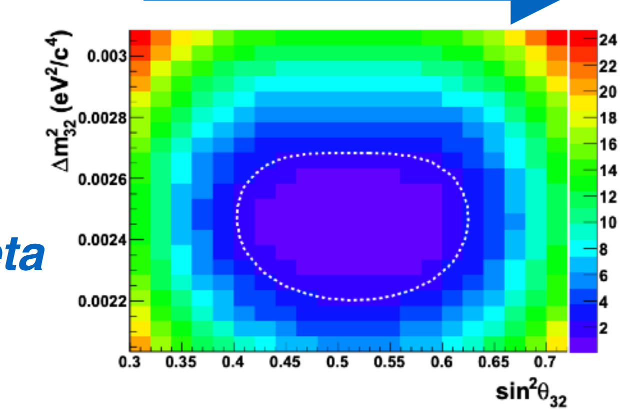
- **Fit the nuisance parameters**

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



- Plug the new matrix into SK oscillation analysis

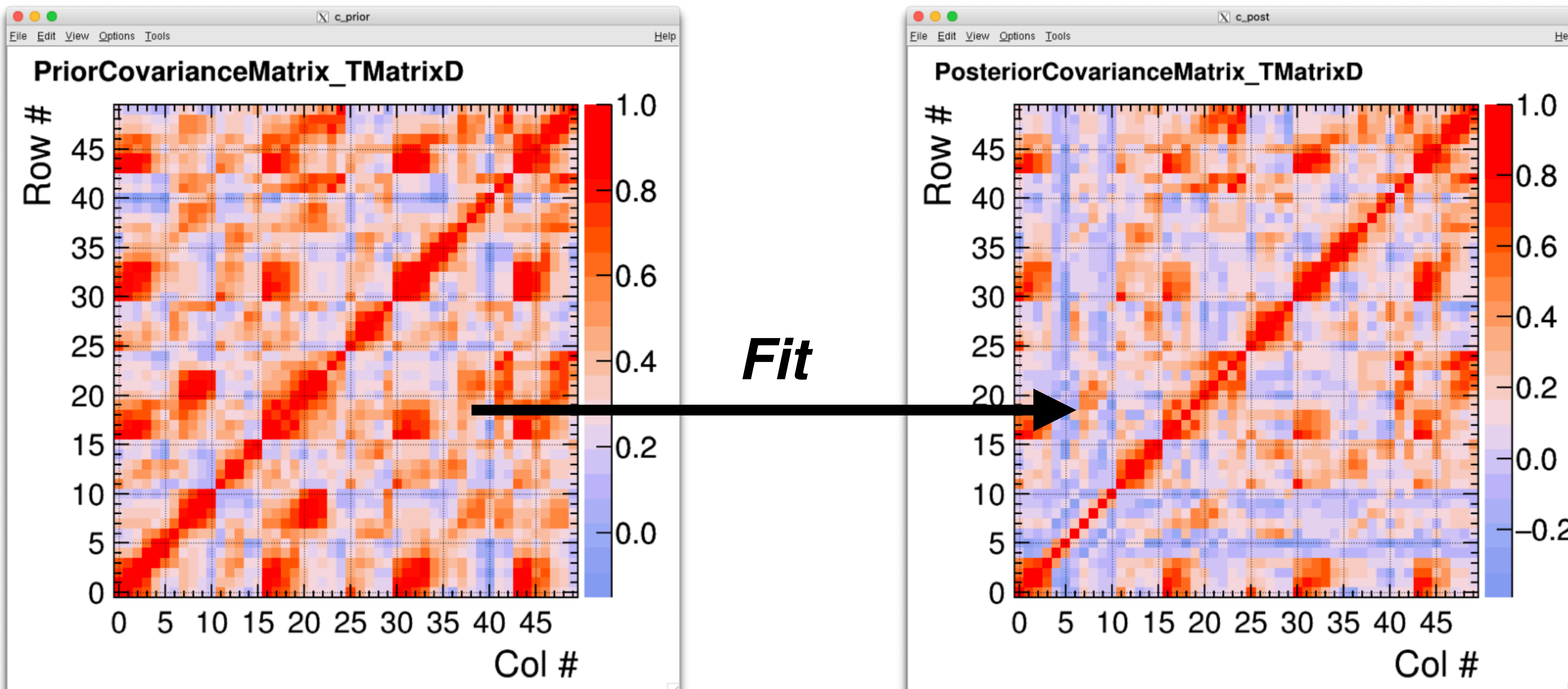
Ex: Use of P-Theta



First Fit Attempt With Flux Covariance

Ingredients :

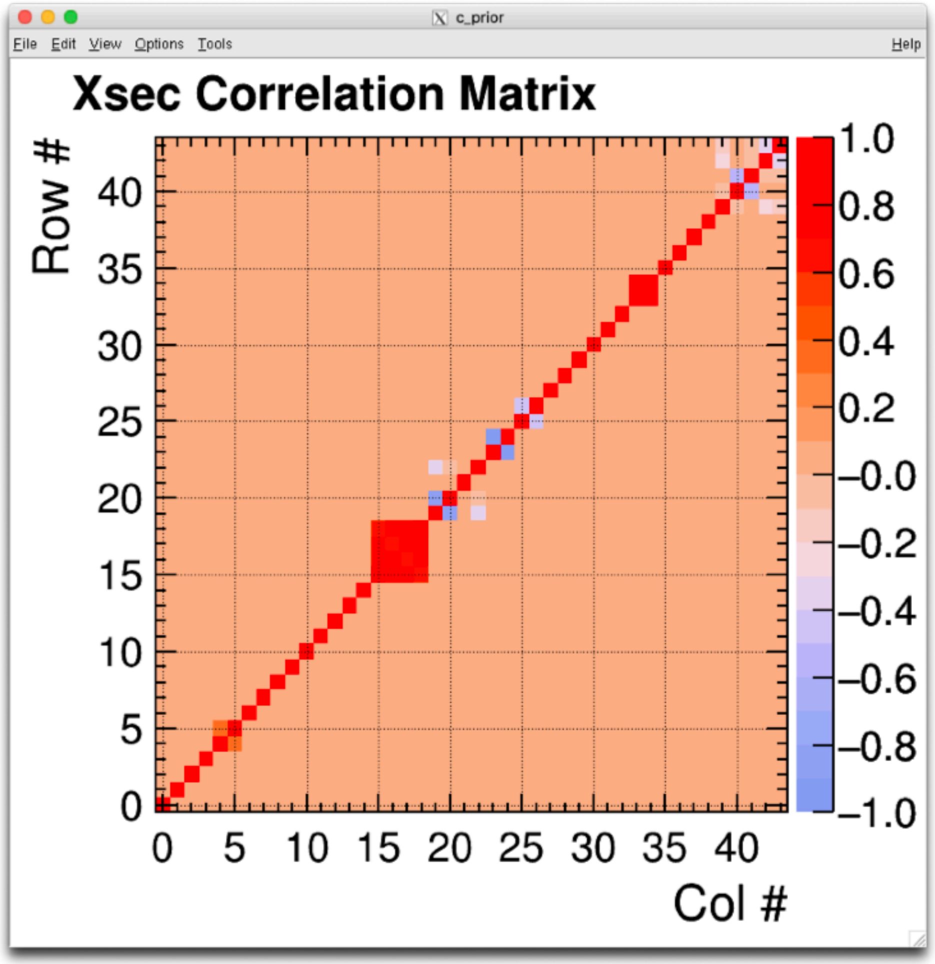
- Using MC files from run2a
- BANFF binning in p_mu, cos_theta
- Using 3 Samples (not 9 yet)
  - Numu + CC0Pi selection cuts
  - Numu + CC1Pi selection cuts
  - Numu + CCOther selection cuts
- BANFF flux covariance matrix (only ND280 part)
- Approx. 10 mins of computing



Covariance Matrices

Xsec covariance matrix (on iRODS)

/QMULZone1/home/asg/asg2019oa/xseccovs

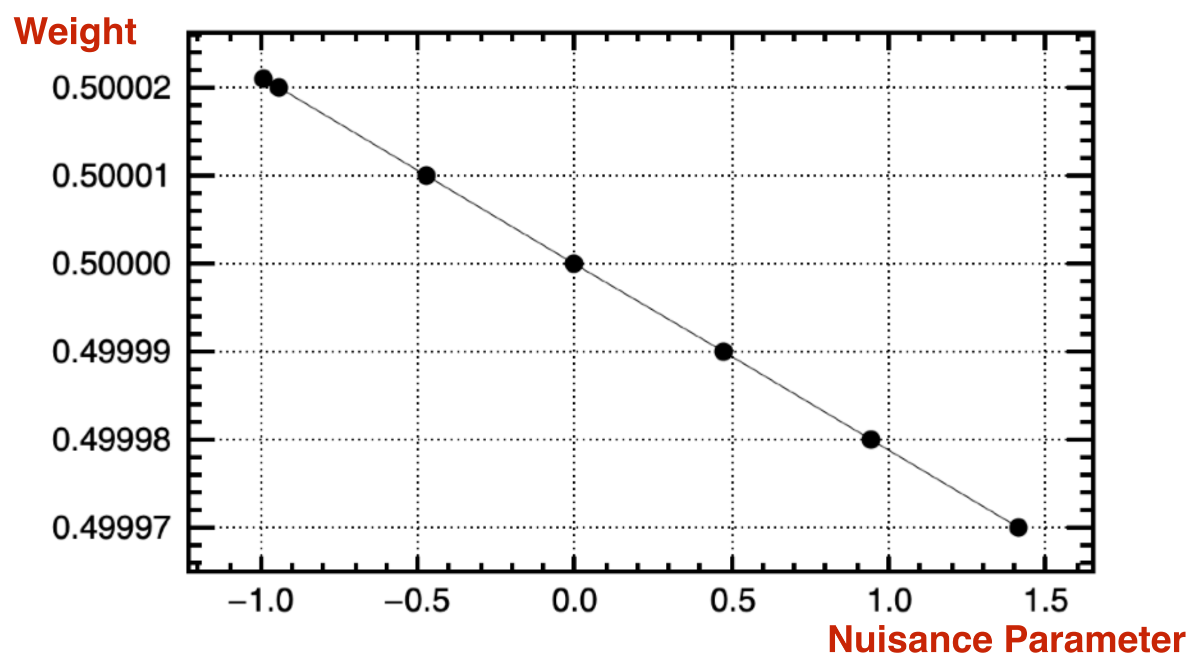


Need to generate splines to propagate the effect of the cross-section uncertainties

Using T2KReWeight

T2KReWeight is a collection of “reweight” engines **that propagate the effect of the systematic** uncertainties on **each event**.

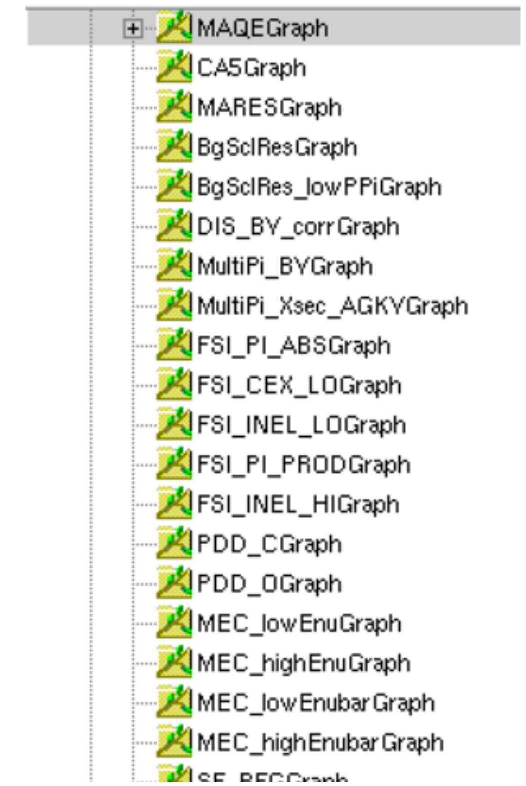
- With the nominal value of nuisance parameters, the event have a weight of “1”.
- Nuisance parameters **are sampled around the prior** (usually ~3 to 5 times) and the **events are re-weighted**.
- For each event, and each systematic, a graph is generated.



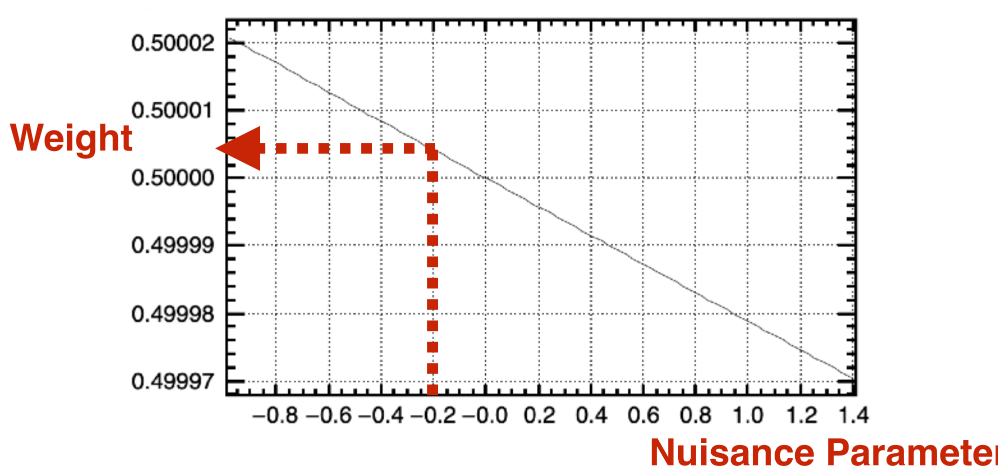
- 2020 OA has its weights generator : *genWeightsFromNRooTracker_BANFF_2020*
- BANFF is using its output to make “unbinned” splines
- *genWeightsFromNRooTracker_BANFF_2020* Generates graphs we wants for the covariance matrix

Using T2KReWeight

- *genWeightsFromNRooTracker_BANFF_2020* Generates graphs we wants for the covariance matrix



- How does the BANFF use these files ?
  - (A) Consider a given **nuisance parameter**
  - (B) Take each event in the flat tree of the genWeights output file
  - (C) Get the **corresponding graph for each event**
  - (D) Convert each graph into splines (continuous)
  - (E) Apply the corresponding weight to the events
  - (F) Gather all the reweighted events in the [p_mu, cos_theta_mu] histogram for the fit



- How does the xsllhFitter deals with systematics ?
  - (A) Consider a given **nuisance parameter**
  - (B) Take a collection of splines that each belong to a given bin (let's say p_mu, ct_mu)
  - (C) Take each event in the MC tree and **attribute them a given spline bin**
  - (D) Reweight the events according to their designated binned spline
  - (E) Gather all the reweighted events in the [p_mu, cos_theta_mu] histogram for the fit

- Need to build those binned splines

Building Binned Splines

- **xsllhGenWeightsBinner** is in charge on this task (my new xsllhFitter executable)
  - xsllhFit uses pre-formatted MC TTrees
  - Make the connection between
  - Match all events within the genWeights output file (meaning the flat-tree associated to the graphs trees)
  - “Run”, “SubRun” and “vertexID” are used to identify all the events

```
[xsllhGenWeightsBinner] Openning genWeights file /sps/t2k/ablanche/work/results/irods/r
r_BANFF_2020_run8w_FlatTree_v2r41_11_25_061.root 191/226...
[xsllhGenWeightsBinner] Building tree sync cache...
[xsllhGenWeightsBinner] Synchronizing trees... (64 matches,2240 miss) : 100%
[xsllhGenWeightsBinner] Grabbing Splines Graphs... (unknown branches may appear)
[xsllhGenWeightsBinner] Looping over all the genWeights entries...
[xsllhGenWeightsBinner] 751 graphs found : 100%
[xsllhGenWeightsBinner] Freeing up memory...
```

  - Extract all “good” graphs, gather them in their corresponding bin (p_mu, ct_mu, topology and reaction)
    - *Directly inspired by the BANFF code to make the extraction*
  - Make an averaged graph out of all the graphs in a corresponding bin
  - Convert the averaged graphs into splines

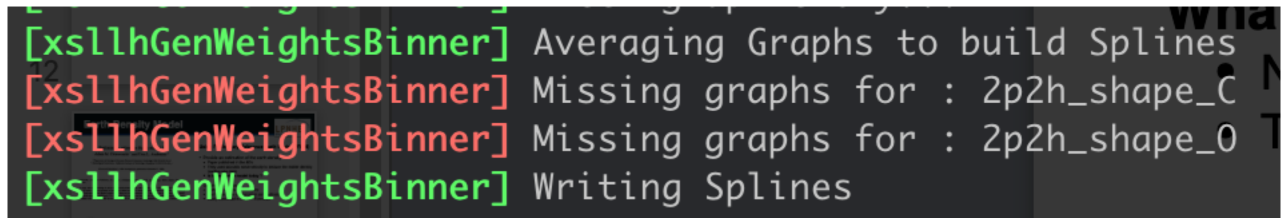
- Some xsec splines are not present in genWeight file : behaving as norm factor
  - Generating those in the same format

- Generate a json config file with all the parameters the fitter need:
  - Systematic name
  - Nominal value
  - Limits
  - Path to the File

Building Binned Splines

What's left to do ?

- Need to generate the splines for anti-neutrinos
- Only ~5 to 10% of the genWeights file are matching (am I cutting too much events ?)
- 2p2h_shape splines are missing (graphs are present):



- For the moment, chopping the matrix
- Some bins are still empty : interpolation needs to be implemented
- Still need to understand some parameters in the fitter config files…
- ND280 fit should be working then

T2K-SK Joint Fit

Generating Atmospheric Neutrinos

- **Using Honda et al. model used for SK analysis**
  - http://www.icrr.u-tokyo.ac.jp/~mhonda/
  - Each neutrino have been simulated
    - Based on cosmogenic muon flux measurements
    - Taking into account seasons fluctuations
    - Including the shadowing of the mountain over SK
    - 2 data samples provided regarding solar activity
  - Data files are delivered with 3 variables:
    - Neutrino energy
    - Cosinus of the zenith angle in SK
    - Phi angle (coarser binning)
  - Convert the data file into 2D ROOT histograms
    - Averaging over phi angle
    - Python script
  - **What's not included ?**
    - Detector acceptance wrt to angle / energy / neutrino type
      - *Assuming uniform inefficiency*

PHYSICAL REVIEW D **92**, 023004 (2015)

Atmospheric neutrino flux calculation using the NRLMSISE-00 atmospheric model

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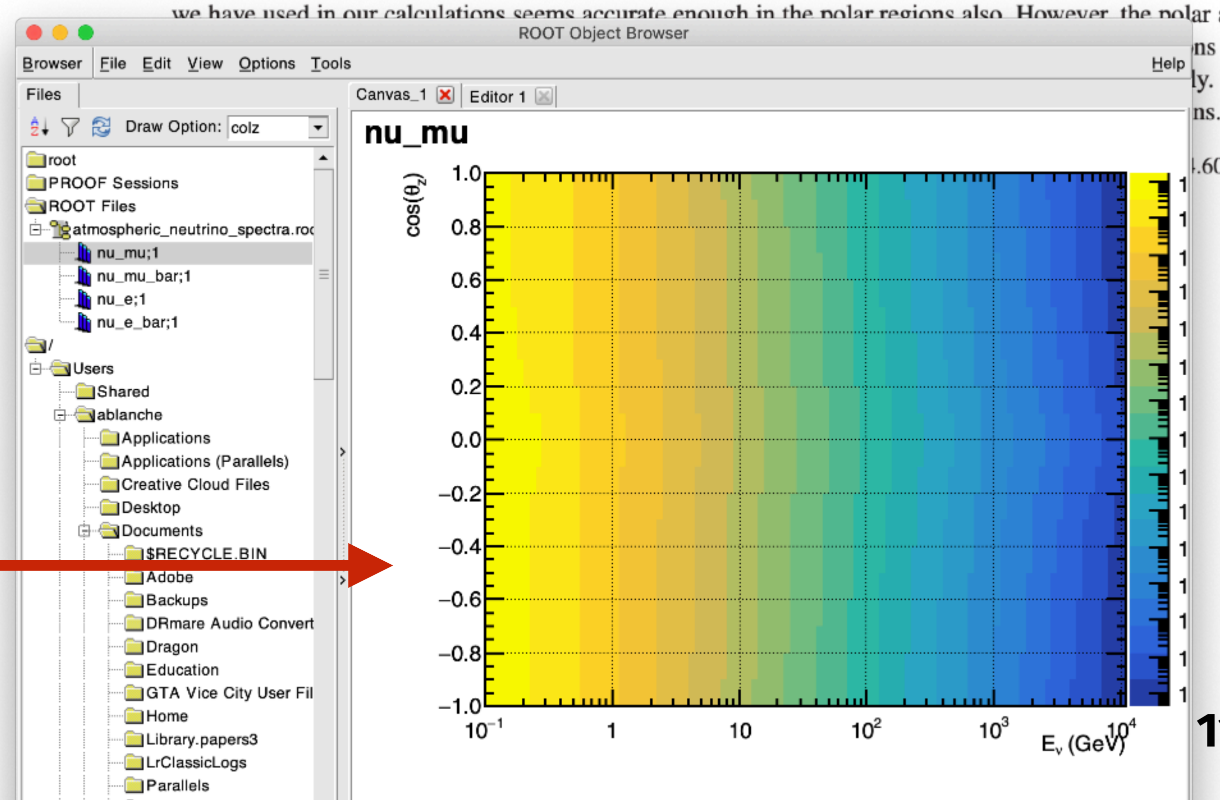
(Received 13 February 2015; published 7 July 2015)

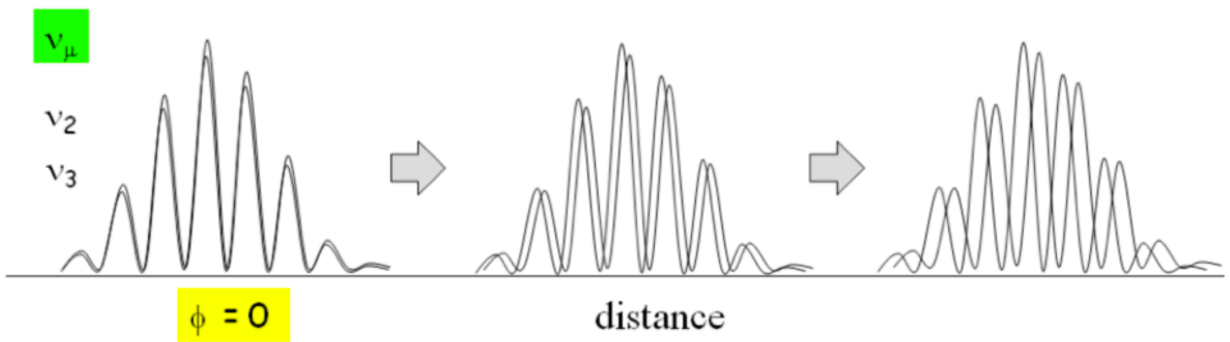
We extend our calculation of the atmospheric neutrino fluxes to polar and tropical regions. It is well known that the air density profiles in the polar and the tropical regions are different from the mid-latitude region. Also there are large seasonal variations in the polar region. In this extension, we use the NRLMSISE-00 global atmospheric model J. M. Picone, J. Geophys. Res. 107, SIA 15 (2002), replacing the U.S.-standard 1976 atmospheric model, which has no positional or seasonal variations. With the NRLMSISE-00 atmospheric model, we study the atmospheric neutrino flux at the polar and tropical regions with seasonal variations. The geomagnetic model international geomagnetic reference field (IGRF) we have used in our calculations seems accurate enough in the polar regions also. However, the polar and ... ns are ... ly. We ... ns.

```
average flux in [cosZ = 0.90 --  1.00, phi_Az =   0 --  30]
 Enu(GeV)   NuMu      NuMubar    NuE       NuEbar   (m^2 sec sr GeV)^-1
 1.0000E-01 4.2450E+03 4.2685E+03 2.0463E+03 2.0858E+03
 1.1220E-01 3.8774E+03 3.8962E+03 1.8578E+03 1.8797E+03
 1.2589E-01 3.5241E+03 3.5282E+03 1.6616E+03 1.6872E+03
 1.4125E-01 3.1769E+03 3.1838E+03 1.5010E+03 1.5004E+03
 1.5849E-01 2.8239E+03 2.8369E+03 1.3326E+03 1.3150E+03
 1.7783E-01 2.4907E+03 2.4895E+03 1.1667E+03 1.1472E+03
 1.9953E-01 2.1749E+03 2.1639E+03 1.0176E+03 9.8667E+02
 2.2387E-01 1.8667E+03 1.8681E+03 8.7223E+02 8.3984E+02
 2.5119E-01 1.6000E+03 1.5946E+03 7.4152E+02 7.1126E+02
 2.8184E-01 1.3560E+03 1.3410E+03 6.2755E+02 5.9460E+02
 3.1623E-01 1.1335E+03 1.1158E+03 5.2543E+02 4.9261E+02
```



Neutrino Propagation in Matter

- **Neutrino oscillation are:**
  - The consequence of a mixing (propagation and interaction states are different)
  - Effect of interference between mass states
  - Manifestation of change of the relative phase



- Propagation through matter affect the mass states

$$i\frac{d\nu_m}{dx} = H^{\text{diag}}\nu_m,$$

  - The Hamiltonian have dependency on the local electron density (and neutron density as well)
  - This leads to new mass states, and thus new mixing with interaction states
  - If matter density is varying, off diagonal terms appears

$$i\frac{d\nu_m}{dt} = \begin{pmatrix} H_{1m} & -i\dot{\theta}_m \\ i\dot{\theta}_m & H_{2m} \end{pmatrix} \nu_m,$$

  - Translate the fact that neutrino can jump mass states when matter density change too quickly (it's what happen in the sun)
    - **Called the MSW effect**

Earth Density Model

LPNHE PARIS

Preliminary reference Earth model *

Adam M. Dziewonski [1] and Don L. Anderson [2]

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(Received December 3, 1980; accepted for publication December 5, 1980)

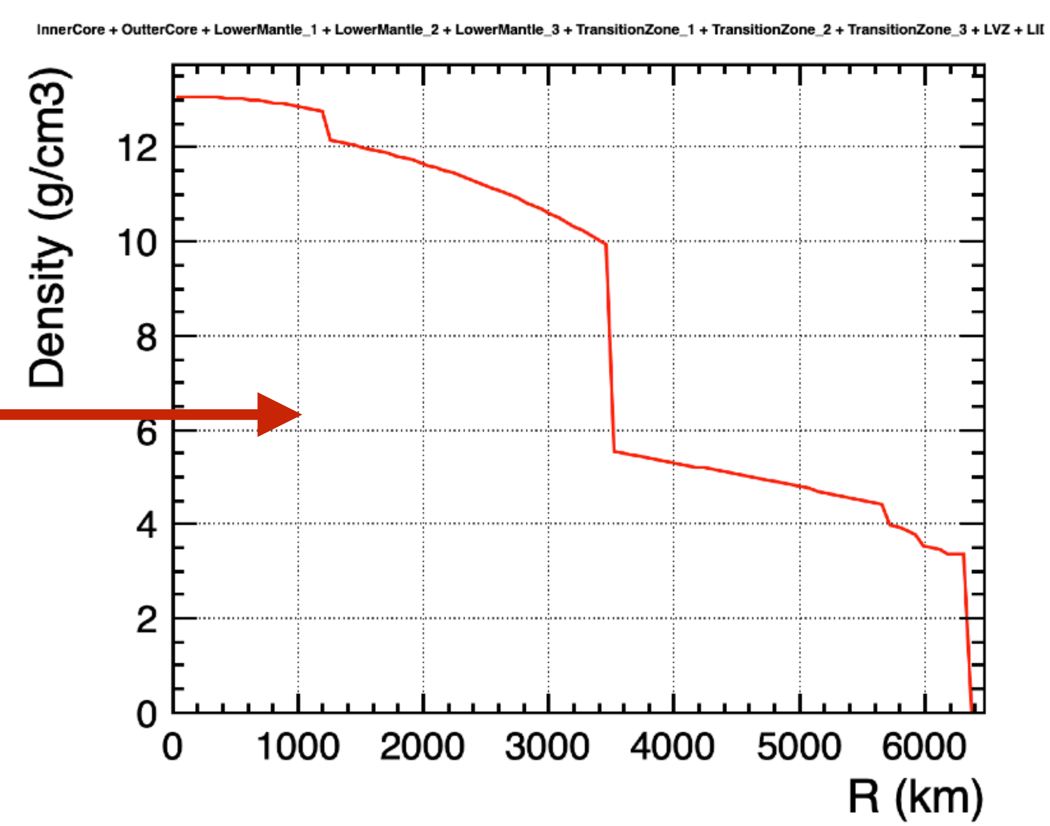
Dziewonski, A.M. and Anderson, D.L., 1981. Preliminary reference Earth model. Phys. Earth Planet. Inter., 25: 297–356.

A large data set consisting of about 1000 normal mode periods, 500 summary travel time observations, 100 normal mode Q values, mass and moment of inertia have been inverted to obtain the radial distribution of elastic properties, Q values and density in the Earth's interior. The data set was supplemented with a special study of 12 years of ISC phase data which yielded an additional 1.75×10^6 travel time observations for P and S waves. In order to obtain satisfactory agreement with the entire data set we were required to take into account anelastic dispersion. The introduction of

- **Using Preliminary Reference Earth Model (PREM)**
  - Provide an estimation of the earth density
    - Paper published in the 80's
    - They used acoustic wave velocity to deduce the matter density (earthquake data)
    - **Is there a better model today ?**
  - Utilising their data
    - Gather in several layers layers
    - Each layer have a polynomial parametrisation
    - Easily converted in ROOT TFormulae

TABLE I
Coefficients of the polynomials describing the Preliminary Reference Earth Model (PREM). The variable x is the normalized radius: $x=r/a$ where $a=6371$ km. The parameters listed are valid at a reference period of 1 s

Region	Radius (km)	Density (g cm^{-3})	V_P (km s^{-1})	V_S (km s^{-1})	Q_μ	Q_K
Inner core	0–1221.5	$13.0885 - 8.8381x^2$	$11.2622 - 6.3640x^2$	$3.6678 - 4.4475x^2$	84.6	1327.7
Outer core	1221.5–3480.0	$12.5815 - 1.2638x - 3.6426x^2 - 5.5281x^3$	$11.0487 - 4.0362x + 4.8023x^2 - 13.5732x^3$	0	∞	57823
Lower mantle	3480.0–3630.0	$7.9565 - 6.4761x + 5.5283x^2 - 3.0807x^3$	$15.3891 - 5.3181x + 5.5242x^2 - 2.5514x^3$	$6.9254 + 1.4672x - 2.0834x^2 + 0.9783x^3$	312	57823
	3630.0–5600.0	$7.9565 - 6.4761x + 5.5283x^2 - 3.0807x^3$	$24.9520 - 40.4673x + 51.4832x^2 - 26.6419x^3$	$11.1671 - 13.7818x + 17.4575x^2 - 9.2777x^3$	312	57823
	5600.0–5701.0	$7.9565 - 6.4761x + 5.5283x^2 - 3.0807x^3$	$29.2766 - 23.6027x + 5.5242x^2 - 2.5514x^3$	$22.3459 - 17.2473x - 2.0834x^2 + 0.9783x^3$	312	57823
Transition zone	5701.0–5771.0	$5.3197 - 1.4836x$	$19.0957 - 9.8672x$	$9.9839 - 4.9324x$	143	57823
	5771.0–	11.2494	39.7027	22.3512	143	57823



Earth Density Model

- **Which Uncertainties on PREM ?**
    - Consider them as negligible as a first order approx
    - Might have to include them as some point

No detection smearing effects

https://www.nature.com/articles/srep15225

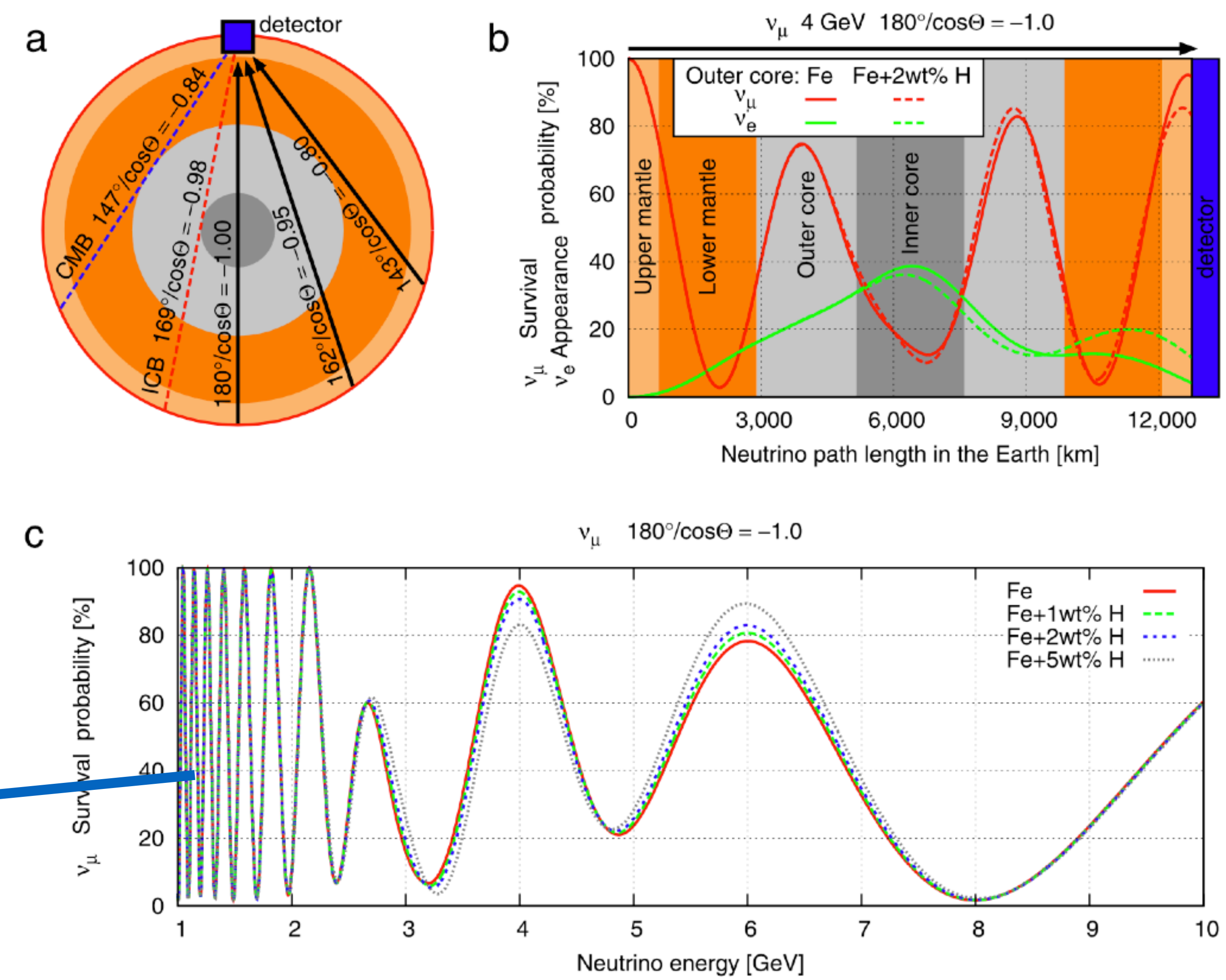


Figure 1. (**a**) Schematic diagram of a neutrino's path through the Earth and the corresponding zenith angles. The inner core boundary (ICB) at $\Theta = 169^\circ$ and the core mantle boundary (CMB) at $\Theta = 147^\circ$ are indicated by dashed red and blue lines, respectively. (**b**) ν_e appearance probability (green) and ν_μ survival probability (red) as functions of path length in the Earth. The neutrino direction is $\Theta = 180^\circ$, as shown in (**a**). The solid/dashed line corresponds to the case in which the composition of the outer core is pure iron/a mixture of iron and 2 wt% hydrogen. (**c**) $\Theta = 180^\circ - \nu_\mu$ survival probabilities as a function of neutrino energy for different outer core compositions. The solid (red), long dashed (green), short dashed (blue), and dotted (gray) lines represent iron, a mixture of iron and 1 wt% hydrogen, a mixture of iron and 2 wt% hydrogen, and a mixture of iron and 5 wt% hydrogen, respectively.

Neutrino Propagation in Matter

- **Neutrino propagation through the earth ?**
  - As Blennow et al. (2013) says :

4.1. *Propagation of Neutrinos through the Earth.* Flavor neutrino evolution in the Earth is essentially oscillations in a multi-layer medium with slowly changing density in the individual layers and sharp density change on the borders of layers. For energies $E > 0.1$ GeV, possible short-scale inhomogeneities of the matter distribution can be neglected and the density profile experienced by neutrinos is symmetric with respect to the midpoint of the trajectory:

$$V(x) = V(L - x). \qquad (141)$$

  - Can neglect state conversions on the fly (No MSW = **adiabatic regime**)
  - Matter effects can either **enhance or suppress the oscillations**
  - We need to monitor the flavor composition along each neutrino track

- ModProb3++ is work package which can do this task
  - It's principle is based on Barger et al. (1980)
  - Consider the earth as multiple layers of constant density
  - This approx is satisfying for most of the phase space but start to show errors at E < 1GeV
  - These energies correspond to the T2K beam energy

- **Need to make more steps of constant density in matter**

Wallraff et al. (2015)

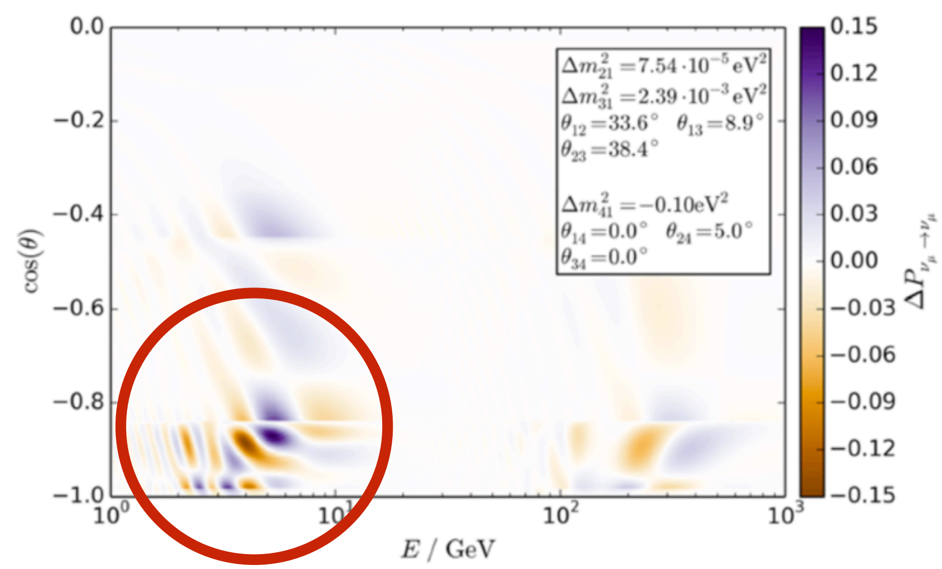
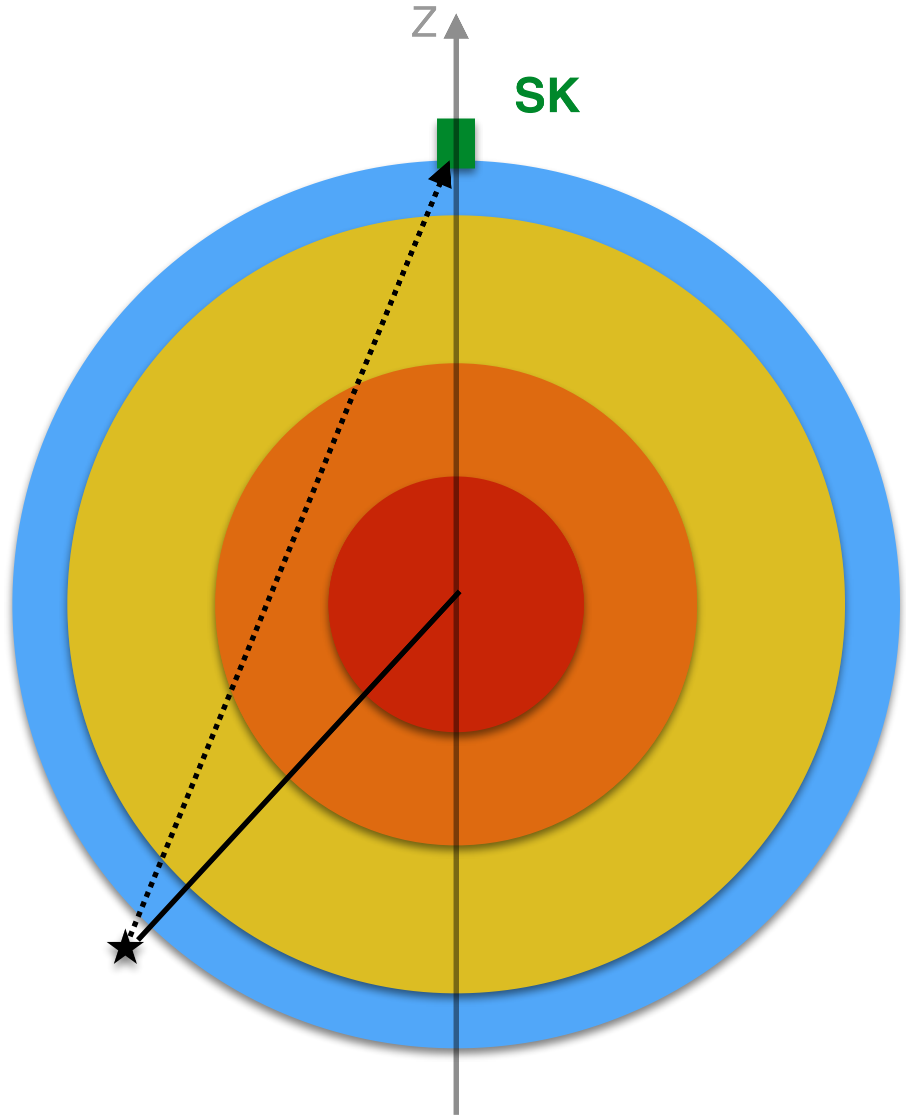
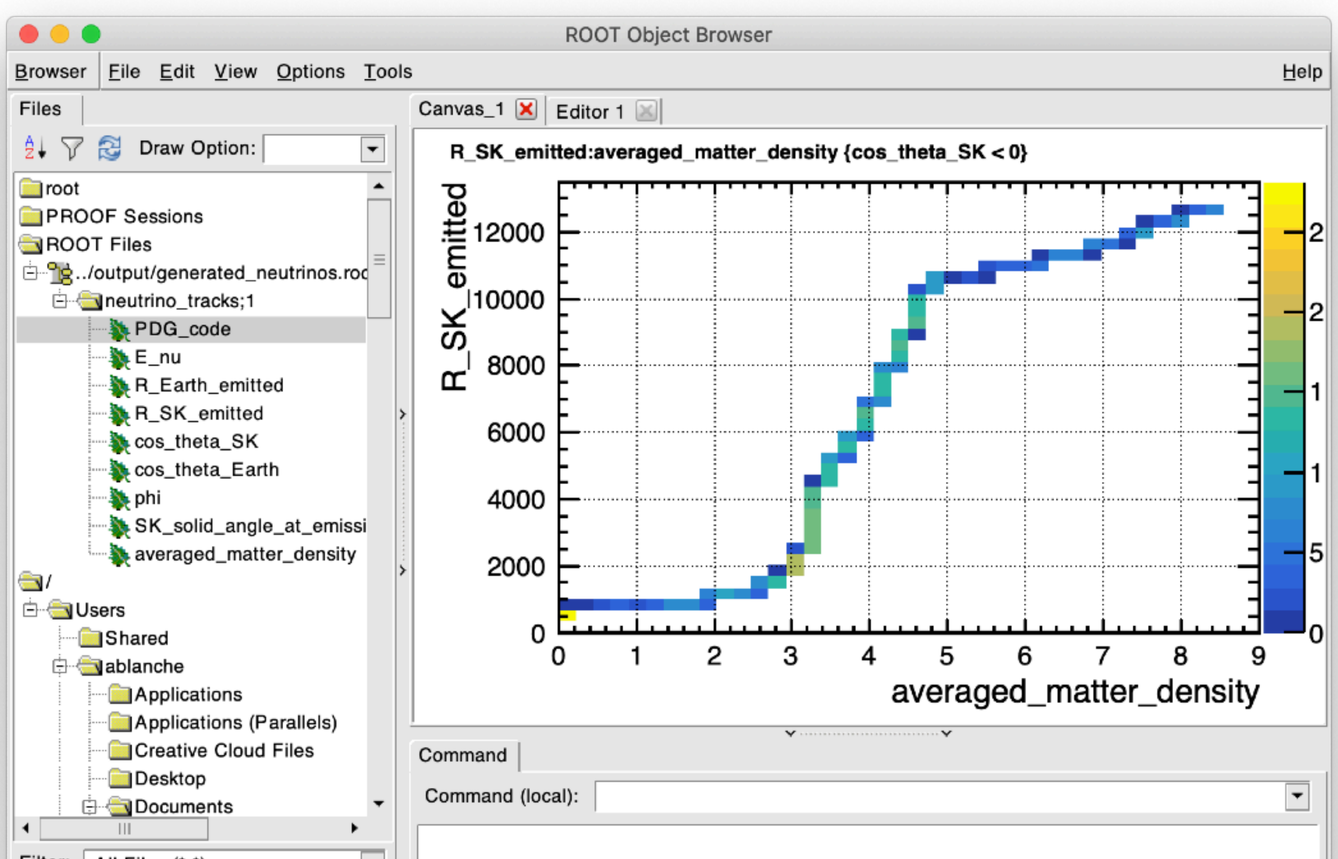


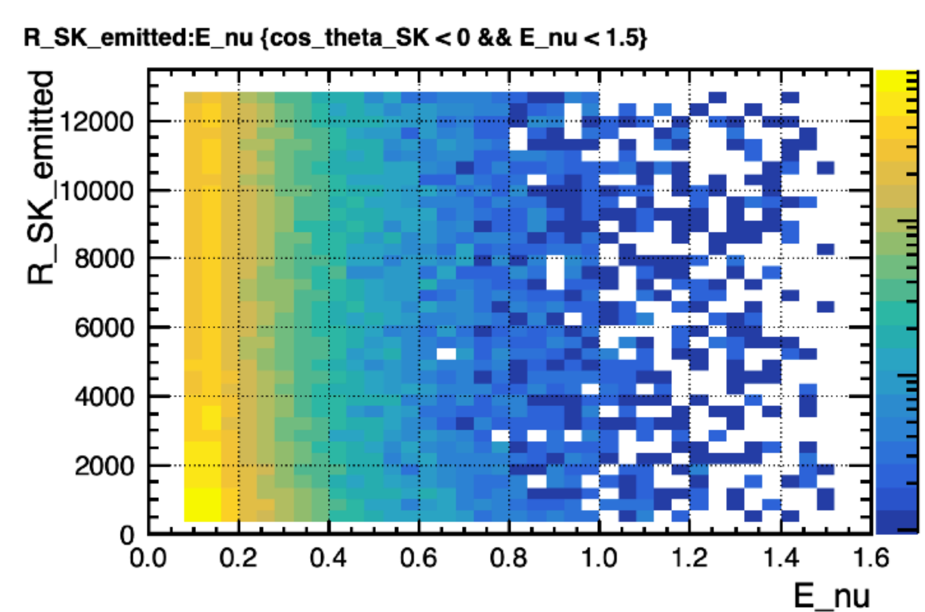
Fig. 6. Difference of the oscillation probability for the default Earth model as implemented in nuCraft and an Earth model with 4 layers of constant density. All oscillation parameters are identical to Fig. 5.

Neutrino Generator

- **Generating a neutrino track**
  - *Honda et al. provides all the information we need*
    - The normalisation of each histogram (nu_mu, nu_mu_bar, nu_e, nu_e_bar) gives the proportion of each neutrino type **(detection efficiency is not considered)**
    - Random sampling of the **Energy/cos_zenital_angle** in the 2D histograms
    - Uniform distribution in **phi**
    - Assuming constant neutrino **production altitude** (15km) : R(earth)
      - *More precise data are being implemented with energy/angular dependency*
  - *Deduce other useful observables*
    - **Propagation length :** radius component in the SK reference frame
    - **Average matter density :** follow the track by probing matter density at multiple steps from emission to SK
    - **SK solid angle :** area of SK (40m^2)/(propagation_length^2)



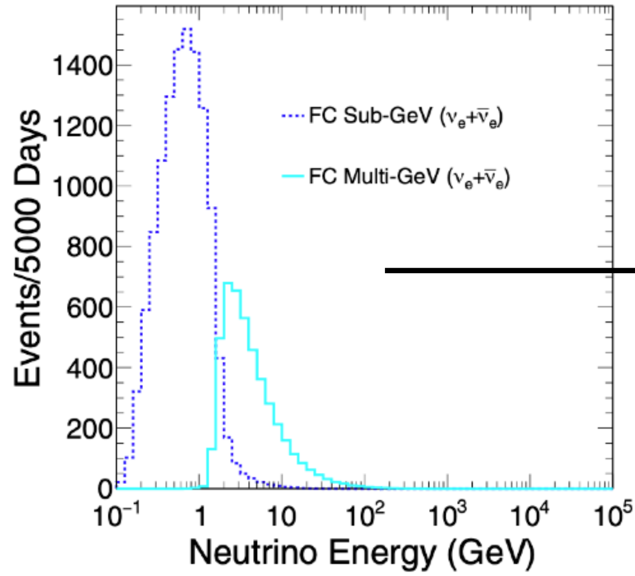




Neutrino Generator

What's left to do ?

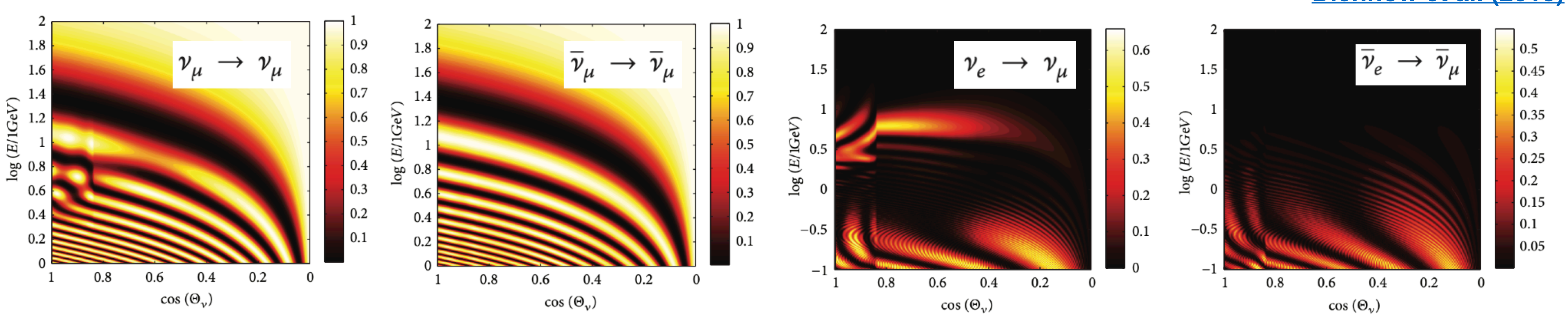
- Integrate rough estimation of the detection efficiencies : use SK paper for energy dependency



Compare this spectrum with the generated tracks

- Propagate neutrino through matter to monitor interaction states at SK
- Build expected oscillograms in SK and identify the regions of interest

Blennow et al. (2013)



Thanks for Listening