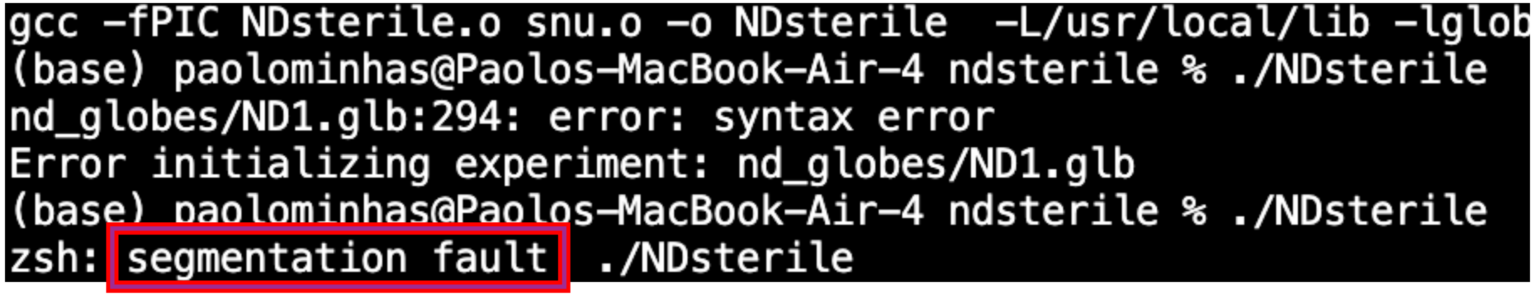
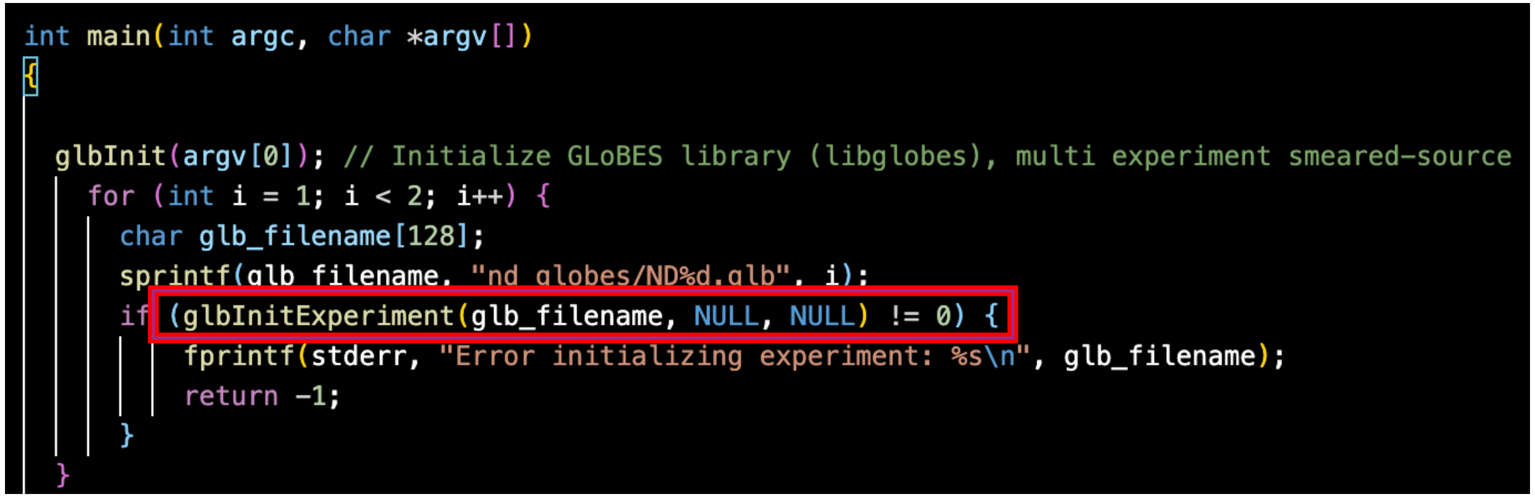
Sterile Neutrino Sensitivities

Paolo Minhas – Week 7

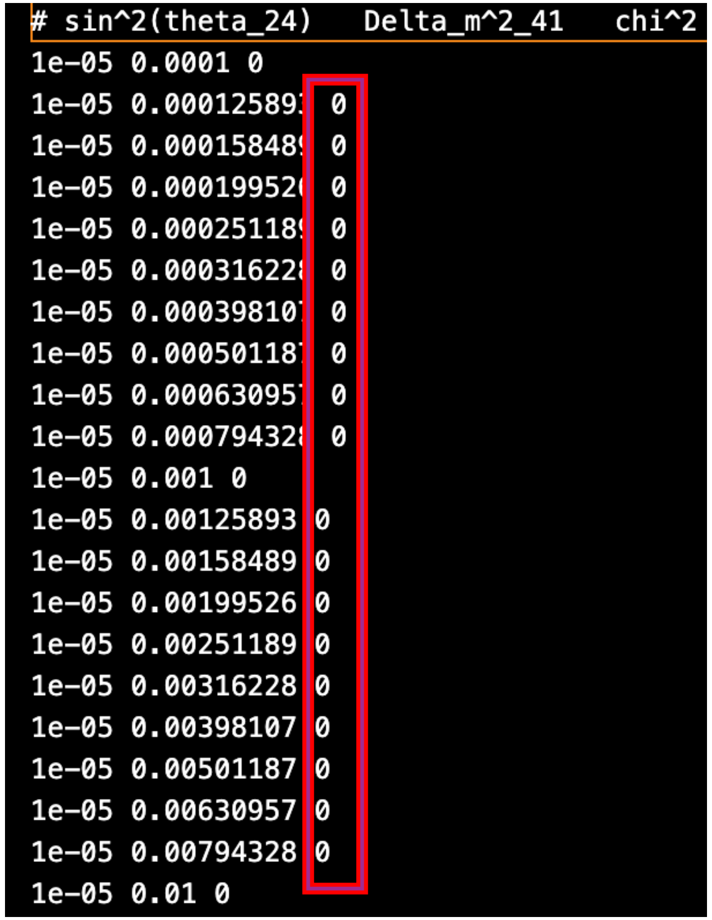
What was going wrong last week?



```
gcc -fPIC NDsterile.o snu.o -o NDsterile  -L/usr/local/lib -lglob
(base) paolominhas@Paolos-MacBook-Air-4 ndsterile % ./NDsterile
nd_globes/ND1.glb:294: error: syntax error
Error initializing experiment: nd_globes/ND1.glb
(base) paolominhas@Paolos-MacBook-Air-4 ndsterile % ./NDsterile
zsh: segmentation fault  ./NDsterile
```



```
int main(int argc, char *argv[])
{

  glbInit(argv[0]); // Initialize GLoBES library (libglobes), multi experiment smeared-source
    for (int i = 1; i < 2; i++) {
      char glb_filename[128];
      sprintf(glb_filename, "nd_globes/ND%d.glb", i);
      if (glbInitExperiment(glb_filename, NULL, NULL) != 0) {
          fprintf(stderr, "Error initializing experiment: %s\n", glb_filename);
          return -1;
      }
  }
```



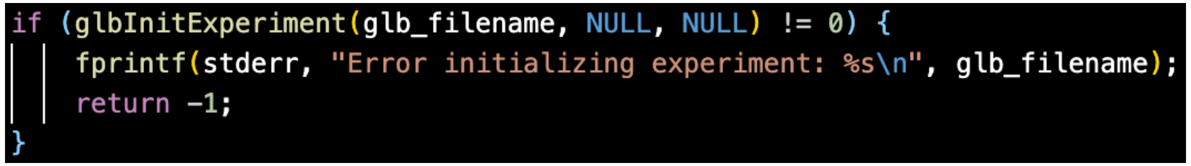
```
# sin^2(theta_24)   Delta_m^2_41   chi^2
1e-05 0.0001 0
1e-05 0.000125893 0
1e-05 0.000158489 0
1e-05 0.000199526 0
1e-05 0.000251189 0
1e-05 0.000316228 0
1e-05 0.000398107 0
1e-05 0.000501187 0
1e-05 0.000630957 0
1e-05 0.000794328 0
1e-05 0.001 0
1e-05 0.00125893 0
1e-05 0.00158489 0
1e-05 0.00199526 0
1e-05 0.00251189 0
1e-05 0.00316228 0
1e-05 0.00398107 0
1e-05 0.00501187 0
1e-05 0.00630957 0
1e-05 0.00794328 0
1e-05 0.01 0
```

Segmentation fault?

- Arise primarily due to errors in use of pointers for virtual memory addressing, particularly illegal access
- Had overwritten memory
- Had tried to put data in memory that didn’t exist
- Fixed by naming files properly and implementing using GLoBES and not a for loop

GLoBES Experiment Initialisation

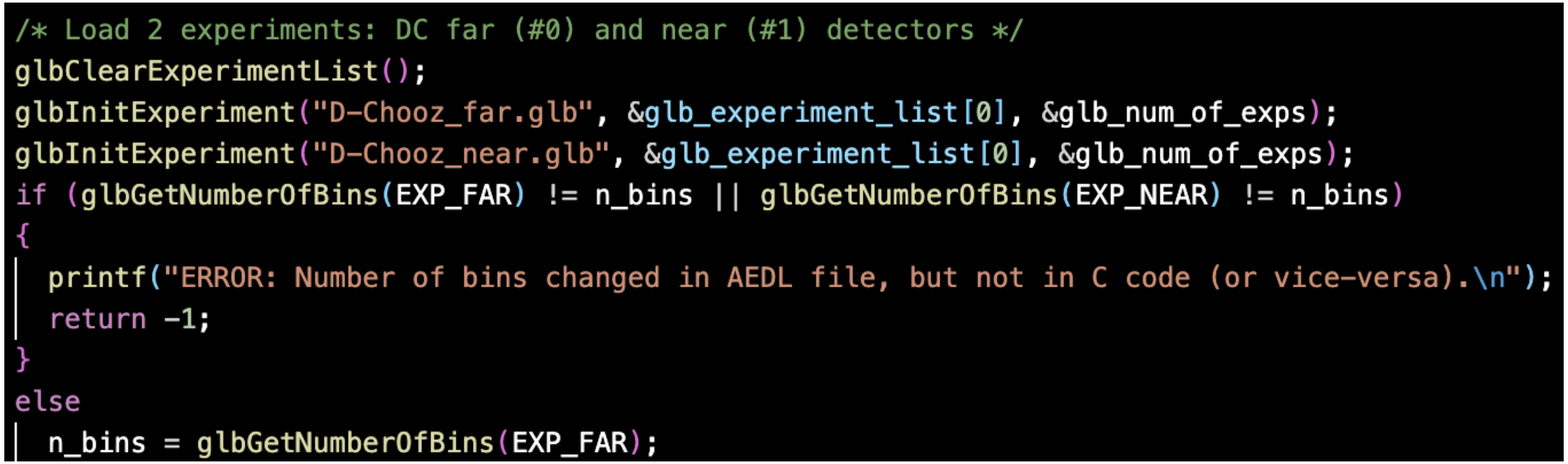
- When `glbInitExperiment()` is called in GLoBES it should be defined once, enumerating for each experiment
- This loop writes over the global definition ever iteration
- Hence the segmentation error



```
if (glbInitExperiment(glb_filename, NULL, NULL) != 0) {
    fprintf(stderr, "Error initializing experiment: %s\n", glb_filename);
    return -1;
}
```

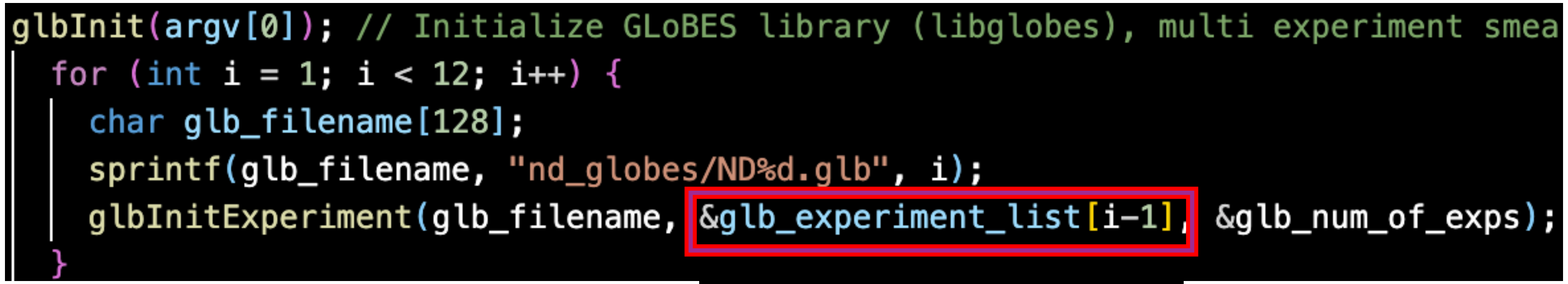
An example of implementation

Example 5 from 2007 course on GLoBES official examples

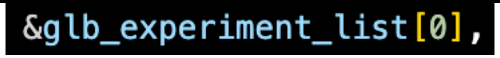


```
/* Load 2 experiments: DC far (#0) and near (#1) detectors */
glbClearExperimentList();
glbInitExperiment("D-Chooz_far.glb", &glb_experiment_list[0], &glb_num_of_exps);
glbInitExperiment("D-Chooz_near.glb", &glb_experiment_list[0], &glb_num_of_exps);
if (glbGetNumberOfBins(EXP_FAR) != n_bins || glbGetNumberOfBins(EXP_NEAR) != n_bins)
{
  printf("ERROR: Number of bins changed in AEDL file, but not in C code (or vice-versa).\n");
  return -1;
}
else
  n_bins = glbGetNumberOfBins(EXP_FAR);
```

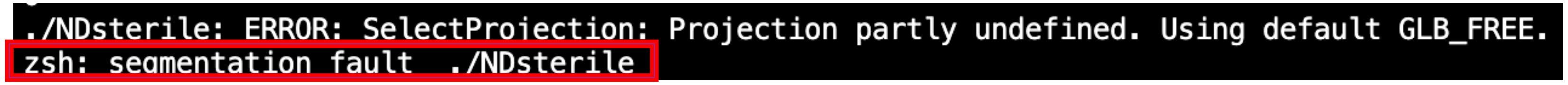
Adjustments



```
glbInit(argv[0]); // Initialize GLoBES library (libglobes), multi experiment smea
  for (int i = 1; i < 12; i++) {
    char glb_filename[128];
    sprintf(glb_filename, "nd_globes/ND%d.glb", i);
    glbInitExperiment(glb_filename, &glb_experiment_list[i-1], &glb_num_of_exps);
  }
```



```
&glb_experiment_list[0],
```

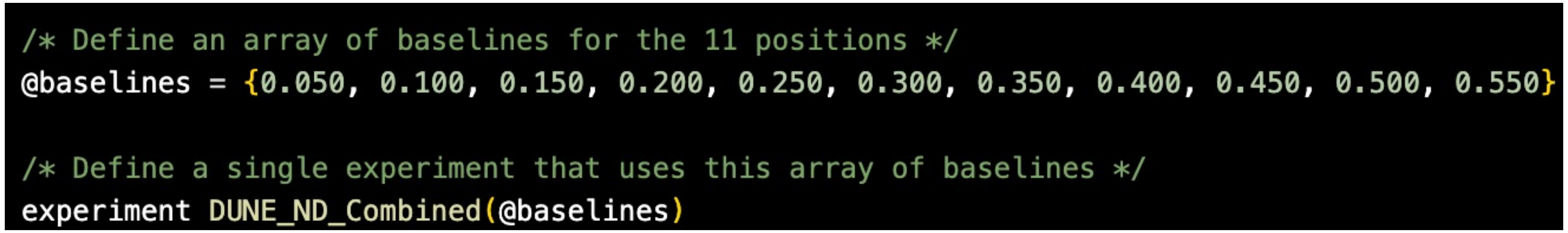


```
./NDsterile: ERROR: SelectProjection: Projection partly undefined. Using default GLB_FREE.
zsh: segmentation fault  ./NDsterile
```

Segmentation fault now disappears when all defined for experiment list 0 but chi^2 still returns zeroes

Suggestions from the internet?

- Combine all 11 .glb files into one then define an experiment inside the file:

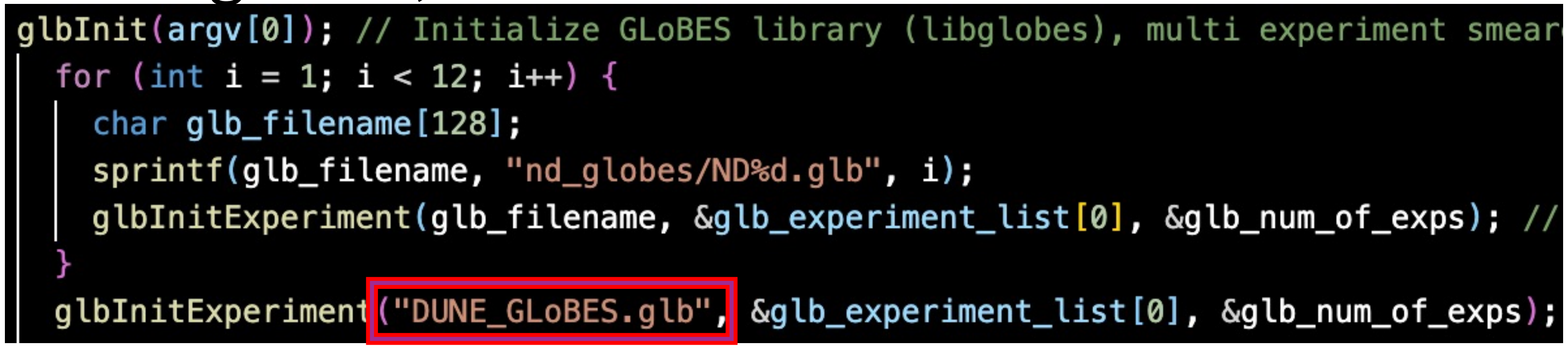


```
/* Define an array of baselines for the 11 positions */
@baselines = {0.050, 0.100, 0.150, 0.200, 0.250, 0.300, 0.350, 0.400, 0.450, 0.500, 0.550}

/* Define a single experiment that uses this array of baselines */
experiment DUNE_ND_Combined(@baselines)
```

- Note these are sample baselines not an accurate representation of the fact neutrinos only produced in the first third of the baseline
- This doesn’t solve the issue if implemented

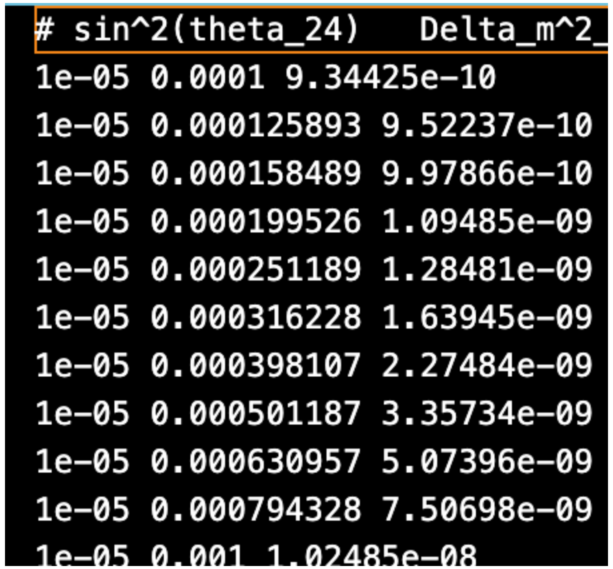
Suggestions from last week’s meeting

- Also run the far detector as there are no errrors on the near from the .glb file, so the result will be zero



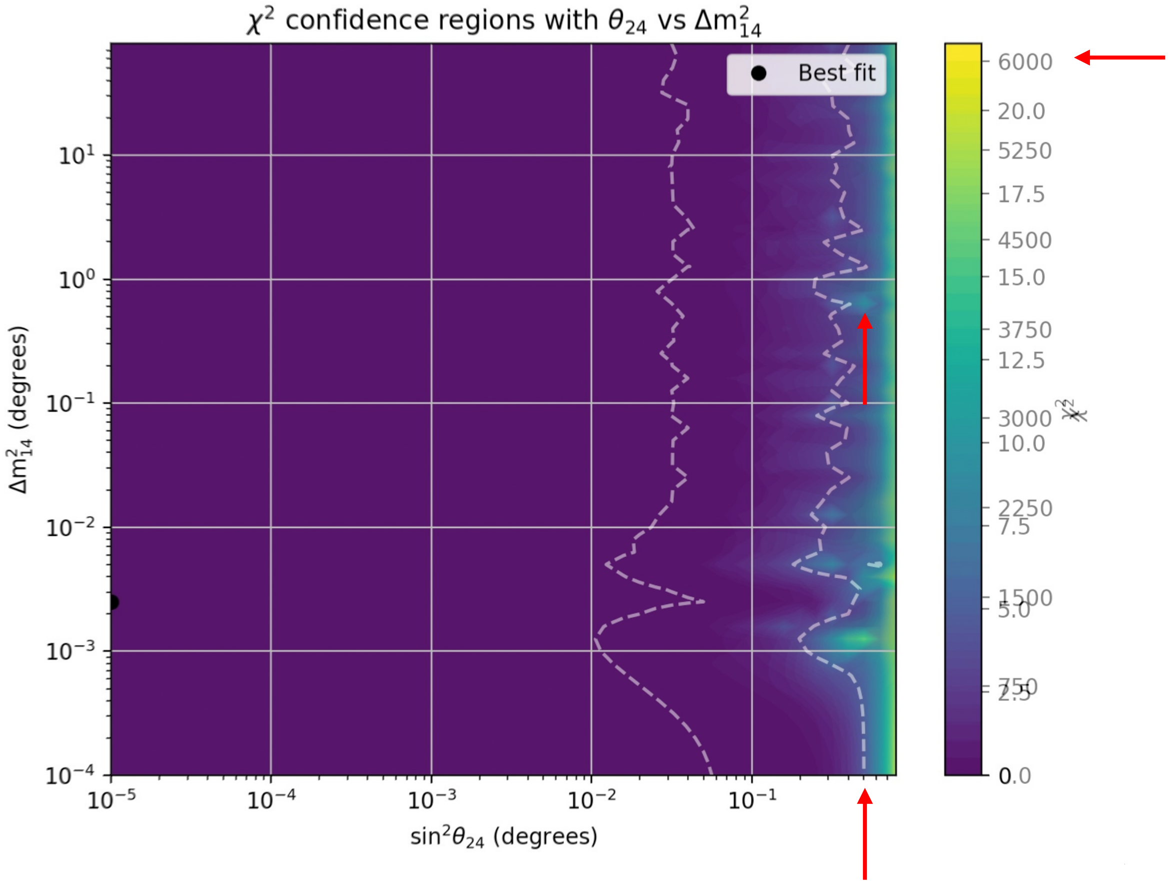
```
glbInit(argv[0]); // Initialize GLoBES library (libglobes), multi experiment smear
  for (int i = 1; i < 12; i++) {
    char glb_filename[128];
    sprintf(glb_filename, "nd_globes/ND%d.glb", i);
    glbInitExperiment(glb_filename, &glb_experiment_list[0], &glb_num_of_exps); //
  }
  glbInitExperiment("DUNE_GLoBES.glb", &glb_experiment_list[0], &glb_num_of_exps);
```

Results:



```
# sin^2(theta_24)    Delta_m^2_
1e-05 0.0001 9.34425e-10
1e-05 0.000125893 9.52237e-10
1e-05 0.000158489 9.97866e-10
1e-05 0.000199526 1.09485e-09
1e-05 0.000251189 1.28481e-09
1e-05 0.000316228 1.63945e-09
1e-05 0.000398107 2.27484e-09
1e-05 0.000501187 3.35734e-09
1e-05 0.000630957 5.07396e-09
1e-05 0.000794328 7.50698e-09
1e-05 0.001 1.02485e-08
```

Resulting Graph

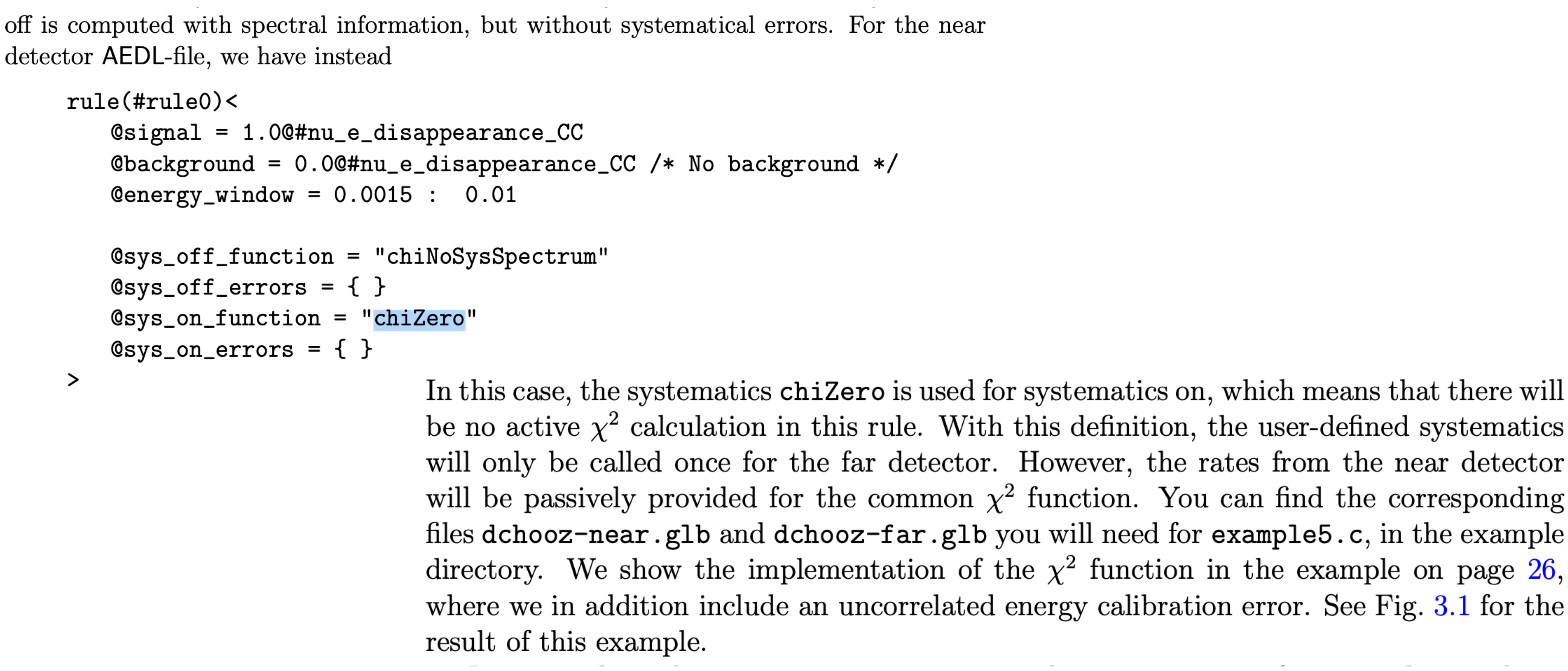


No matter how many of the files are used, or assuming as a point source the graph remains like this

The error therefore lies in the statistical model of the ND as only systematics on the FD are being accounted for

Analysis of statistics

- The `@sys_on_function = "chiZero"` function returns a value of zero

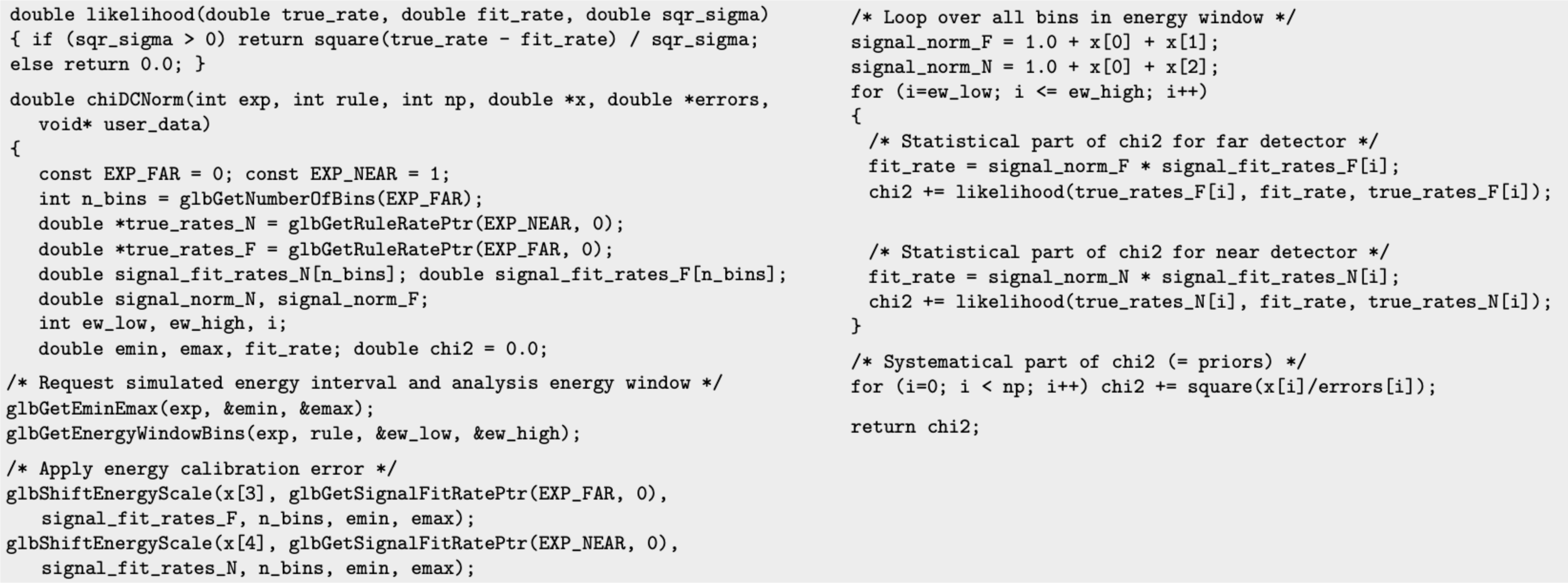


off is computed with spectral information, but without systematical errors. For the near detector AEDL-file, we have instead

```
rule(#rule0)<
    @signal = 1.0@#nu_e_disappearance_CC
    @background = 0.0@#nu_e_disappearance_CC /* No background */
    @energy_window = 0.0015 :  0.01

    @sys_off_function = "chiNoSysSpectrum"
    @sys_off_errors = { }
    @sys_on_function = "chiZero"
    @sys_on_errors = { }
>
```

In this case, the systematics **chiZero** is used for systematics on, which means that there will be no active χ^2 calculation in this rule. With this definition, the user-defined systematics will only be called once for the far detector. However, the rates from the near detector will be passively provided for the common χ^2 function. You can find the corresponding files `dchooz-near.glb` and `dchooz-far.glb` you will need for `example5.c`, in the example directory. We show the implementation of the χ^2 function in the example on page 26, where we in addition include an uncorrelated energy calibration error. See Fig. 3.1 for the result of this example.

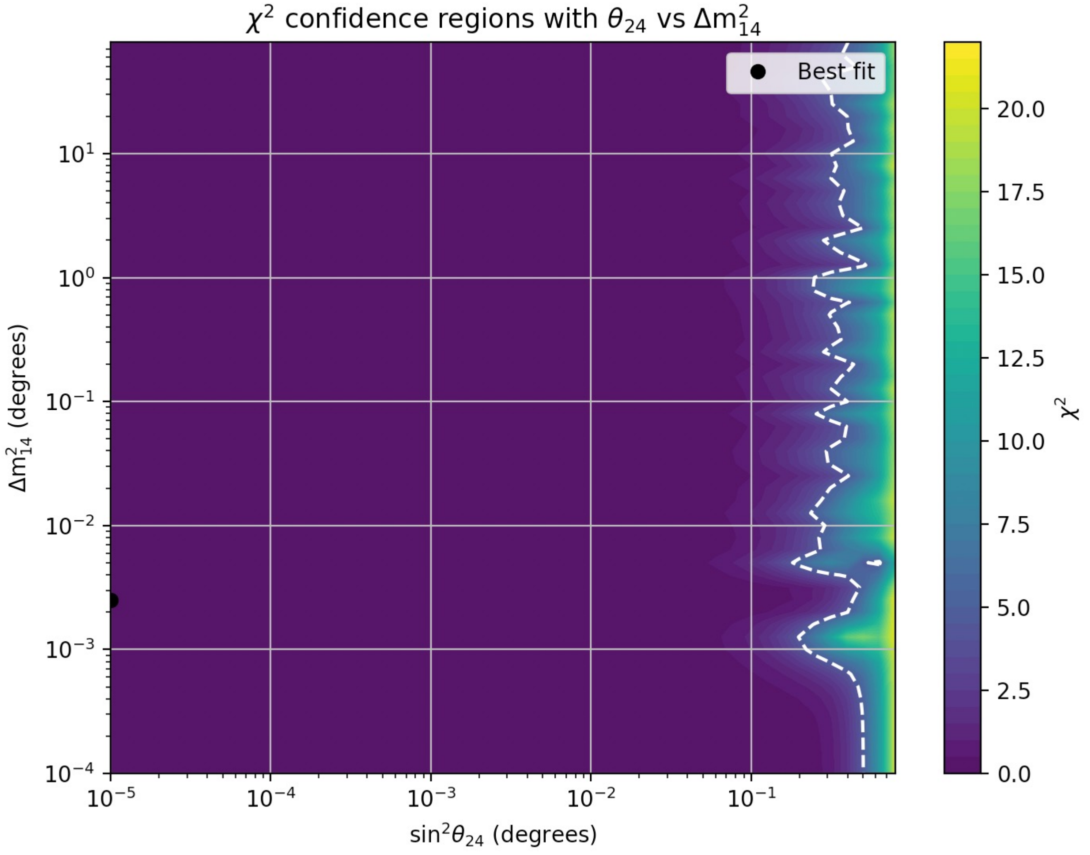
Example 5 Implementation

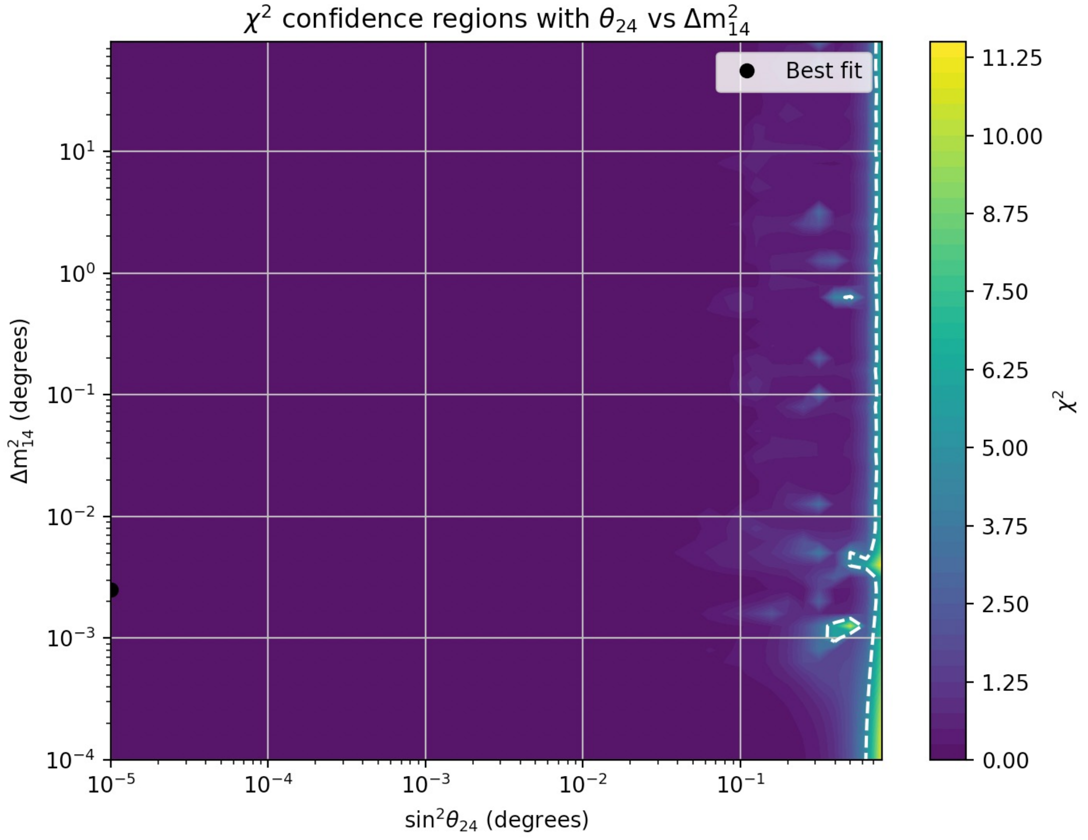


```
double likelihood(double true_rate, double fit_rate, double sqr_sigma)
{ if (sqr_sigma > 0) return square(true_rate - fit_rate) / sqr_sigma;
else return 0.0; }

double chiDCNorm(int exp, int rule, int np, double *x, double *errors,
   void* user_data)
{
   const EXP_FAR = 0; const EXP_NEAR = 1;
   int n_bins = glbGetNumberOfBins(EXP_FAR);
   double *true_rates_N = glbGetRuleRatePtr(EXP_NEAR, 0);
   double *true_rates_F = glbGetRuleRatePtr(EXP_FAR, 0);
   double signal_fit_rates_N[n_bins]; double signal_fit_rates_F[n_bins];
   double signal_norm_N, signal_norm_F;
   int ew_low, ew_high, i;
   double emin, emax, fit_rate; double chi2 = 0.0;

/* Request simulated energy interval and analysis energy window */
glbGetEminEmax(exp, &emin, &emax);
glbGetEnergyWindowBins(exp, rule, &ew_low, &ew_high);

/* Apply energy calibration error */
glbShiftEnergyScale(x[3], glbGetSignalFitRatePtr(EXP_FAR, 0),
   signal_fit_rates_F, n_bins, emin, emax);
glbShiftEnergyScale(x[4], glbGetSignalFitRatePtr(EXP_NEAR, 0),
   signal_fit_rates_N, n_bins, emin, emax);
```

```
/* Loop over all bins in energy window */
signal_norm_F = 1.0 + x[0] + x[1];
signal_norm_N = 1.0 + x[0] + x[2];
for (i=ew_low; i <= ew_high; i++)
{
  /* Statistical part of chi2 for far detector */
  fit_rate = signal_norm_F * signal_fit_rates_F[i];
  chi2 += likelihood(true_rates_F[i], fit_rate, true_rates_F[i]);

  /* Statistical part of chi2 for near detector */
  fit_rate = signal_norm_N * signal_fit_rates_N[i];
  chi2 += likelihood(true_rates_N[i], fit_rate, true_rates_N[i]);
}

/* Systematical part of chi2 (= priors) */
for (i=0; i < np; i++) chi2 += square(x[i]/errors[i]);

return chi2;
```

The most recent attempts





Progress as of this week

- Final plots are not accurate
- Showing a decrease in sensitivity due to addition of the near detector
- Statistical model was implemented for example 5 as has been implemented here
- Baseline and other effects for a sterile neutrino at DUNE by J. T. Penedo and Joao Pulido paper shows proper implementation accounting for more errors
- Will move forward with this model