DUNE OA using GUNDAM

GUNDAM Oscillation Analysis Tools

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DUNE LBL meeting
August, 19th 2024

Stony Brook
University

The GUNDAM group

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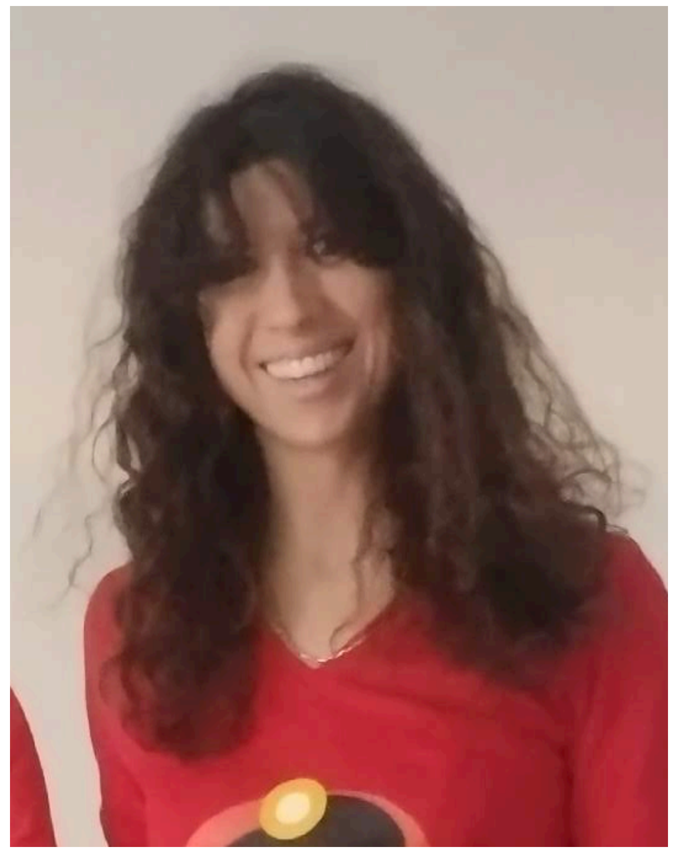

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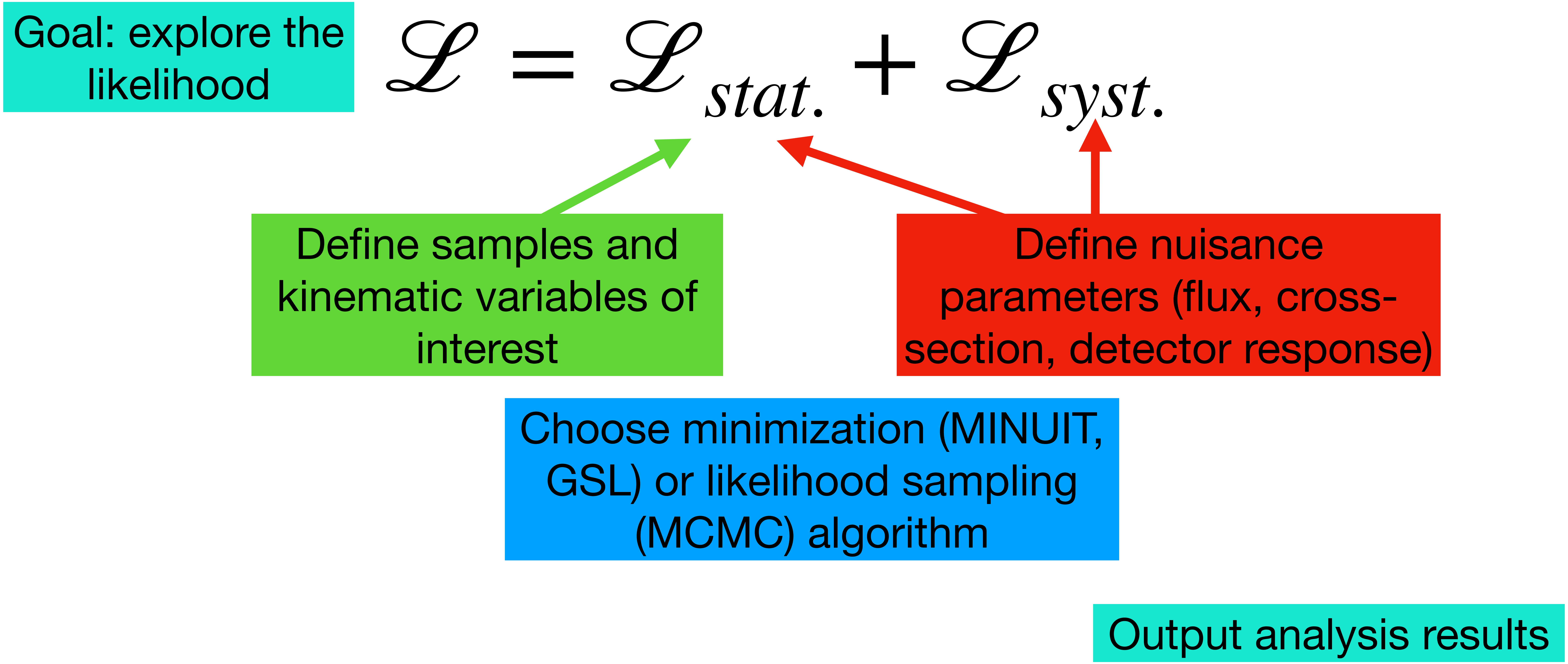
What is GUNDAM?

- GUNDAM, which stand for *Generalized and Unified Neutrino Data Analysis Methods*, is an analysis tool developed in the context of the upgrade of the off-axis near detector of T2K
- It is a synthesis of two tools used in the T2K cross-section and OA WGs (xsLLhFitter and BANFF)
- Its goal is to explore a likelihood function that can be defined by using a set of YAML/JSON configuration files
- Code structure designed for handling different analyses and as much as possible analysis independent
- Code optimized for both CPUs and GPUs
  - 10s - 100s Hz depending on the analysis, system and if using CPUs only or GPUs
  - Example: analysis with ~4000 sample bins and ~600 parameters few hours (~3d previous generation tool)
- Collaborative code developed on GitHub under same GPL as ROOT

GUNDAM Workflow



Goal: explore the likelihood

$$\mathscr{L} = \mathscr{L}_{stat.} + \mathscr{L}_{syst.}$$

Define samples and kinematic variables of interest

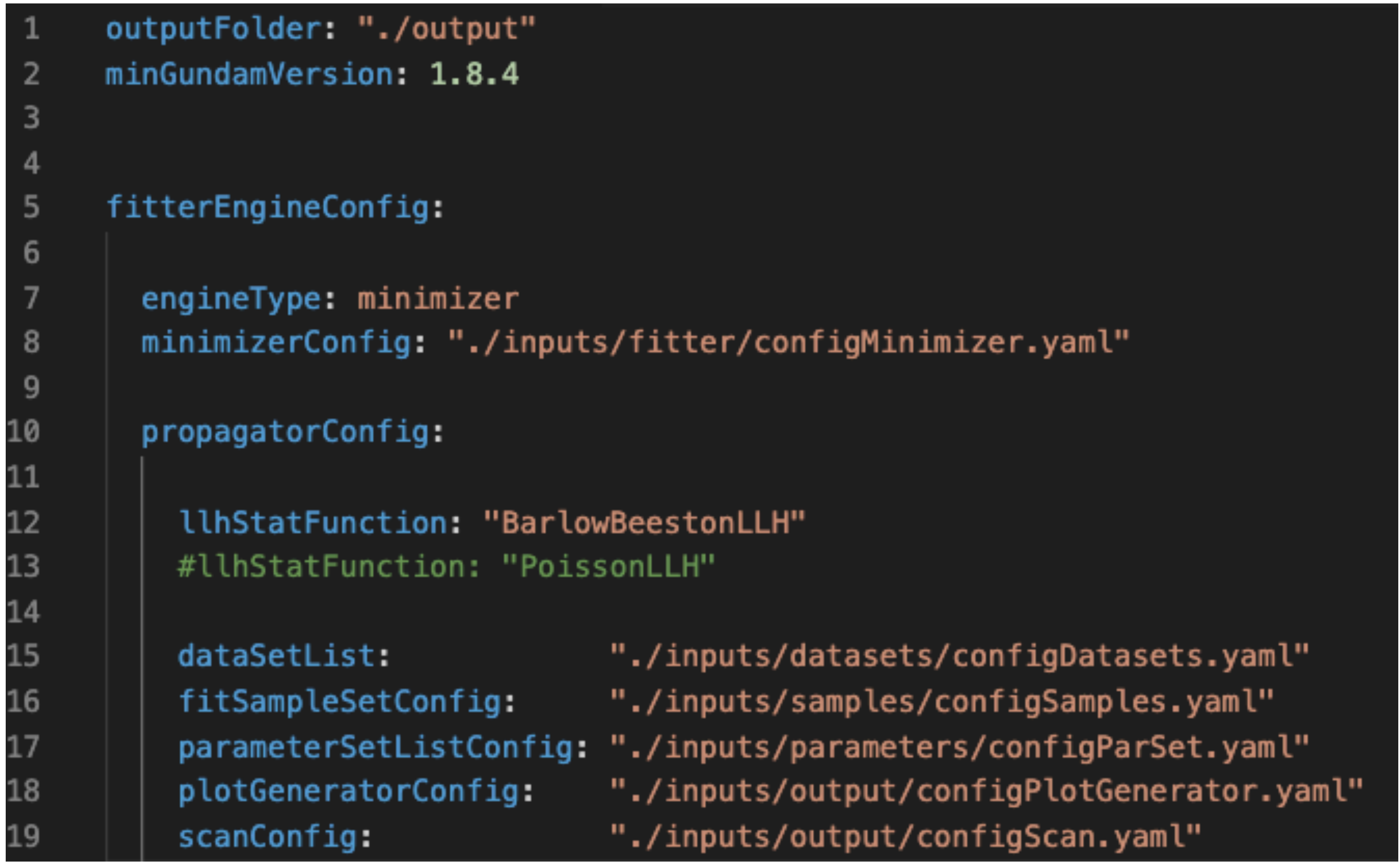
Define nuisance parameters (flux, cross-section, detector response)

Choose minimization (MINUIT, GSL) or likelihood sampling (MCMC) algorithm

Output analysis results

Config examples

mainConfig.yaml



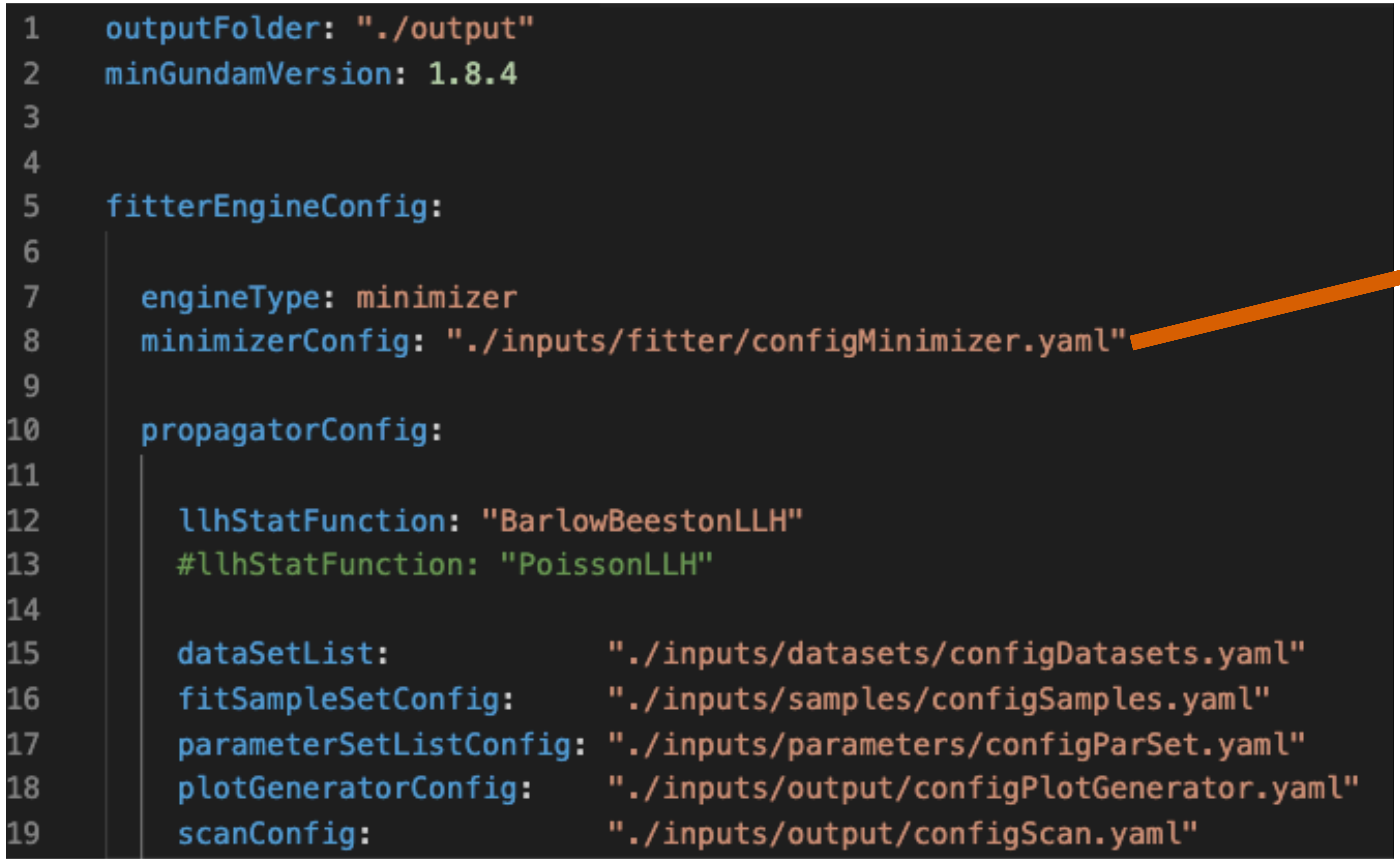
```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:             "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:      "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:     "./inputs/output/configPlotGenerator.yaml"
    scanConfig:              "./inputs/output/configScan.yaml"
```

Convenient to break this is several files but doesn't have to be

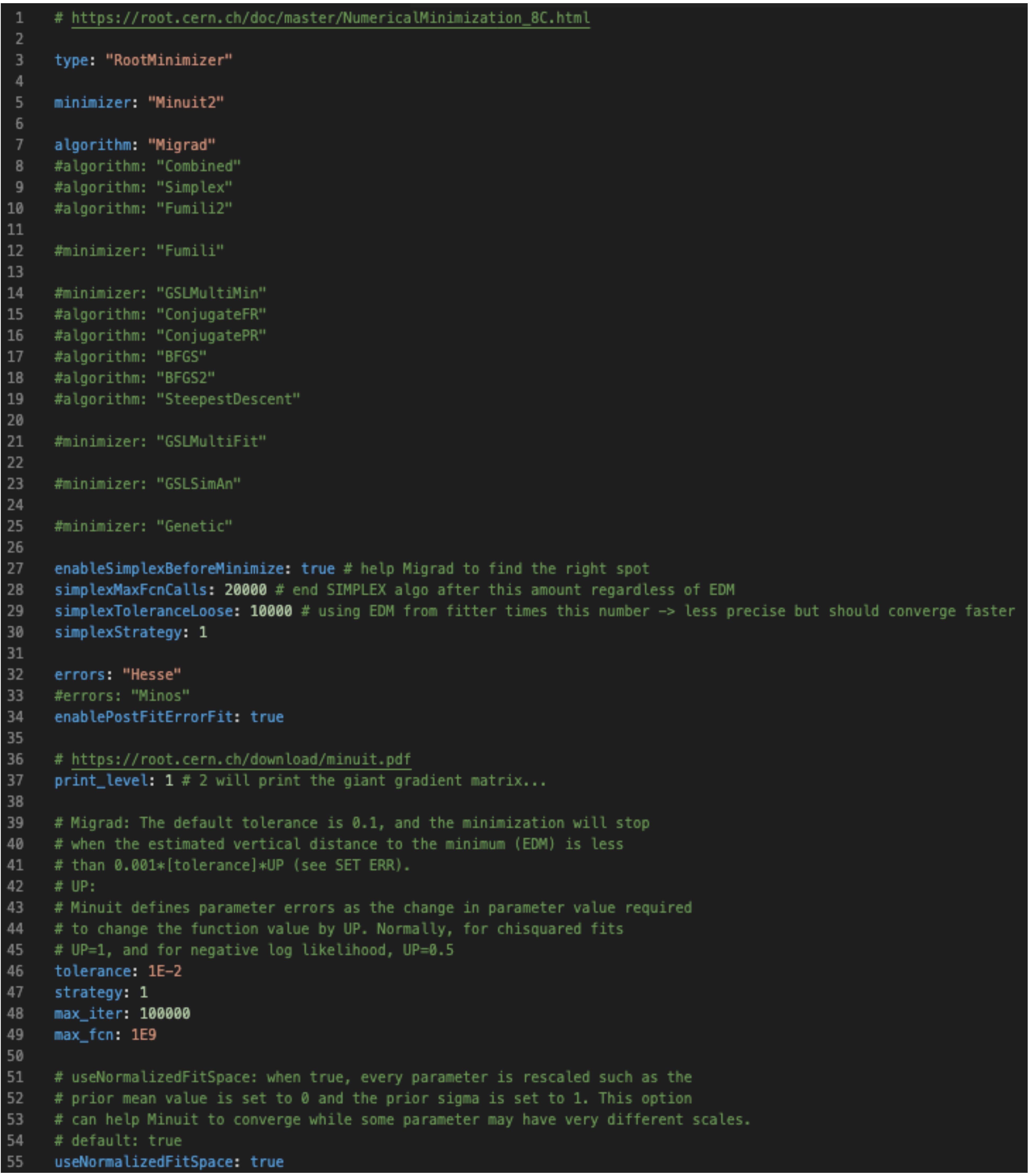
Note: illustrative only examples

Engine configuration

mainConfig.yaml



```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:            "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:     "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:    "./inputs/output/configPlotGenerator.yaml"
    scanConfig:             "./inputs/output/configScan.yaml"
```

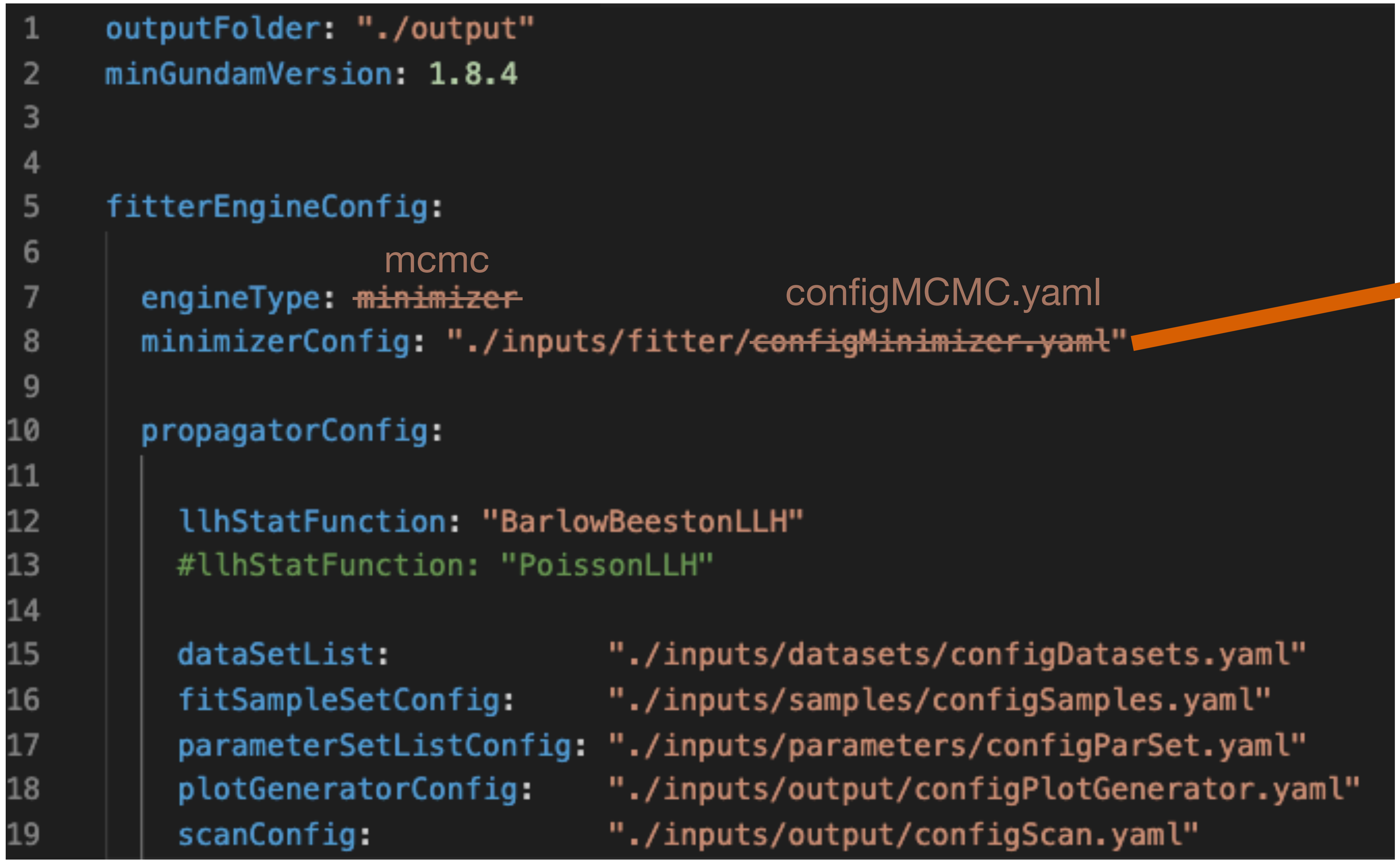


```yaml
# https://root.cern.ch/doc/master/NumericalMinimization_8C.html

type: "RootMinimizer"

minimizer: "Minuit2"

algorithm: "Migrad"
#algorithm: "Combined"
#algorithm: "Simplex"
#algorithm: "Fumili2"

#minimizer: "Fumili"

#minimizer: "GSLMultiMin"
#algorithm: "ConjugateFR"
#algorithm: "ConjugatePR"
#algorithm: "BFGS"
#algorithm: "BFGS2"
#algorithm: "SteepestDescent"

#minimizer: "GSLMultiFit"

#minimizer: "GSLSimAn"

#minimizer: "Genetic"

enableSimplexBeforeMinimize: true # help Migrad to find the right spot
simplexMaxFcnCalls: 20000 # end SIMPLEX algo after this amount regardless of EDM
simplexToleranceLoose: 10000 # using EDM from fitter times this number -> less precise but should converge faster
simplexStrategy: 1

errors: "Hesse"
#errors: "Minos"
enablePostFitErrorFit: true

# https://root.cern.ch/download/minuit.pdf
print_level: 1 # 2 will print the giant gradient matrix...

# Migrad: The default tolerance is 0.1, and the minimization will stop
# when the estimated vertical distance to the minimum (EDM) is less
# than 0.001*[tolerance]*UP (see SET ERR).
# UP:
# Minuit defines parameter errors as the change in parameter value required
# to change the function value by UP. Normally, for chisquared fits
# UP=1, and for negative log likelihood, UP=0.5
tolerance: 1E-2
strategy: 1
max_iter: 100000
max_fcn: 1E9

# useNormalizedFitSpace: when true, every parameter is rescaled such as the
# prior mean value is set to 0 and the prior sigma is set to 1. This option
# can help Minuit to converge while some parameter may have very different scales.
# default: true
useNormalizedFitSpace: true
```

Note: illustrative only examples

Engine configuration

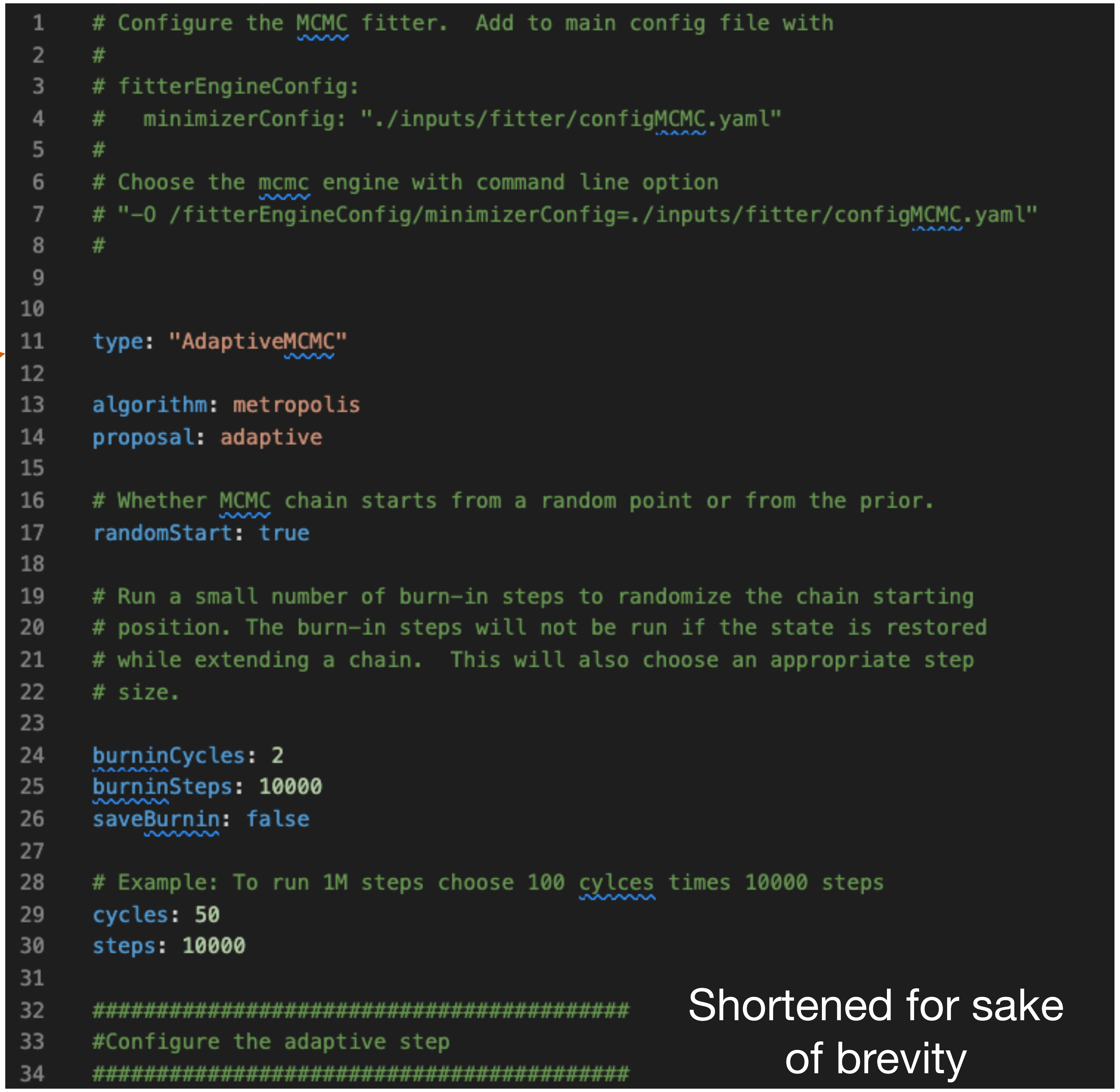
mainConfig.yaml



mcmc

configMCMC.yaml

```
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: ~~minimizer~~
  minimizerConfig: "./inputs/fitter/~~configMinimizer.yaml~~"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:             "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:      "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:     "./inputs/output/configPlotGenerator.yaml"
    scanConfig:              "./inputs/output/configScan.yaml"
```



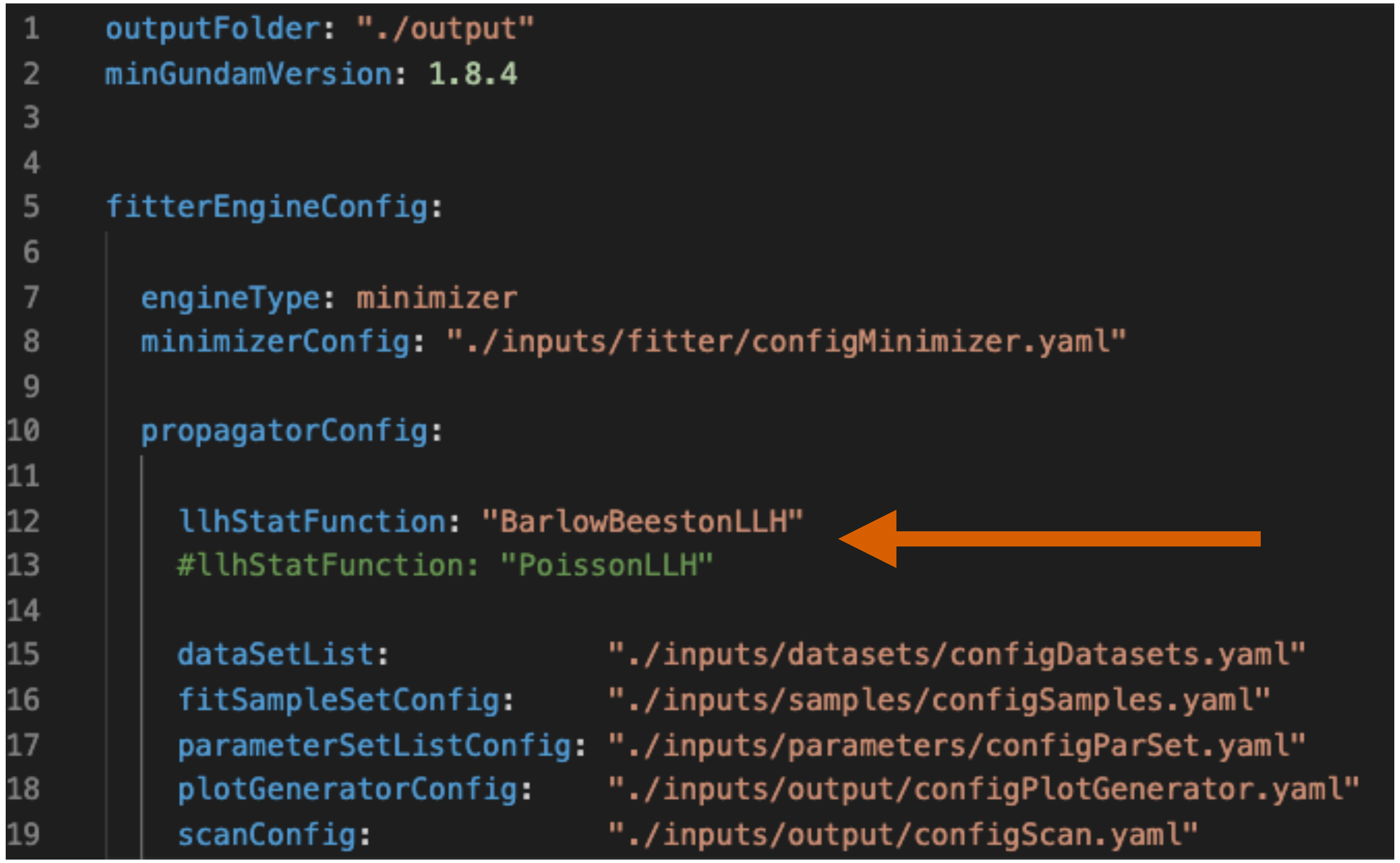
```
# Configure the MCMC fitter.  Add to main config file with
#
# fitterEngineConfig:
#   minimizerConfig: "./inputs/fitter/configMCMC.yaml"
#
# Choose the mcmc engine with command line option
# "-O /fitterEngineConfig/minimizerConfig=./inputs/fitter/configMCMC.yaml"
#



type: "AdaptiveMCMC"

algorithm: metropolis
proposal: adaptive

# Whether MCMC chain starts from a random point or from the prior.
randomStart: true

# Run a small number of burn-in steps to randomize the chain starting
# position. The burn-in steps will not be run if the state is restored
# while extending a chain.  This will also choose an appropriate step
# size.

burninCycles: 2
burninSteps: 10000
saveBurnin: false

# Example: To run 1M steps choose 100 cylces times 10000 steps
cycles: 50
steps: 10000

##########################################
#Configure the adaptive step
##########################################
```

Shortened for sake of brevity

Note: illustrative only examples

Likelihood definition

mainConfig.yaml



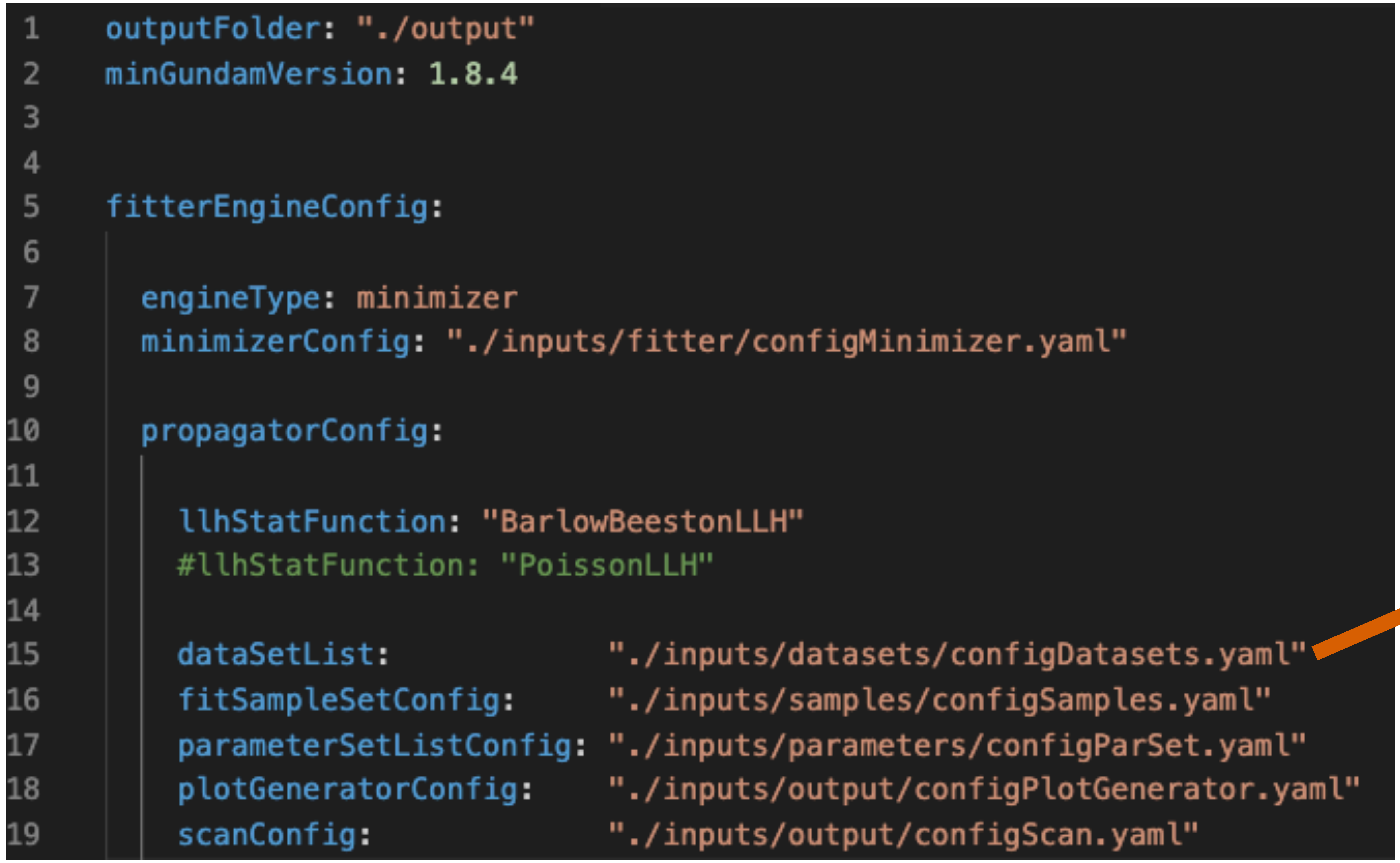
```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:            "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:     "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:    "./inputs/output/configPlotGenerator.yaml"
    scanConfig:             "./inputs/output/configScan.yaml"
```

Different test statistics implemented in the core code

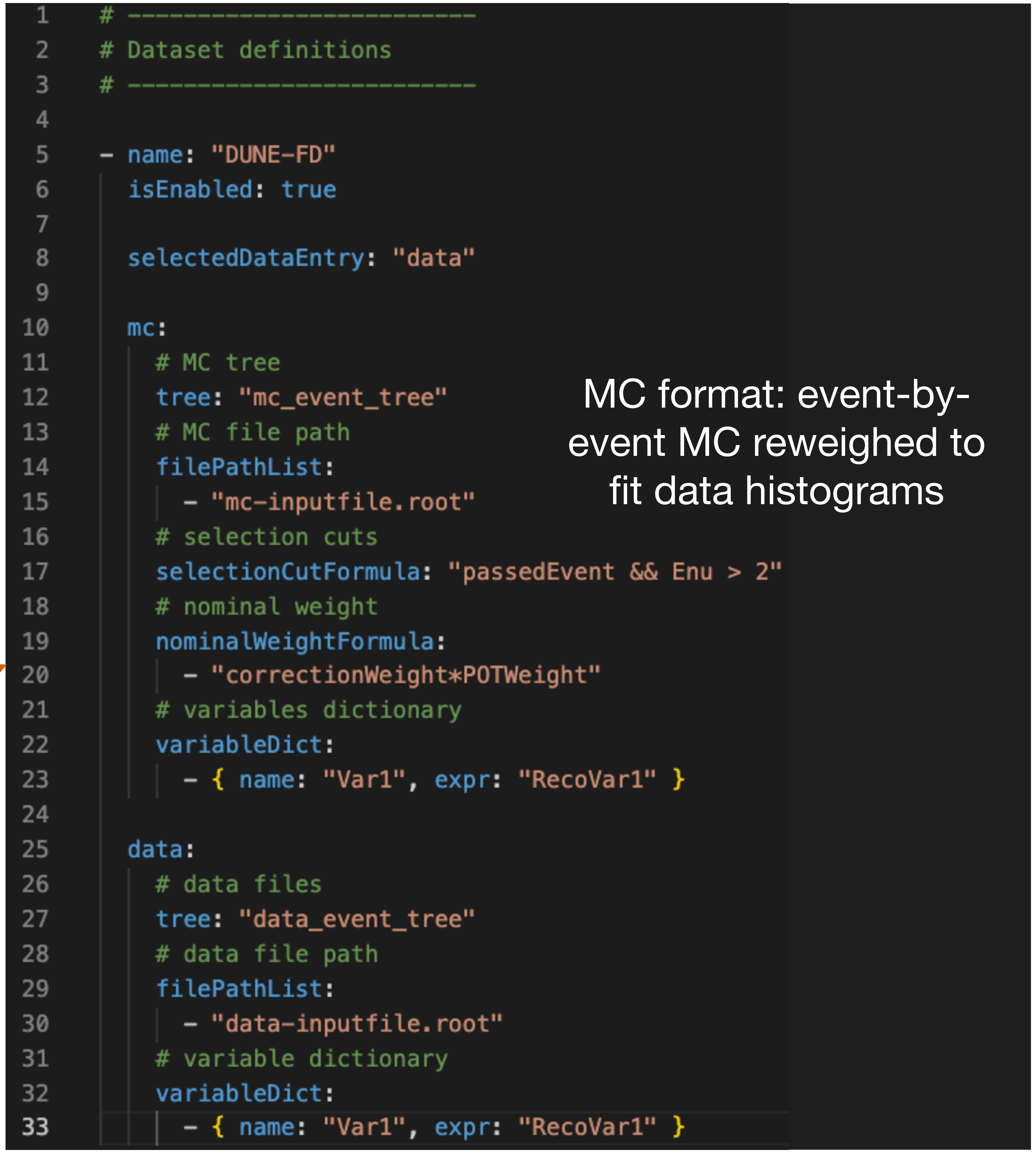
Note: illustrative only examples

Dataset definition

mainConfig.yaml



```
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:            "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:     "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:    "./inputs/output/configPlotGenerator.yaml"
    scanConfig:             "./inputs/output/configScan.yaml"
```



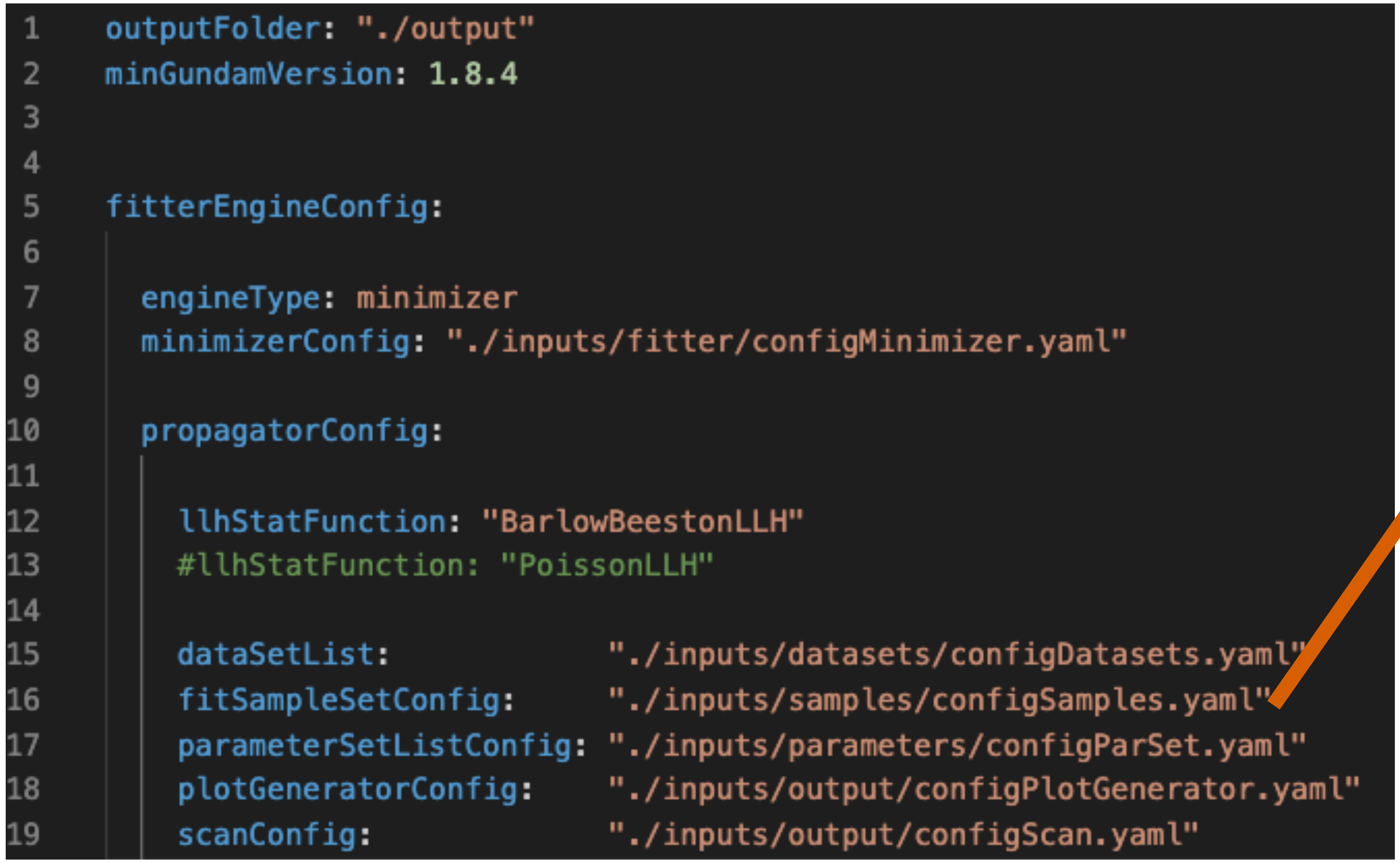
```
# -------------------------
# Dataset definitions
# -------------------------

- name: "DUNE-FD"
  isEnabled: true

  selectedDataEntry: "data"

  mc:
    # MC tree
    tree: "mc_event_tree"
    # MC file path
    filePathList:
      - "mc-inputfile.root"
    # selection cuts
    selectionCutFormula: "passedEvent && Enu > 2"
    # nominal weight
    nominalWeightFormula:
      - "correctionWeight*POTWeight"
    # variables dictionary
    variableDict:
      - { name: "Var1", expr: "RecoVar1" }

  data:
    # data files
    tree: "data_event_tree"
    # data file path
    filePathList:
      - "data-inputfile.root"
    # variable dictionary
    variableDict:
      - { name: "Var1", expr: "RecoVar1" }
```

MC format: event-by-event MC reweighed to fit data histograms

Note: illustrative only examples

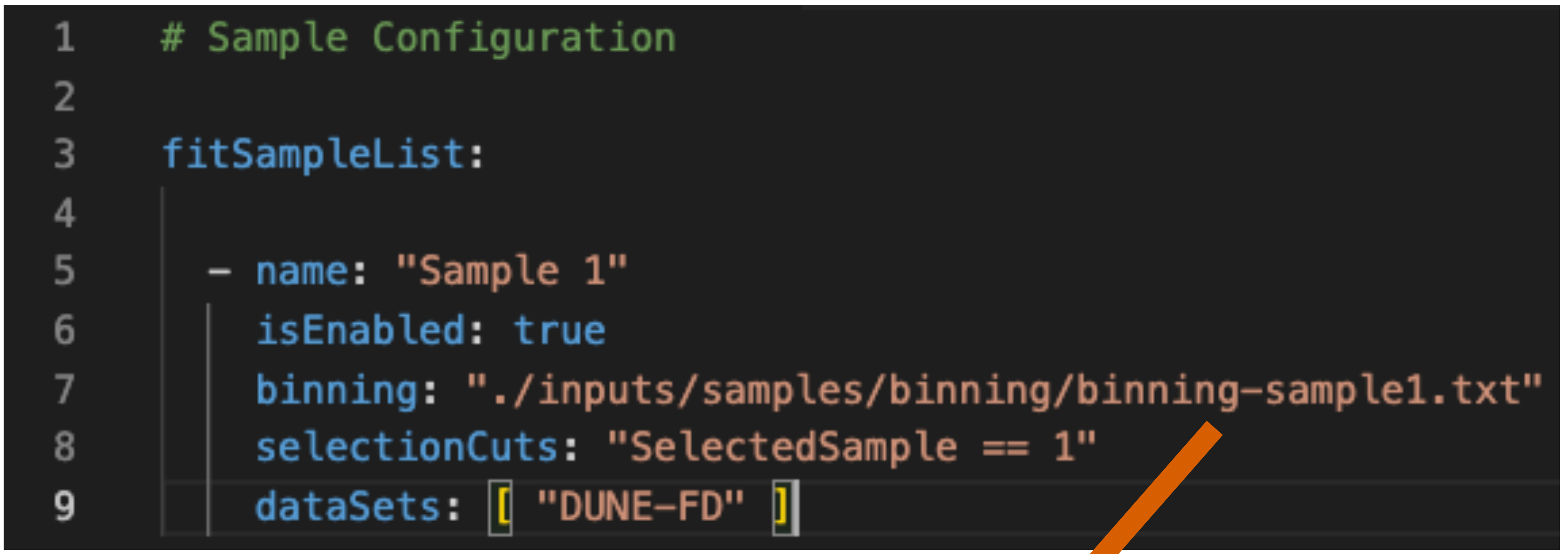
Samples definition

mainConfig.yaml

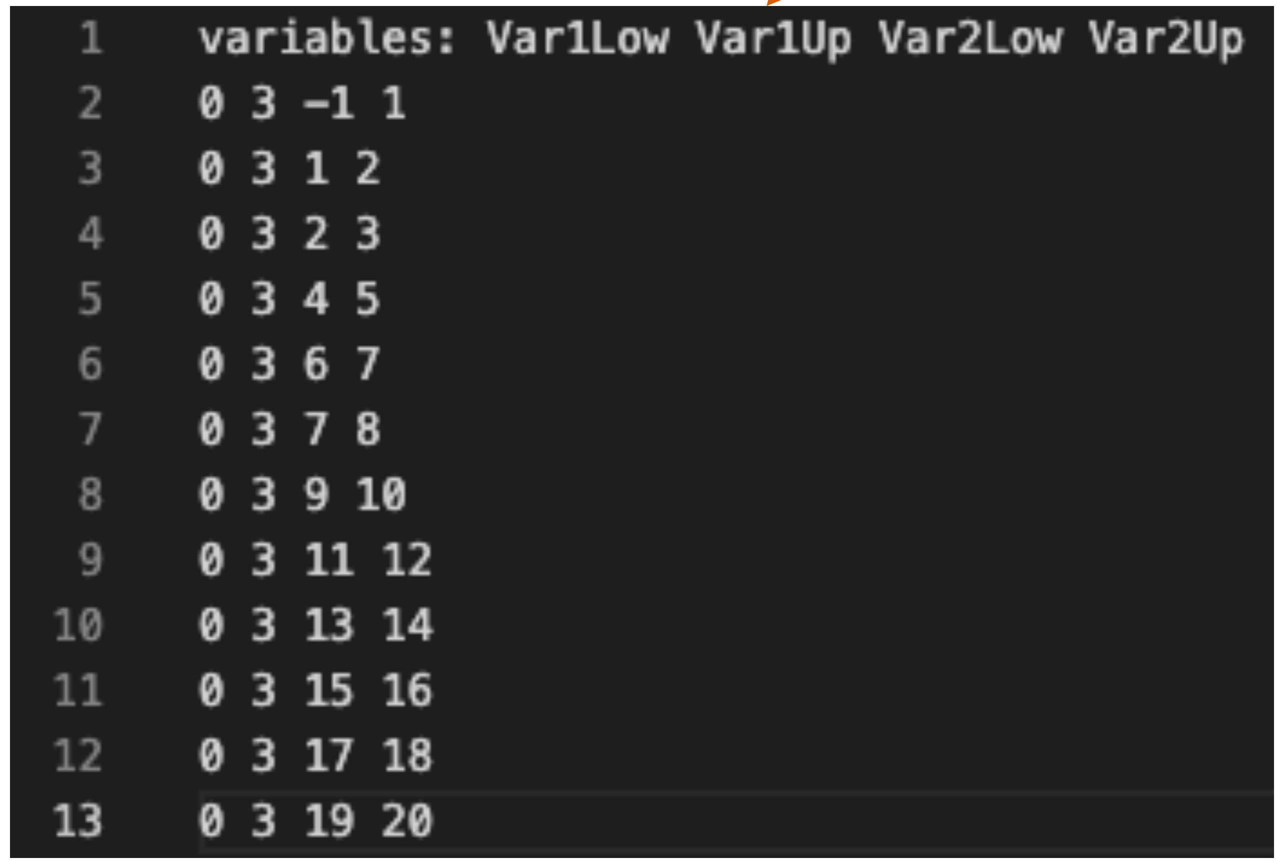


```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:            "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:     "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:    "./inputs/output/configPlotGenerator.yaml"
    scanConfig:             "./inputs/output/configScan.yaml"
```

Any number of samples



```yaml
# Sample Configuration

fitSampleList:

  - name: "Sample 1"
    isEnabled: true
    binning: "./inputs/samples/binning/binning-sample1.txt"
    selectionCuts: "SelectedSample == 1"
    dataSets: [ "DUNE-FD" ]
```



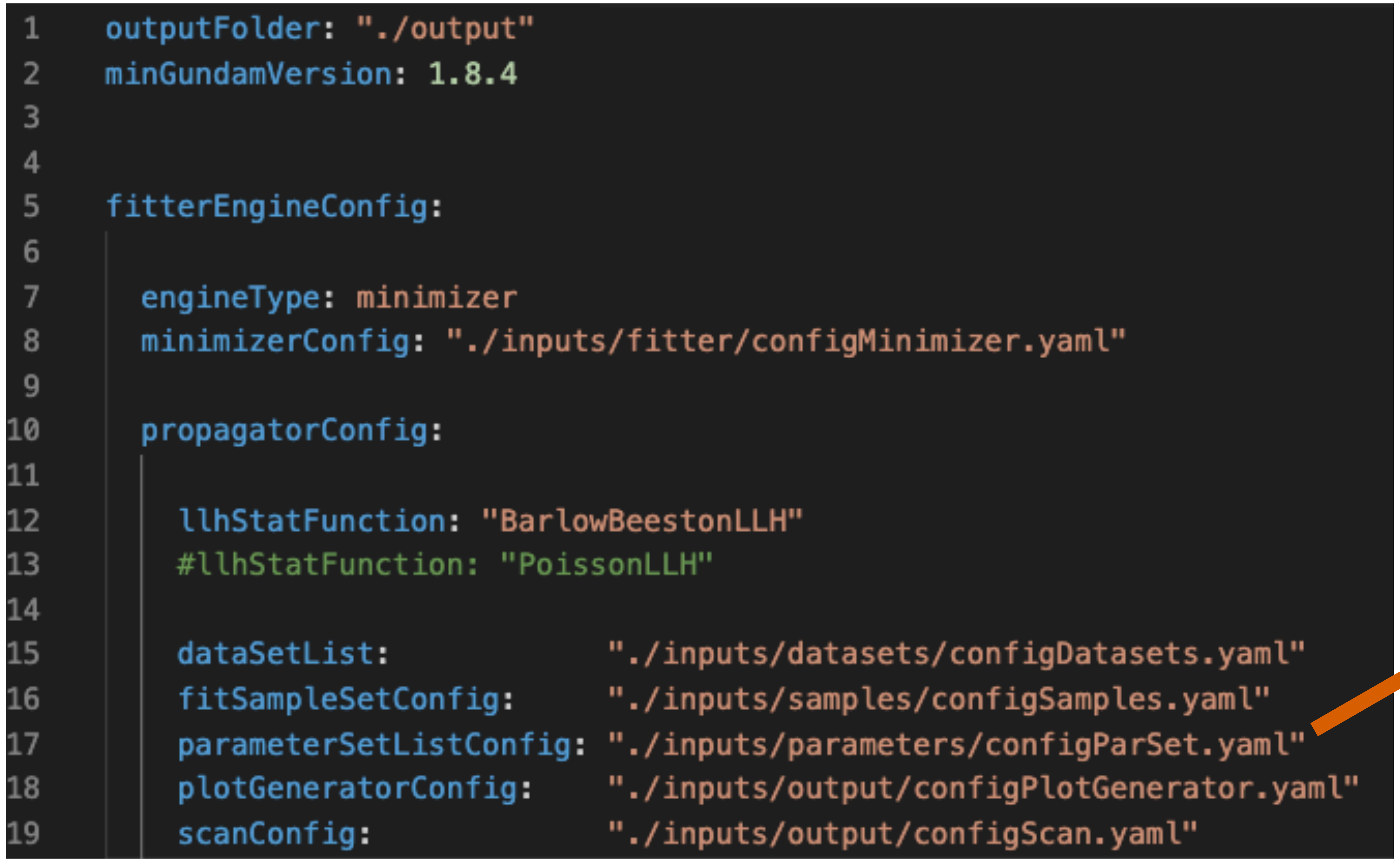
```
variables: Var1Low Var1Up Var2Low Var2Up
0 3 -1 1
0 3 1 2
0 3 2 3
0 3 4 5
0 3 6 7
0 3 7 8
0 3 9 10
0 3 11 12
0 3 13 14
0 3 15 16
0 3 17 18
0 3 19 20
```

Bin in any number of dimension

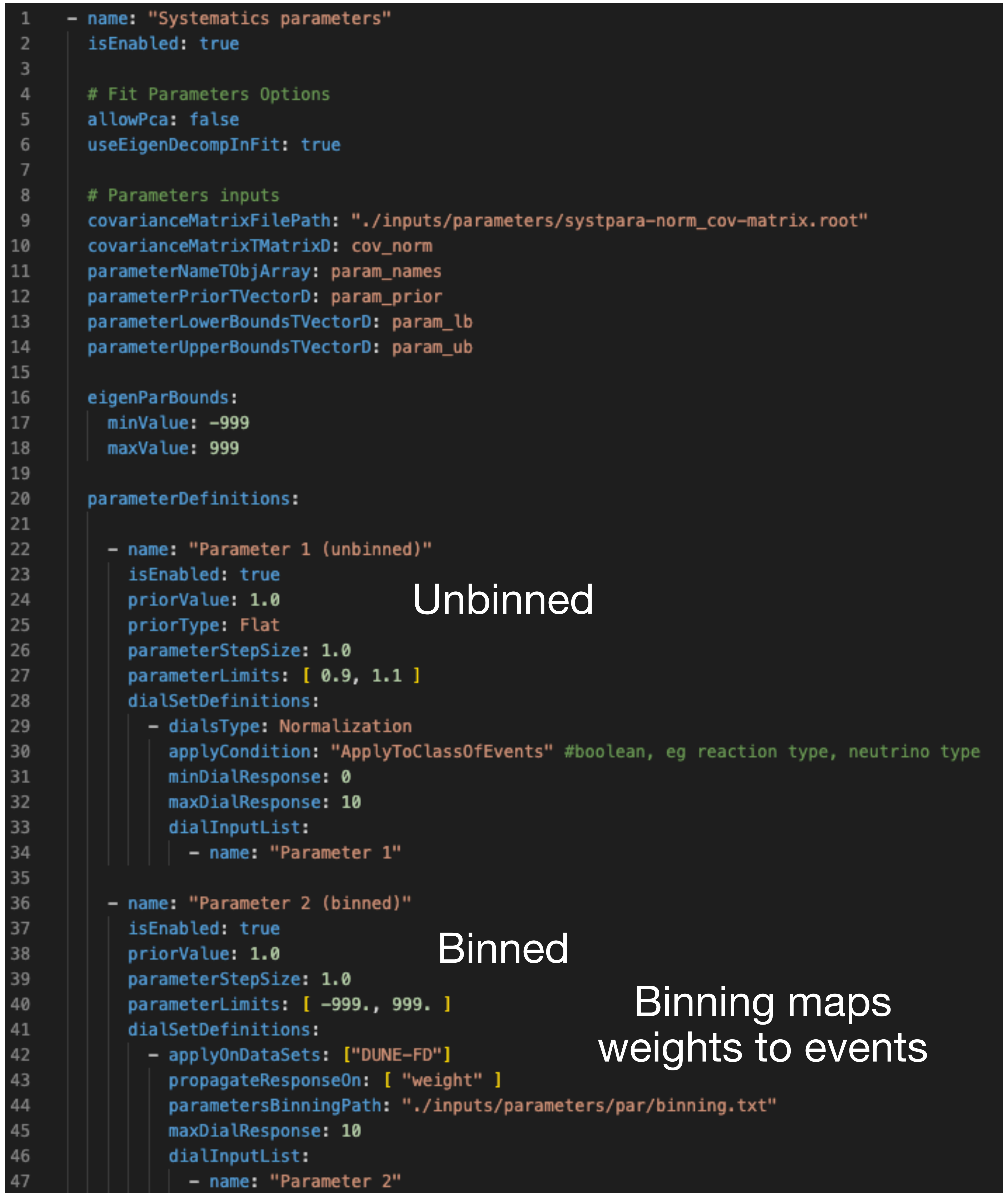
Note: illustrative only examples

Parameter set: normalization

mainConfig.yaml



```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:            "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:     "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:    "./inputs/output/configPlotGenerator.yaml"
    scanConfig:             "./inputs/output/configScan.yaml"
```



```yaml
- name: "Systematics parameters"
  isEnabled: true

  # Fit Parameters Options
  allowPca: false
  useEigenDecompInFit: true

  # Parameters inputs
  covarianceMatrixFilePath: "./inputs/parameters/systpara-norm_cov-matrix.root"
  covarianceMatrixTMatrixD: cov_norm
  parameterNameTObjArray: param_names
  parameterPriorTVectorD: param_prior
  parameterLowerBoundsTVectorD: param_lb
  parameterUpperBoundsTVectorD: param_ub

  eigenParBounds:
    minValue: -999
    maxValue: 999

  parameterDefinitions:

    - name: "Parameter 1 (unbinned)"
      isEnabled: true
      priorValue: 1.0
      priorType: Flat
      parameterStepSize: 1.0
      parameterLimits: [ 0.9, 1.1 ]
      dialSetDefinitions:
        - dialsType: Normalization
          applyCondition: "ApplyToClassOfEvents" #boolean, eg reaction type, neutrino type
          minDialResponse: 0
          maxDialResponse: 10
          dialInputList:
            - name: "Parameter 1"

    - name: "Parameter 2 (binned)"
      isEnabled: true
      priorValue: 1.0
      parameterStepSize: 1.0
      parameterLimits: [ -999., 999. ]
      dialSetDefinitions:
        - applyOnDataSets: ["DUNE-FD"]
          propagateResponseOn: [ "weight" ]
          parametersBinningPath: "./inputs/parameters/par/binning.txt"
          maxDialResponse: 10
          dialInputList:
            - name: "Parameter 2"
```

Unbinned

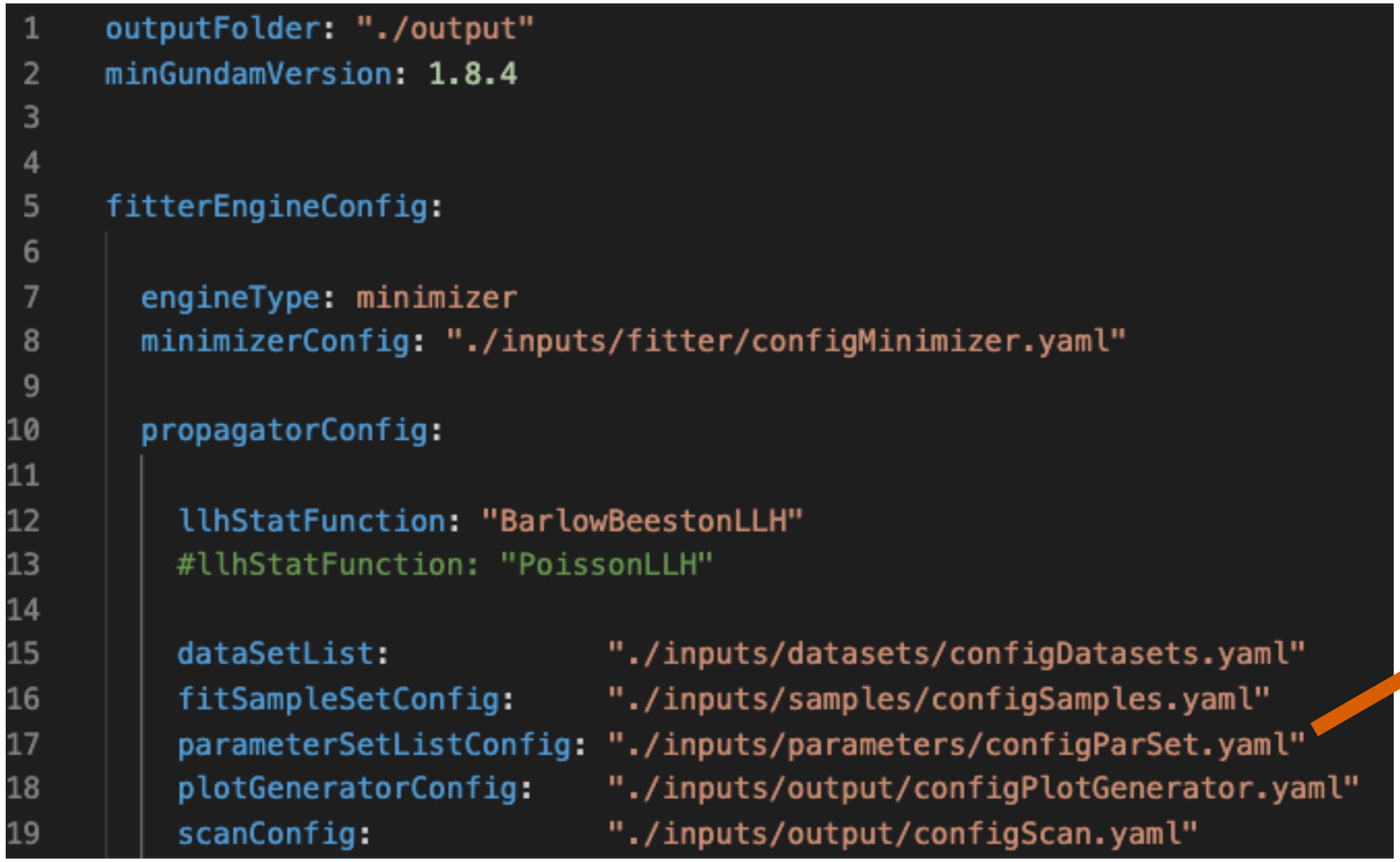
Binned

Binning maps weights to events

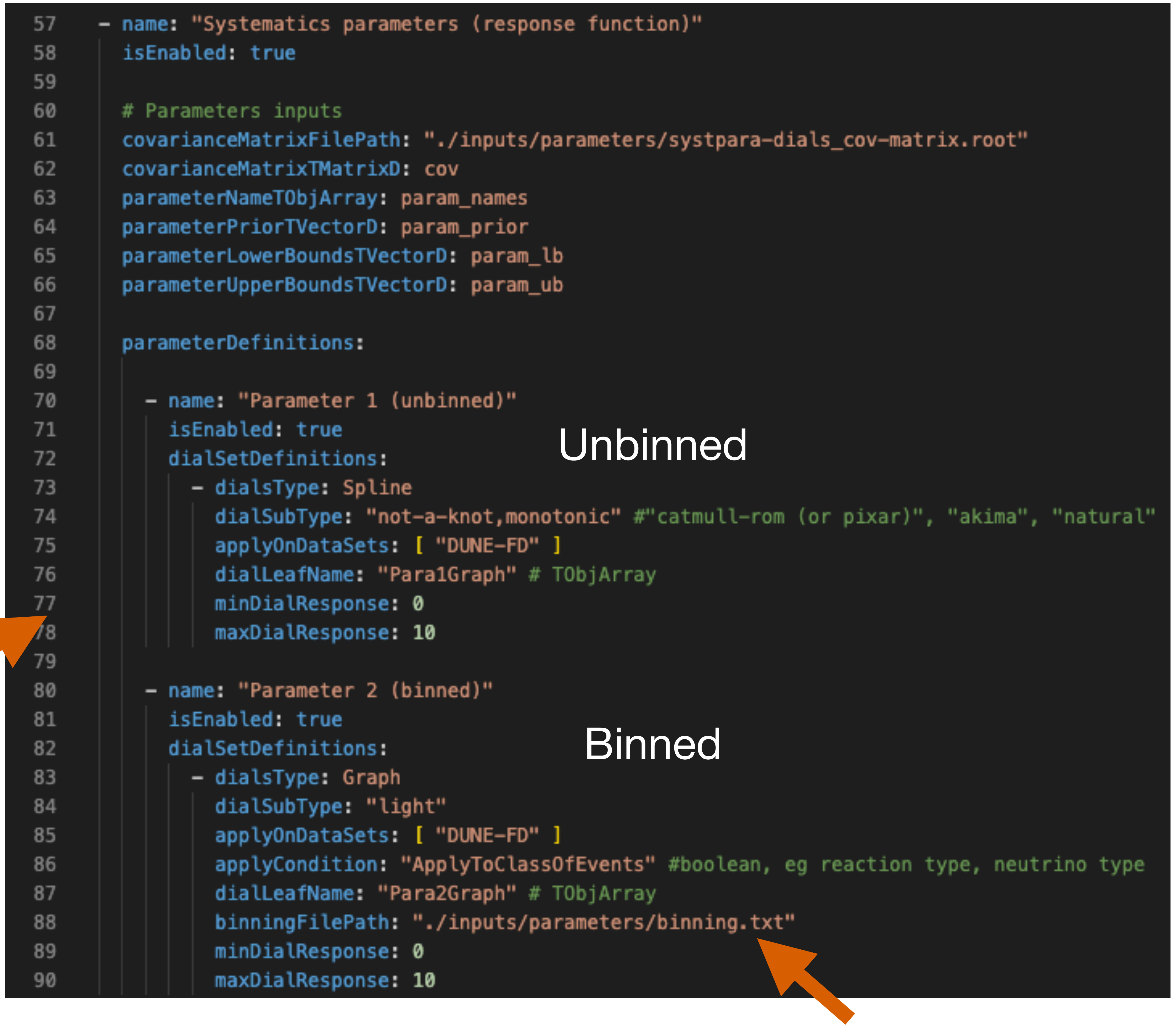
Note: illustrative only examples

Parameter set: response function

mainConfig.yaml



```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:            "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:     "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:    "./inputs/output/configPlotGenerator.yaml"
    scanConfig:             "./inputs/output/configScan.yaml"
```



```yaml
- name: "Systematics parameters (response function)"
  isEnabled: true

  # Parameters inputs
  covarianceMatrixFilePath: "./inputs/parameters/systpara-dials_cov-matrix.root"
  covarianceMatrixTMatrixD: cov
  parameterNameTObjArray: param_names
  parameterPriorTVectorD: param_prior
  parameterLowerBoundsTVectorD: param_lb
  parameterUpperBoundsTVectorD: param_ub

  parameterDefinitions:

    - name: "Parameter 1 (unbinned)"
      isEnabled: true
      dialSetDefinitions:
        - dialsType: Spline
          dialSubType: "not-a-knot,monotonic" #"catmull-rom (or pixar)", "akima", "natural"
          applyOnDataSets: [ "DUNE-FD" ]
          dialLeafName: "Para1Graph" # TObjArray
          minDialResponse: 0
          maxDialResponse: 10

    - name: "Parameter 2 (binned)"
      isEnabled: true
      dialSetDefinitions:
        - dialsType: Graph
          dialSubType: "light"
          applyOnDataSets: [ "DUNE-FD" ]
          applyCondition: "ApplyToClassOfEvents" #boolean, eg reaction type, neutrino type
          dialLeafName: "Para2Graph" # TObjArray
          binningFilePath: "./inputs/parameters/binning.txt"
          minDialResponse: 0
          maxDialResponse: 10
```

Unbinned

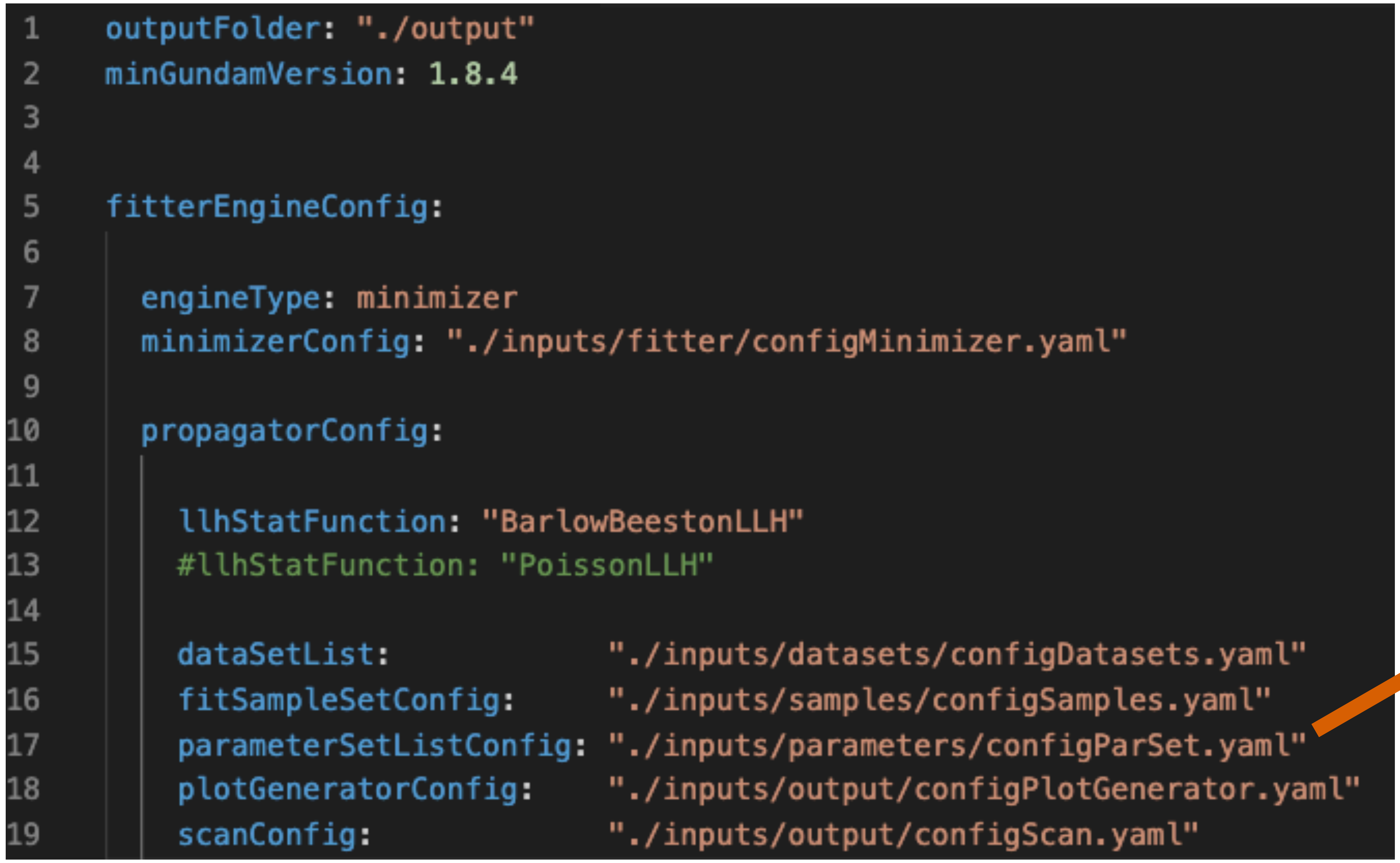
Binned

Binning maps response functions to events

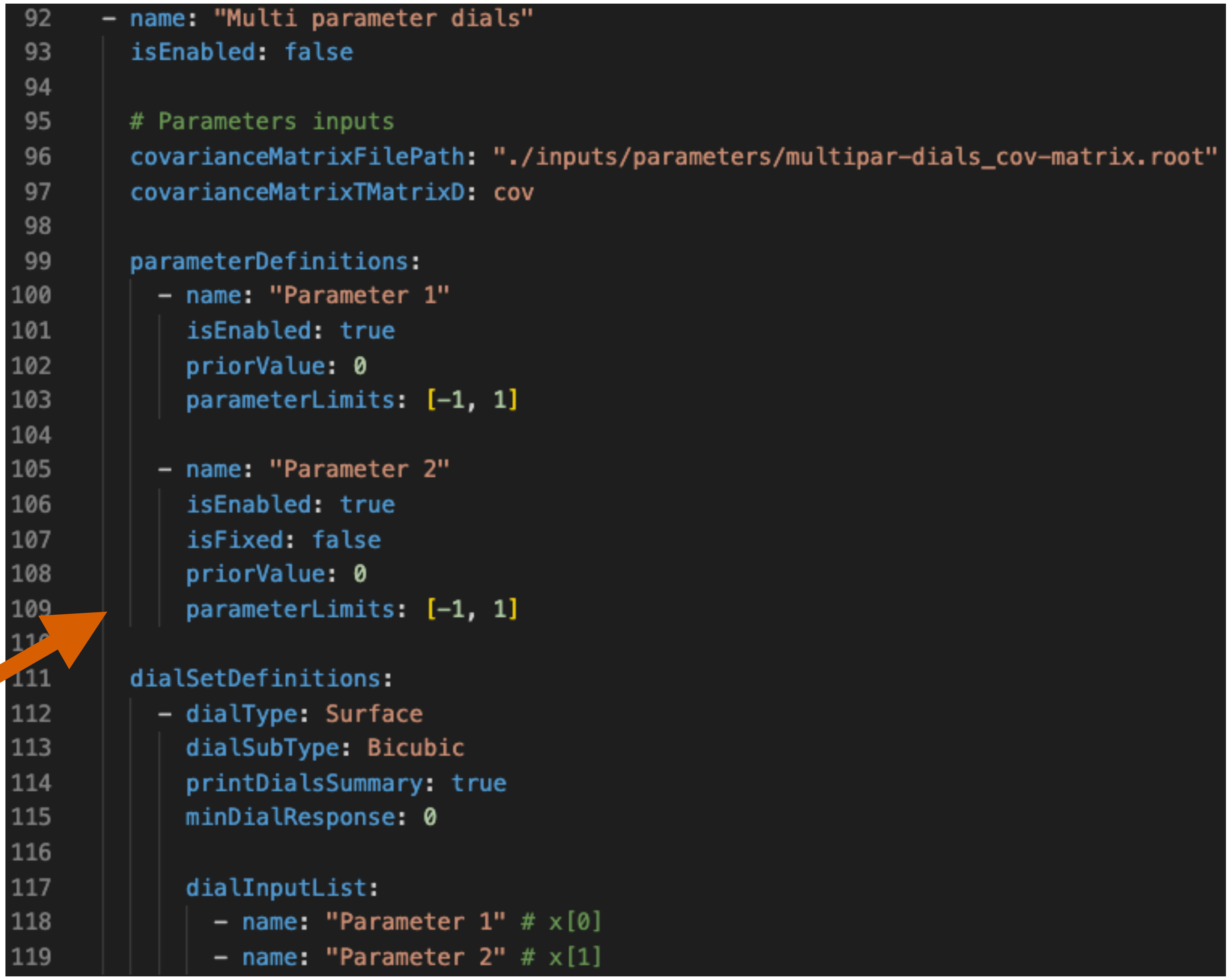
Note: illustrative only examples

Multi-parameter dials

mainConfig.yaml



```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:             "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:      "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:     "./inputs/output/configPlotGenerator.yaml"
    scanConfig:              "./inputs/output/configScan.yaml"
```

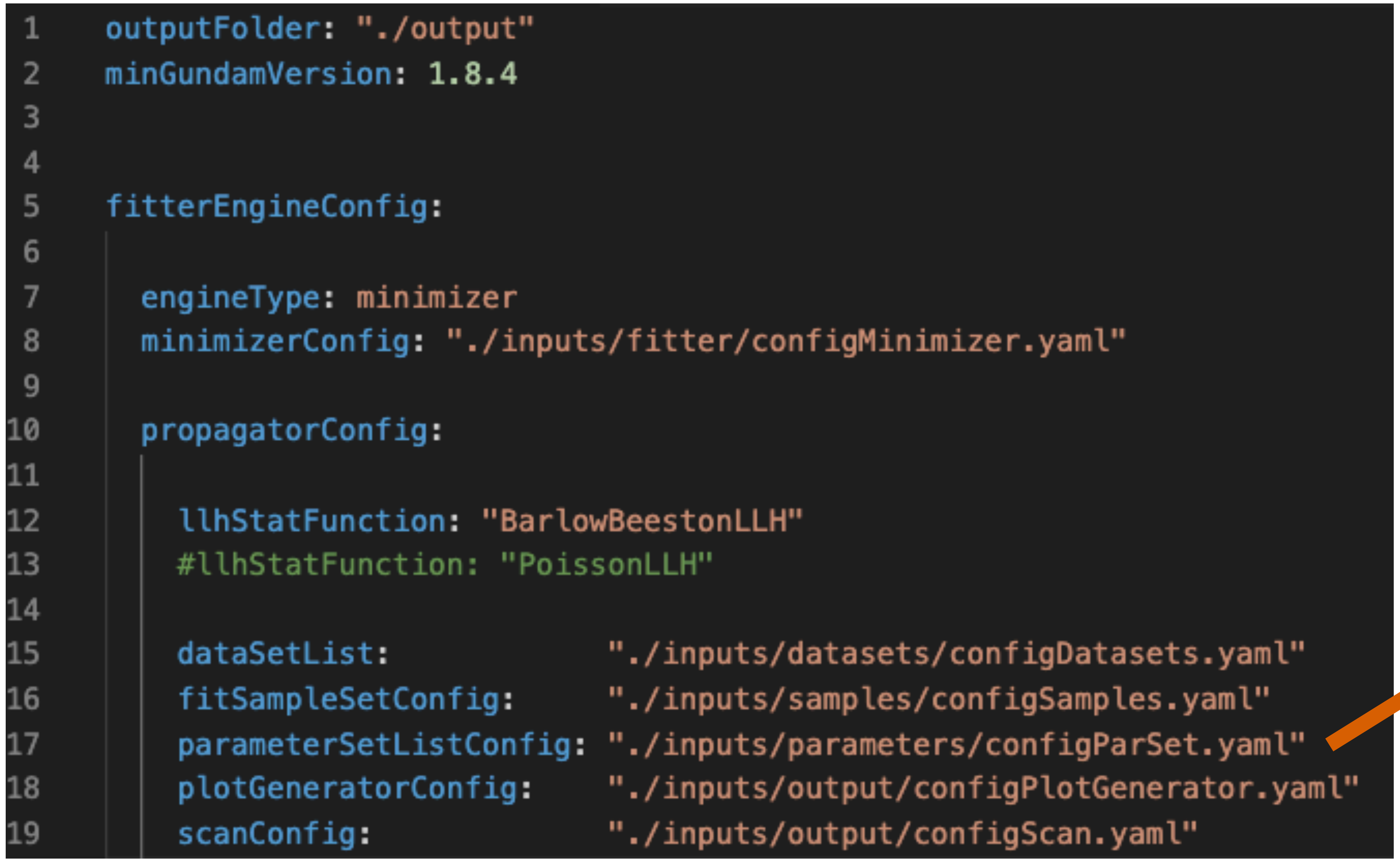


```yaml
- name: "Multi parameter dials"
  isEnabled: false

  # Parameters inputs
  covarianceMatrixFilePath: "./inputs/parameters/multipar-dials_cov-matrix.root"
  covarianceMatrixTMatrixD: cov

  parameterDefinitions:
    - name: "Parameter 1"
      isEnabled: true
      priorValue: 0
      parameterLimits: [-1, 1]

    - name: "Parameter 2"
      isEnabled: true
      isFixed: false
      priorValue: 0
      parameterLimits: [-1, 1]

  dialSetDefinitions:
    - dialType: Surface
      dialSubType: Bicubic
      printDialsSummary: true
      minDialResponse: 0

      dialInputList:
        - name: "Parameter 1" # x[0]
        - name: "Parameter 2" # x[1]
```

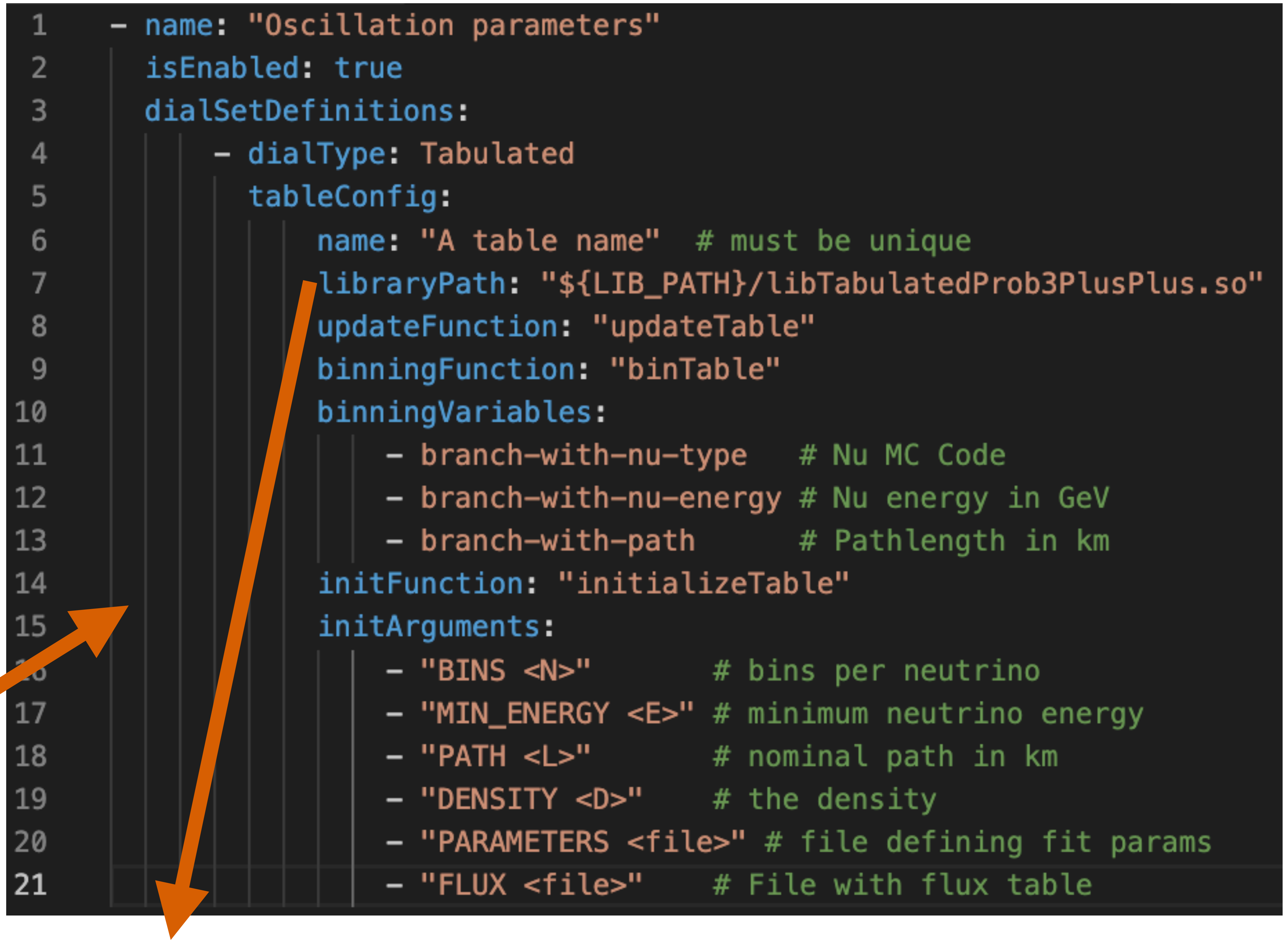
Note: illustrative only examples

Tabulated dials

mainConfig.yaml



```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:           "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:    "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:   "./inputs/output/configPlotGenerator.yaml"
    scanConfig:            "./inputs/output/configScan.yaml"
```

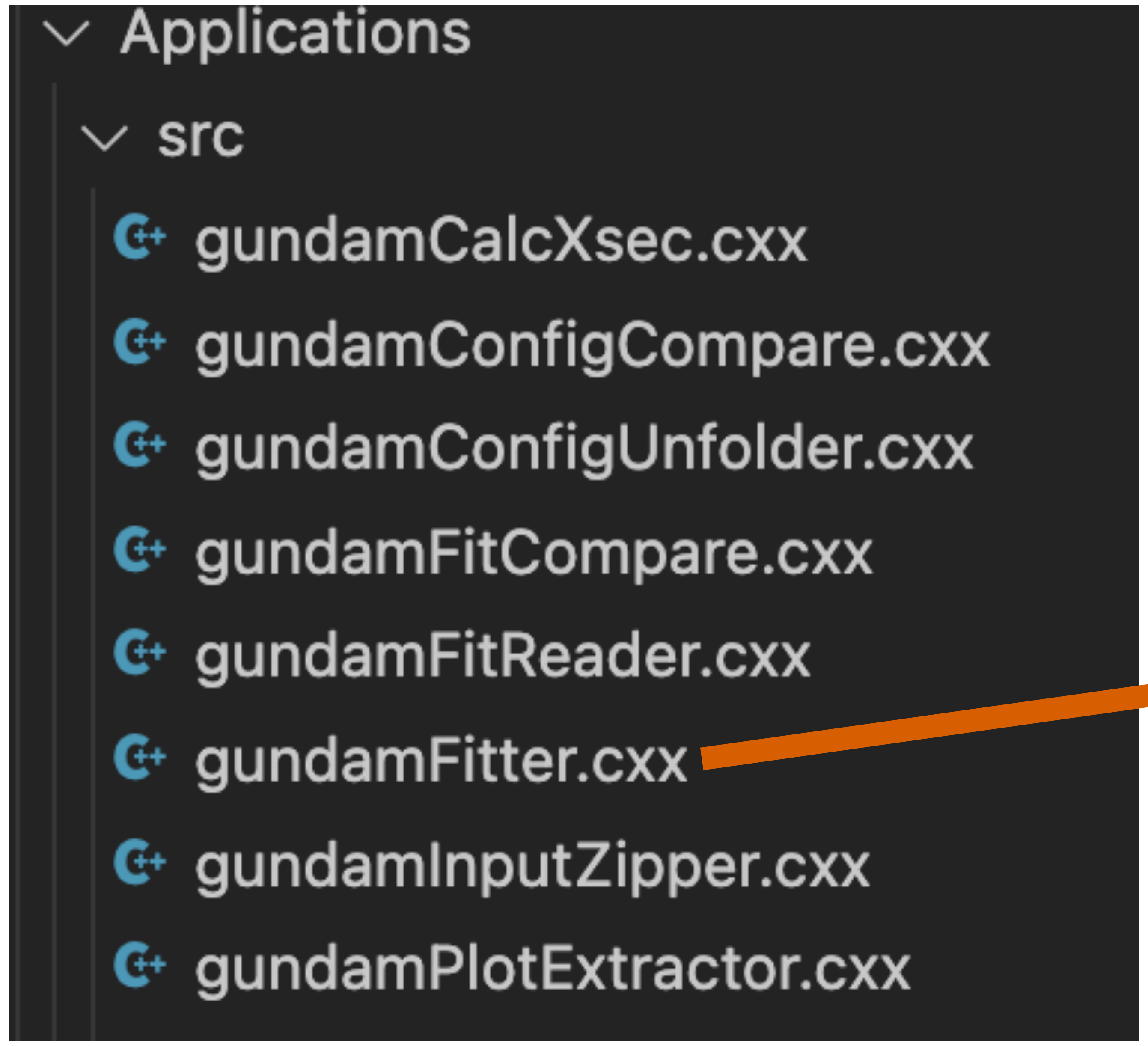


```yaml
- name: "Oscillation parameters"
  isEnabled: true
  dialSetDefinitions:
    - dialType: Tabulated
      tableConfig:
        name: "A table name"  # must be unique
        libraryPath: "${LIB_PATH}/libTabulatedProb3PlusPlus.so"
        updateFunction: "updateTable"
        binningFunction: "binTable"
        binningVariables:
          - branch-with-nu-type   # Nu MC Code
          - branch-with-nu-energy # Nu energy in GeV
          - branch-with-path      # Pathlength in km
        initFunction: "initializeTable"
        initArguments:
          - "BINS <N>"       # bins per neutrino
          - "MIN_ENERGY <E>" # minimum neutrino energy
          - "PATH <L>"       # nominal path in km
          - "DENSITY <D>"    # the density
          - "PARAMETERS <file>" # file defining fit params
          - "FLUX <file>"    # File with flux table
```

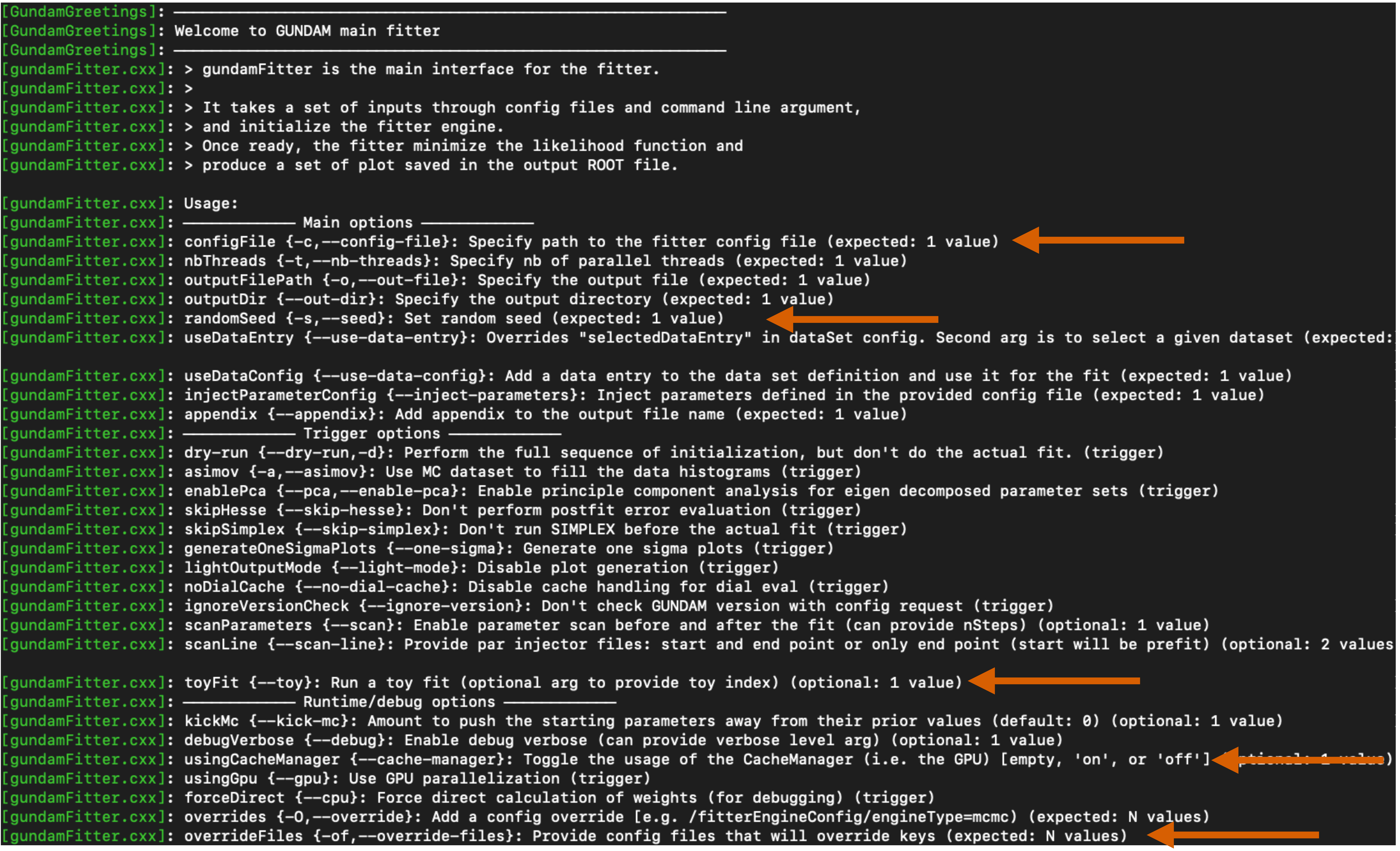
Note: External pre-compiled C++ libraries which belong to the inputs, not the code of GUNDAM itself

Note: illustrative only examples

Applications



```
Applications
  src
    gundamCalcXsec.cxx
    gundamConfigCompare.cxx
    gundamConfigUnfolder.cxx
    gundamFitCompare.cxx
    gundamFitReader.cxx
    gundamFitter.cxx
    gundamInputZipper.cxx
    gundamPlotExtractor.cxx
```

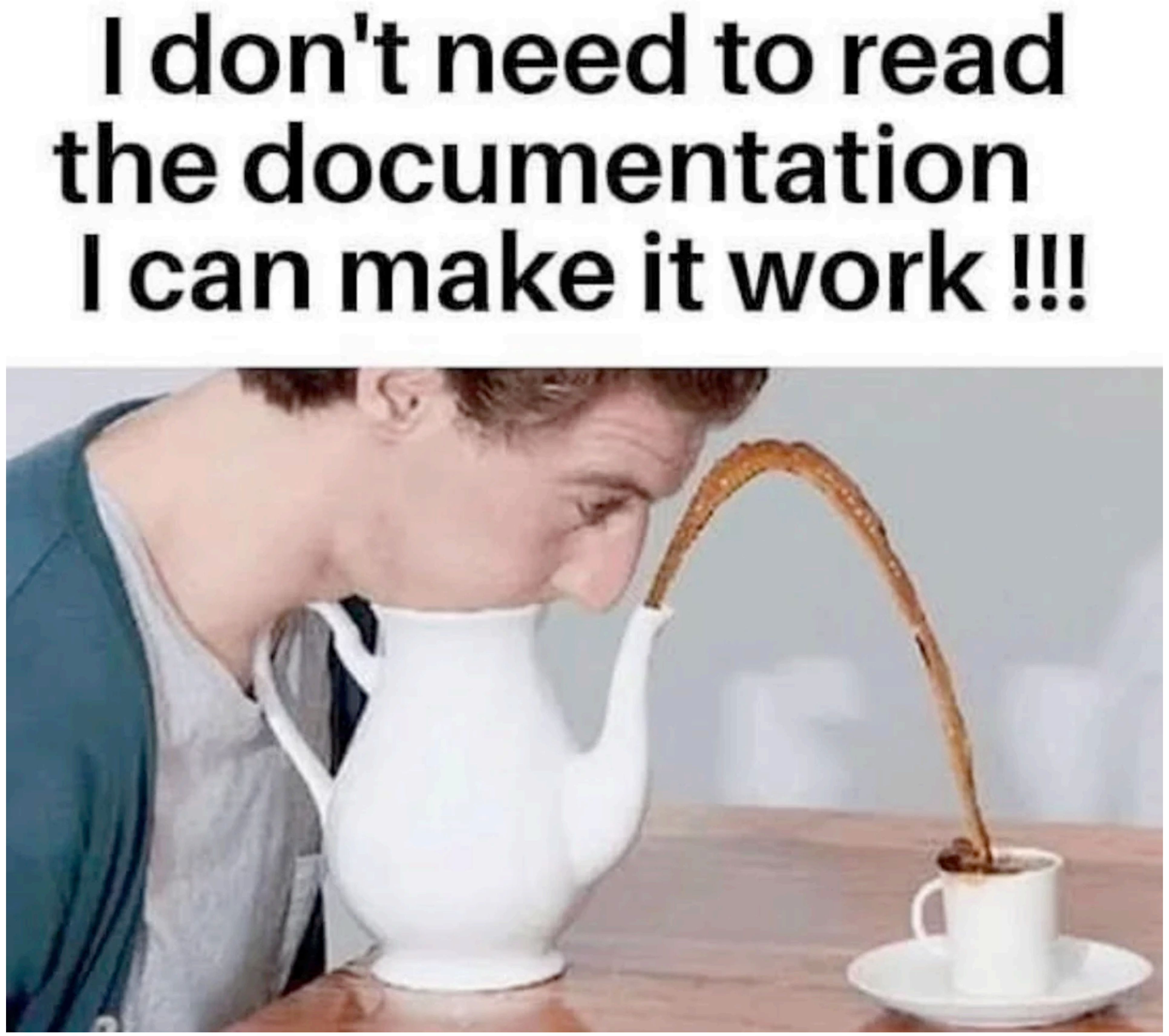


```
[GundamGreetings]: ────────────────────────────────────────────────────────────
[GundamGreetings]: Welcome to GUNDAM main fitter
[GundamGreetings]: ────────────────────────────────────────────────────────────
[gundamFitter.cxx]: > gundamFitter is the main interface for the fitter.
[gundamFitter.cxx]: >
[gundamFitter.cxx]: > It takes a set of inputs through config files and command line argument,
[gundamFitter.cxx]: > and initialize the fitter engine.
[gundamFitter.cxx]: > Once ready, the fitter minimize the likelihood function and
[gundamFitter.cxx]: > produce a set of plot saved in the output ROOT file.

[gundamFitter.cxx]: Usage:
[gundamFitter.cxx]: ──────────── Main options ────────────
[gundamFitter.cxx]: configFile {-c,--config-file}: Specify path to the fitter config file (expected: 1 value)
[gundamFitter.cxx]: nbThreads {-t,--nb-threads}: Specify nb of parallel threads (expected: 1 value)
[gundamFitter.cxx]: outputFilePath {-o,--out-file}: Specify the output file (expected: 1 value)
[gundamFitter.cxx]: outputDir {--out-dir}: Specify the output directory (expected: 1 value)
[gundamFitter.cxx]: randomSeed {-s,--seed}: Set random seed (expected: 1 value)
[gundamFitter.cxx]: useDataEntry {--use-data-entry}: Overrides "selectedDataEntry" in dataSet config. Second arg is to select a given dataset (expected:

[gundamFitter.cxx]: useDataConfig {--use-data-config}: Add a data entry to the data set definition and use it for the fit (expected: 1 value)
[gundamFitter.cxx]: injectParameterConfig {--inject-parameters}: Inject parameters defined in the provided config file (expected: 1 value)
[gundamFitter.cxx]: appendix {--appendix}: Add appendix to the output file name (expected: 1 value)
[gundamFitter.cxx]: ──────────── Trigger options ────────────
[gundamFitter.cxx]: dry-run {--dry-run,-d}: Perform the full sequence of initialization, but don't do the actual fit. (trigger)
[gundamFitter.cxx]: asimov {-a,--asimov}: Use MC dataset to fill the data histograms (trigger)
[gundamFitter.cxx]: enablePca {--pca,--enable-pca}: Enable principle component analysis for eigen decomposed parameter sets (trigger)
[gundamFitter.cxx]: skipHesse {--skip-hesse}: Don't perform postfit error evaluation (trigger)
[gundamFitter.cxx]: skipSimplex {--skip-simplex}: Don't run SIMPLEX before the actual fit (trigger)
[gundamFitter.cxx]: generateOneSigmaPlots {--one-sigma}: Generate one sigma plots (trigger)
[gundamFitter.cxx]: lightOutputMode {--light-mode}: Disable plot generation (trigger)
[gundamFitter.cxx]: noDialCache {--no-dial-cache}: Disable cache handling for dial eval (trigger)
[gundamFitter.cxx]: ignoreVersionCheck {--ignore-version}: Don't check GUNDAM version with config request (trigger)
[gundamFitter.cxx]: scanParameters {--scan}: Enable parameter scan before and after the fit (can provide nSteps) (optional: 1 value)
[gundamFitter.cxx]: scanLine {--scan-line}: Provide par injector files: start and end point or only end point (start will be prefit) (optional: 2 values

[gundamFitter.cxx]: toyFit {--toy}: Run a toy fit (optional arg to provide toy index) (optional: 1 value)
[gundamFitter.cxx]: ──────────── Runtime/debug options ────────────
[gundamFitter.cxx]: kickMc {--kick-mc}: Amount to push the starting parameters away from their prior values (default: 0) (optional: 1 value)
[gundamFitter.cxx]: debugVerbose {--debug}: Enable debug verbose (can provide verbose level arg) (optional: 1 value)
[gundamFitter.cxx]: usingCacheManager {--cache-manager}: Toggle the usage of the CacheManager (i.e. the GPU) [empty, 'on', or 'off'] (optional: 1 value)
[gundamFitter.cxx]: usingGpu {--gpu}: Use GPU parallelization (trigger)
[gundamFitter.cxx]: forceDirect {--cpu}: Force direct calculation of weights (for debugging) (trigger)
[gundamFitter.cxx]: overrides {-O,--override}: Add a config override [e.g. /fitterEngineConfig/engineType=mcmc) (expected: N values)
[gundamFitter.cxx]: overrideFiles {-of,--override-files}: Provide config files that will override keys (expected: N values)
```

```
Example: gundamFitter -c mainConfig.yaml -t 16 --cache-manager -s 123 --toy 1 -of configOverride.yaml
```

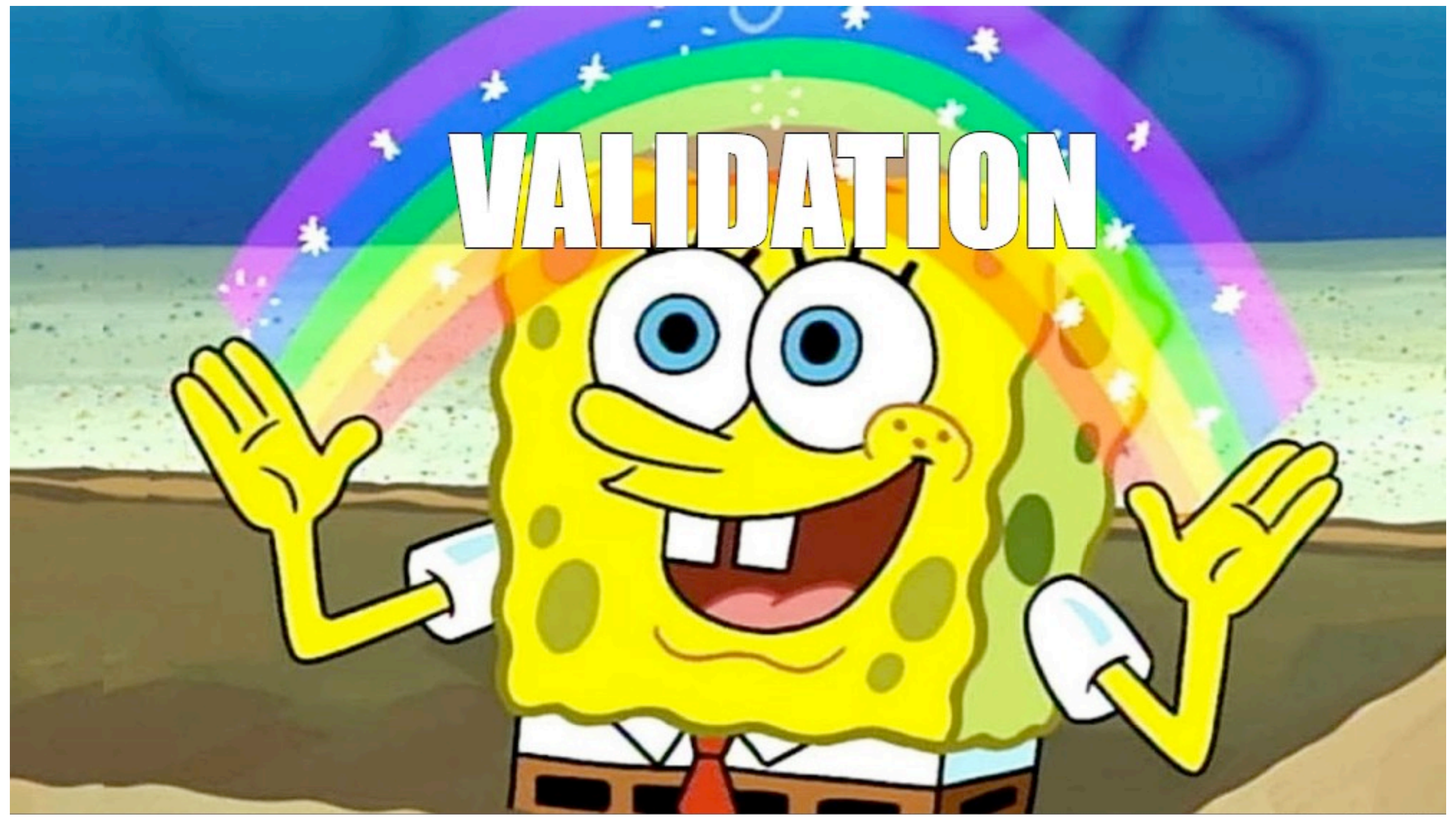
Documentation

- Short outline:
  - A general introduction
  - Installation guide
  - How to set up the configuration files with examples
  - Meaning of the entries of a configuration file
  - How to use the different applications
- Work in progress (almost by definition)



Testing and Validation

- Tests workflow implemented for a continuous validation
- We have two type of tests running: unit tests with GoogleTest and executable testing with specialized script (running mock analysis and checking expectations)
- Executable testing with specialized script can be divided in:
  - Fast: always run and used during continuous integration (eg. few-parameter fit)
  - Regular: quick tests that are not used for CI, but should be run locally before any PR (eg. response functions interpolation)
  - Extended: slower tests (eg. MCMC)
  - Slow: long validation tests (eg. more complex fit)
- Always looking for missing tests!!!



GUNDAM Oscillation Analysis Tools

- Oscillation probability calculation
  - Already using Prob3++ but other libraries can be used
- OA functionality to be implemented:
  - Frequentist analysis, ie profiling:
    - Constant $\Delta\chi^2$ (fast fit), $\Delta\chi^2$ with FC, etc.
  - Bayesian analysis
    - Marginalization with MCMC
- Would like to test what has developed so far and continue
  - Wei Shi (SBU) pointed us toward inputs at this link used for DUNE PRISM
  - Guidance on the latest inputs DUNE-LBL WG is using would help us setting up our config files and add features to the code base if needed

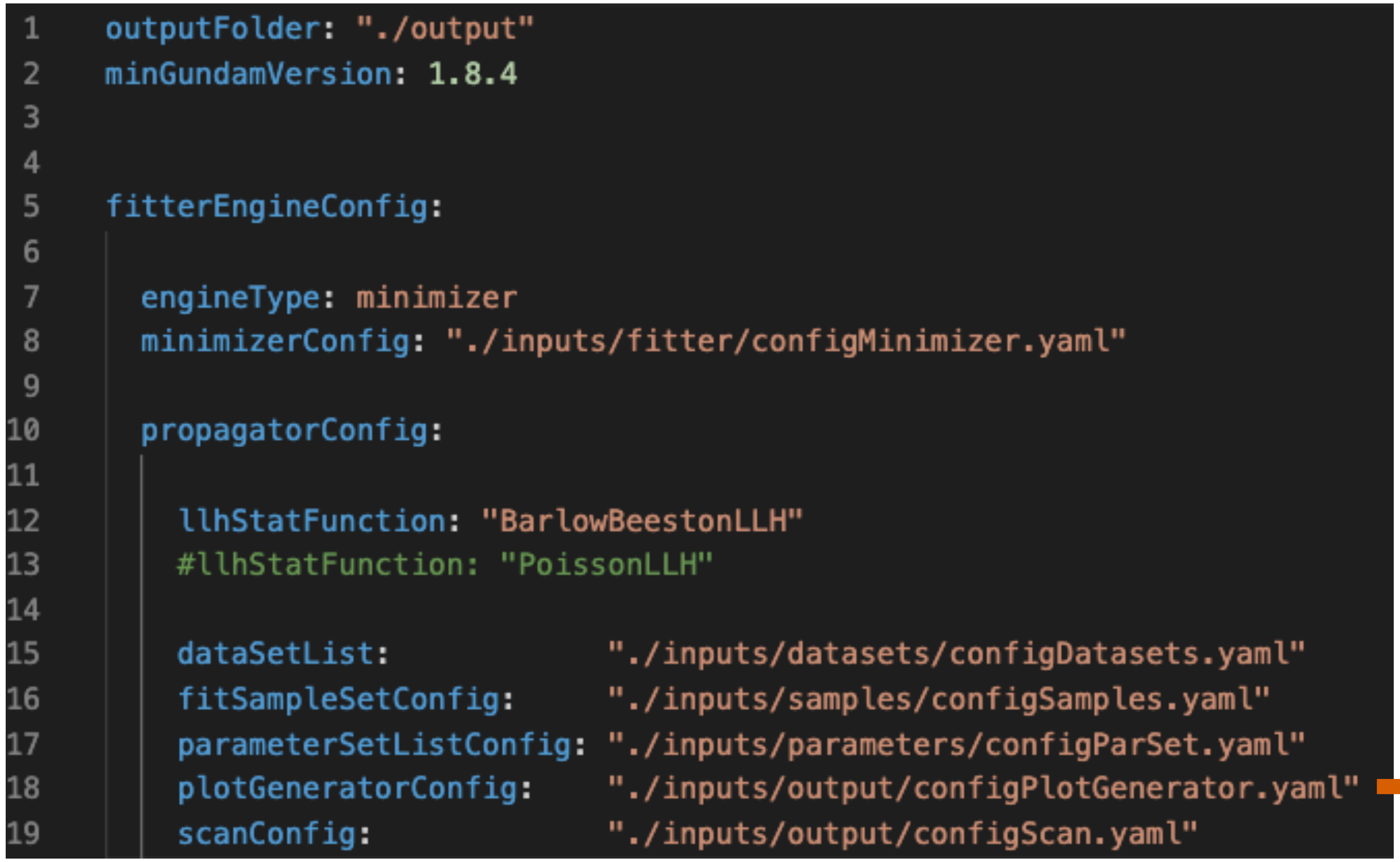
Conclusions

- GUNDAM is a versatile, fully configurable and high-performance tool that can analyze high-dimensional models and binning
- Used for T2K OA-ND and cross-section analyses, but also ICARUS Collaborators are using it for a cross-section analysis
- Can contribute to DUNE LBL in many ways:
  - LBL and LBL+atm sensitivities
    - DUNE PRISM and “classical” ND sensitivities
  - Cross-section analyses (future)
  - Many other analyses
- GUNDAM Oscillation Analysis Tools work ongoing and we exploring the interests of other groups and individuals

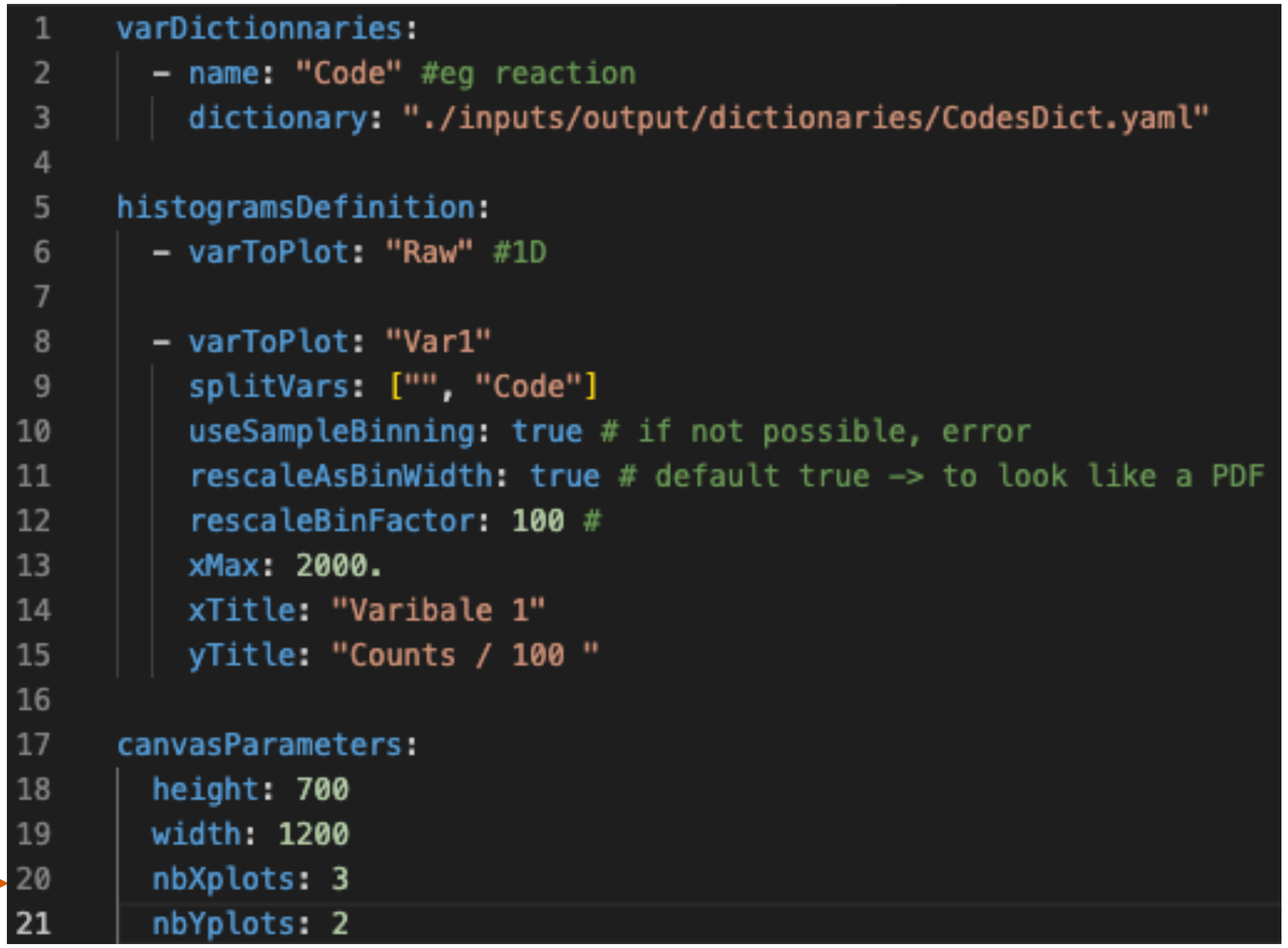
Backup

Plot generator

mainConfig.yaml



```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:              "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:       "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:      "./inputs/output/configPlotGenerator.yaml"
    scanConfig:               "./inputs/output/configScan.yaml"
```

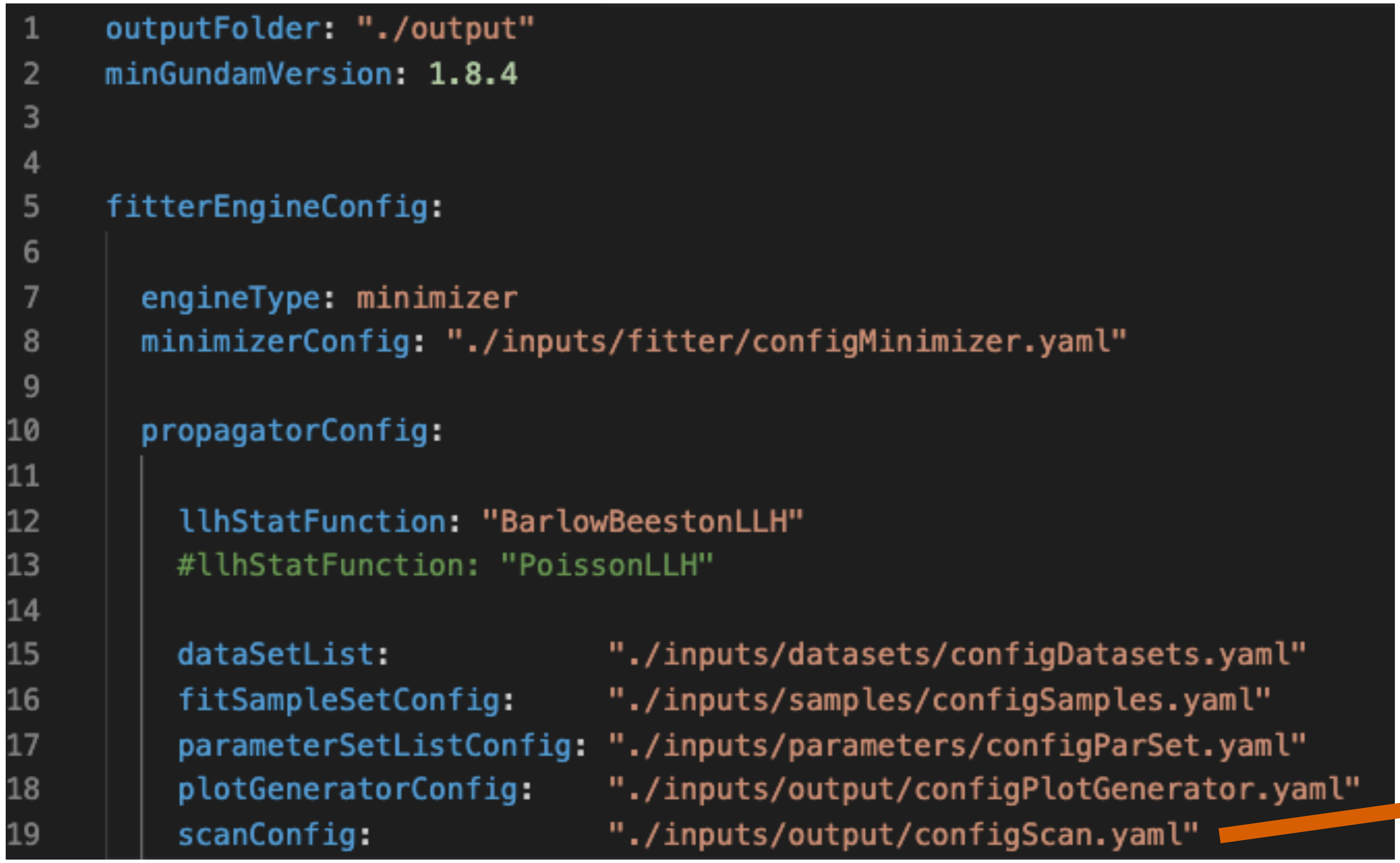


```yaml
varDictionnaries:
  - name: "Code" #eg reaction
    dictionary: "./inputs/output/dictionaries/CodesDict.yaml"

histogramsDefinition:
  - varToPlot: "Raw" #1D

  - varToPlot: "Var1"
    splitVars: ["", "Code"]
    useSampleBinning: true # if not possible, error
    rescaleAsBinWidth: true # default true -> to look like a PDF
    rescaleBinFactor: 100 #
    xMax: 2000.
    xTitle: "Varibale 1"
    yTitle: "Counts / 100 "

canvasParameters:
  height: 700
  width: 1200
  nbXplots: 3
  nbYplots: 2
```

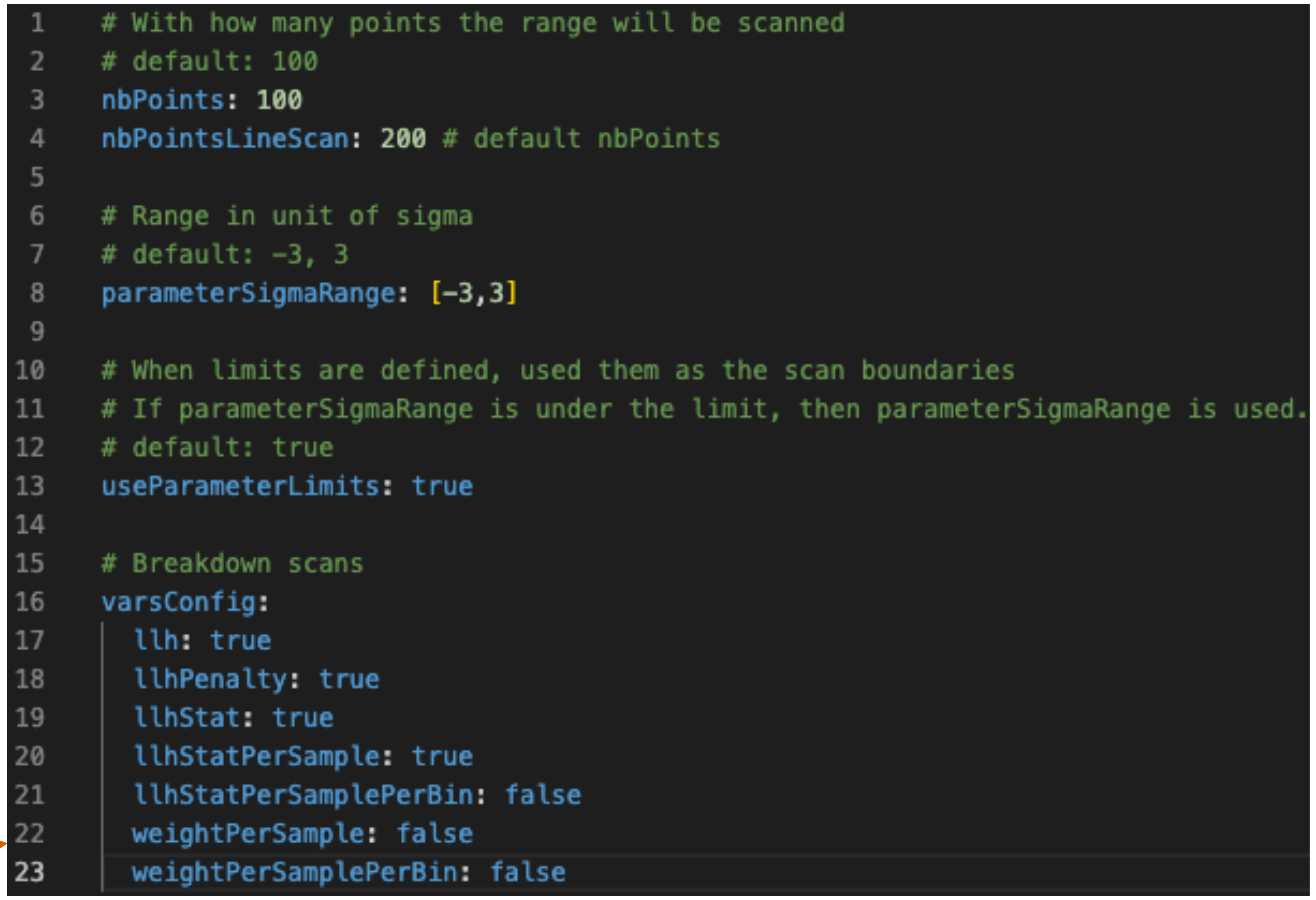
Note: illustrative only examples

Likelihood scanning

mainConfig.yaml



```yaml
outputFolder: "./output"
minGundamVersion: 1.8.4


fitterEngineConfig:

  engineType: minimizer
  minimizerConfig: "./inputs/fitter/configMinimizer.yaml"

  propagatorConfig:

    llhStatFunction: "BarlowBeestonLLH"
    #llhStatFunction: "PoissonLLH"

    dataSetList:            "./inputs/datasets/configDatasets.yaml"
    fitSampleSetConfig:     "./inputs/samples/configSamples.yaml"
    parameterSetListConfig: "./inputs/parameters/configParSet.yaml"
    plotGeneratorConfig:    "./inputs/output/configPlotGenerator.yaml"
    scanConfig:             "./inputs/output/configScan.yaml"
```



```yaml
# With how many points the range will be scanned
# default: 100
nbPoints: 100
nbPointsLineScan: 200 # default nbPoints

# Range in unit of sigma
# default: -3, 3
parameterSigmaRange: [-3,3]

# When limits are defined, used them as the scan boundaries
# If parameterSigmaRange is under the limit, then parameterSigmaRange is used.
# default: true
useParameterLimits: true

# Breakdown scans
varsConfig:
  llh: true
  llhPenalty: true
  llhStat: true
  llhStatPerSample: true
  llhStatPerSamplePerBin: false
  weightPerSample: false
  weightPerSamplePerBin: false
```

Note: illustrative only examples

Development policy

- For internal development an issue should be opened and it should happen in a dedicated branch with a descriptive name of the feature. We recommend the following tags:
  - fix/myFix: to address specific issues with the code
  - feature/myFeature: to add specific feature
  - doc/myDoc: for documentation additions
  - experimental/myBranch: for idea developments
- Change description (commit messages and PR) must be explicit and limited to a single issue
- Create a PR and merge after review and CI is successfully completed
- External developers are encouraged following the same procedure as above (might fork the code)