MonteCUBES
A MCMC for neutrino oscillations

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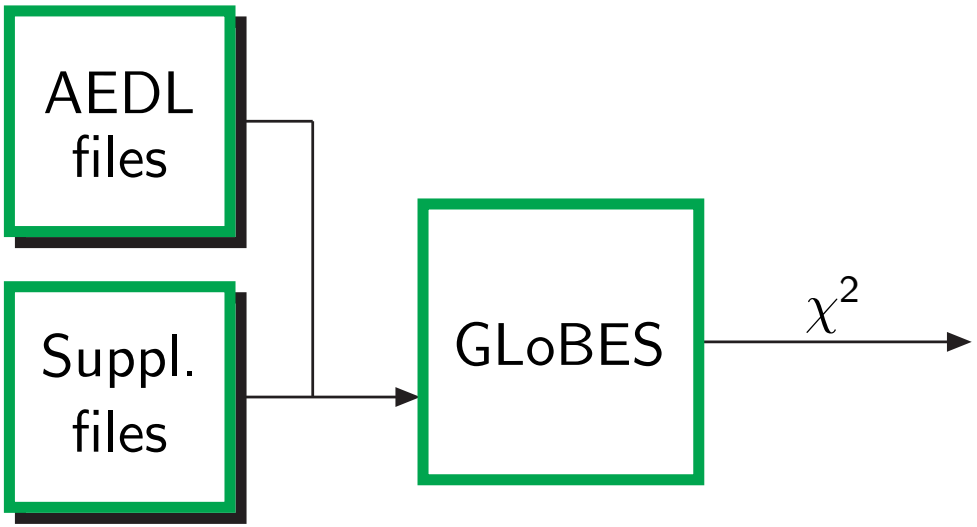
http://wwwth.mppmu.mpg.de/members/blennow/montecubes/

July 22, 2009 @ NuFact, Chicago, Illinois, USA

(Based on MB, Fernandez-Martinez, arXiv:0903.3985)

1 General Long Baseline Experiment Simulator (GLoBES)

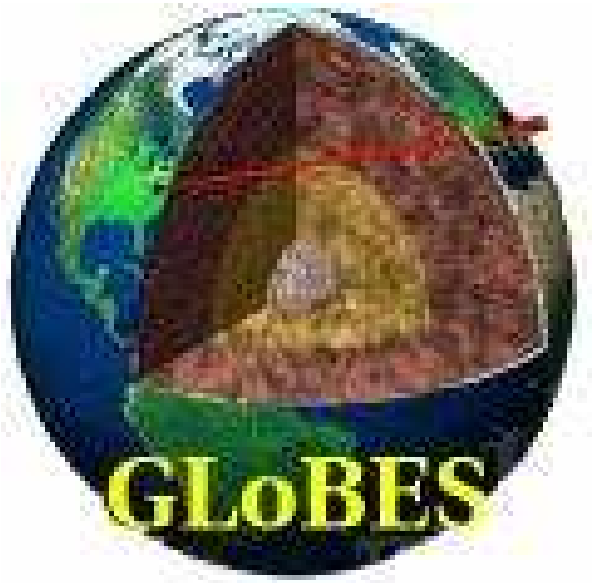
Software flowchart



What is GLoBES?

From the GLoBES homepage:

"GLoBES is a modular software system to simulate long-baseline neutrino oscillation experiments"



See talk by Patrick Huber

Features of GLoBES

- Highly modular experimental definitions (AEDL)
- $\Delta\chi^2$ computation and minimization
- Since version 3.0:
  - Modular implementation of new physics
  - Customizable systematic error treatment
- Frequentist approach

Drawbacks of non-stochastic methods

- Large parameter spaces (especially for new physics scenarios)
- Minimization techniques ineffective
- Minimization techniques sometimes miss the minimum in complicated parameter spaces

This translates to long running times and/or restrictions on the parameter space.

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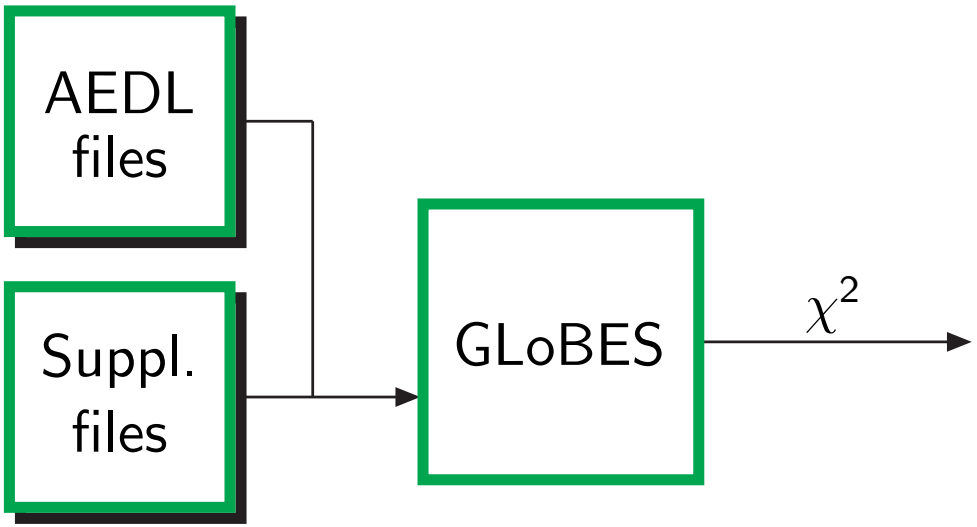

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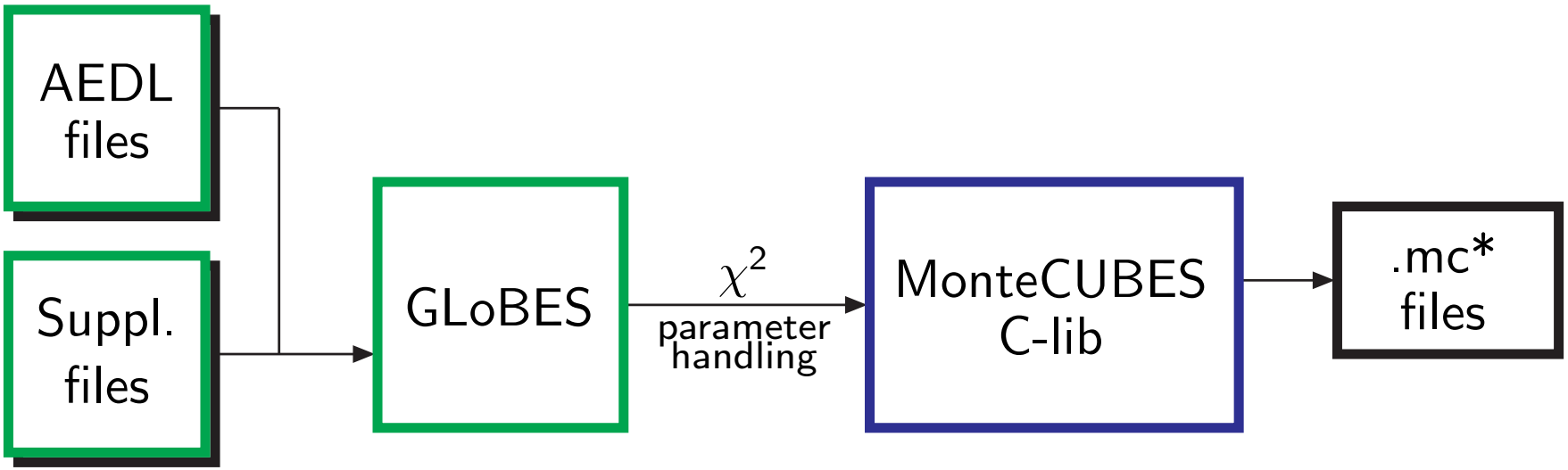


MonteCUBES in a nutshell

- It is a *plug-in* for GLoBES.
- Fully customizable MCMC codes.
- Uses a Matlab GUI for visualizing and interpreting the results.
- Effective also for a large number of parameters.
- Finding degenerate solutions.
- Fully compatible with standard GLoBES experimental definitions (AEDL files).

Markov Chain Monte Carlo

- Bayesian inference
- Creates a sample of the posterior likelihood $L(x)$
- Basic usage uses Metropolis–Hastings sampling
  - Start from the point x_0
  - Pick x' according to step proposal function $W(x_0 \longrightarrow x')$
  - With probability

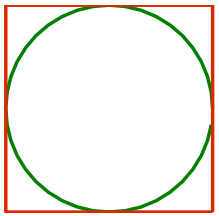
$$P = \min\left[1, \frac{L(x')W(x' \longrightarrow x_0)}{L(x_0)W(x_0 \longrightarrow x')}\right]$$

    Sample x' and put $x_0 = x'$ for next MCMC step
  - Otherwise: Sample x_0 and keep it for the next MCMC step

Why MCMC?

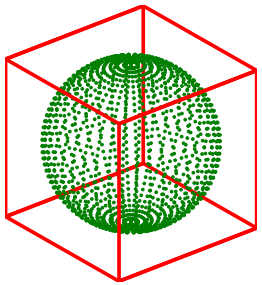
1D: $r = V_{\text{sphere}}/V_{\text{cube}} = 1$

2D:



$r = \frac{\pi}{4} \simeq 0.79$

3D:



$r = \frac{\pi}{6} \simeq 0.52$

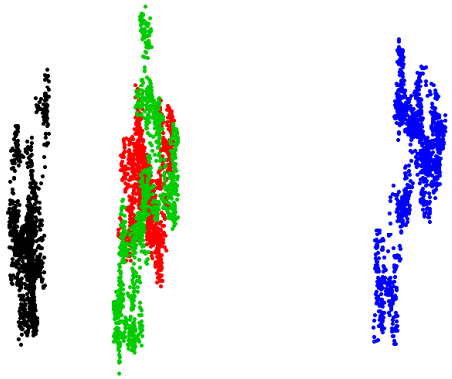
nD: $r = \frac{1}{n!!}\left(\frac{\pi}{2}\right)^{\lfloor n/2 \rfloor}$

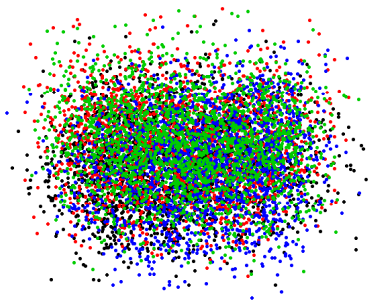
- Explores the *relevant* region in each function evaluation
- Increasingly important in higher dimensions
- Projection instead of minimization
- $r(6) \simeq 0.08$, $r(15) \simeq 0.000012$

MCMC convergence

The Metropolis–Hastings algorithm has the likelihood as the *equilibrium distribution*

- Need to check convergence of sample
- Implemented in run-time
- Run several MCMC simulations (chains) in parallel
- Compare the variance within chains with variance of full sample





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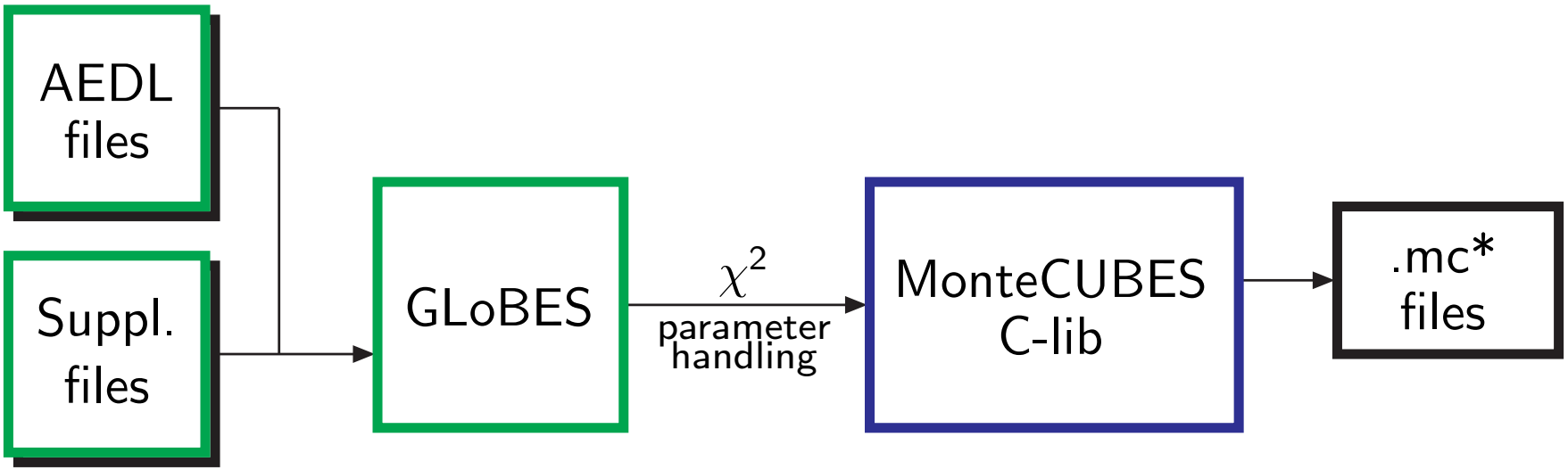

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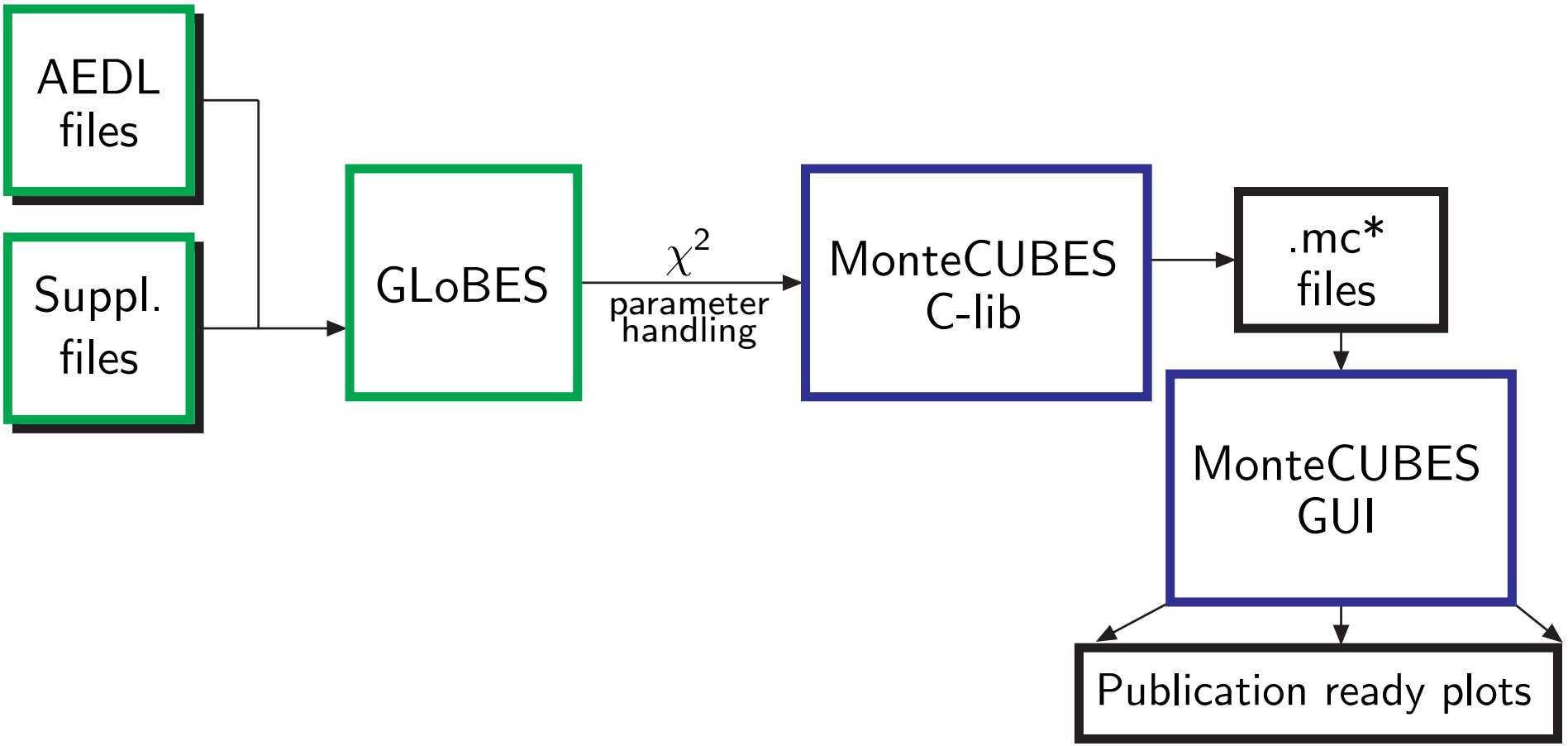
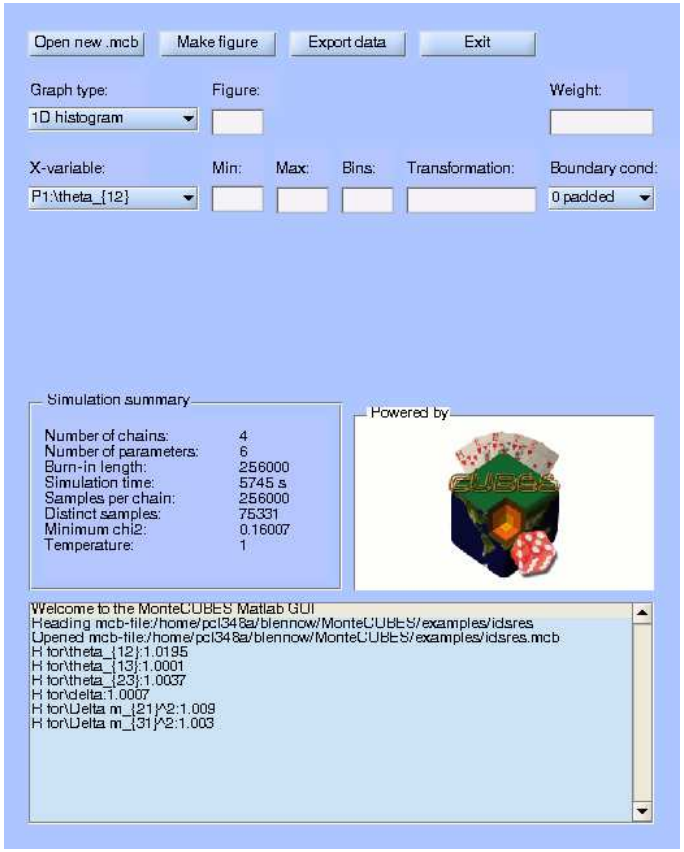


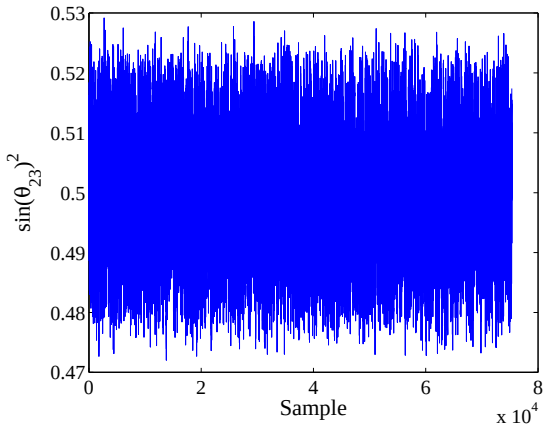
The Matlab GUI

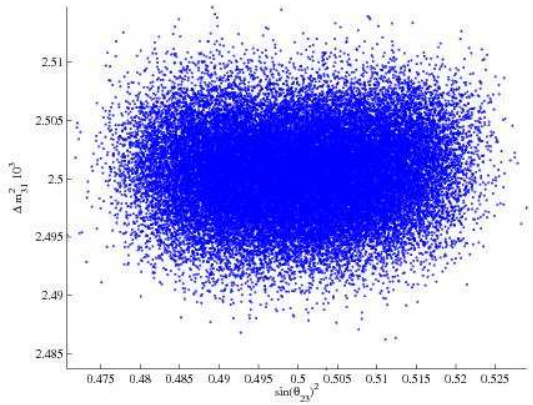


- Convenient for interpreting output files
- Includes both diagnostic and result plotting tools
- Basic usage: Click-and-plot
- Advanced usage includes:
  - Gaussian smearing
  - Different boundary conditions
  - Post-simulation priors/variable transformations

Chain diagnostics

- Allows visual diagnostics
  - Chain progression
  - Sample distribution
- Computes convergence parameters
- Allows for efficient tuning of MCMC step-sizes





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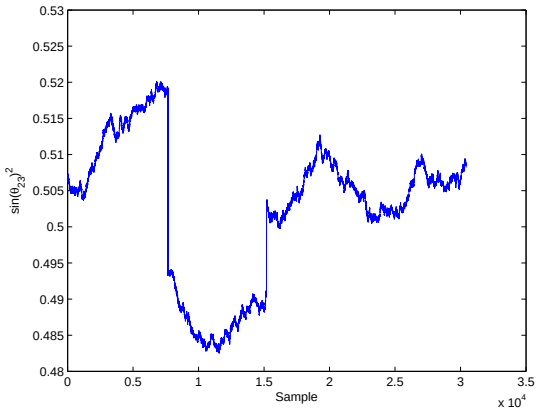
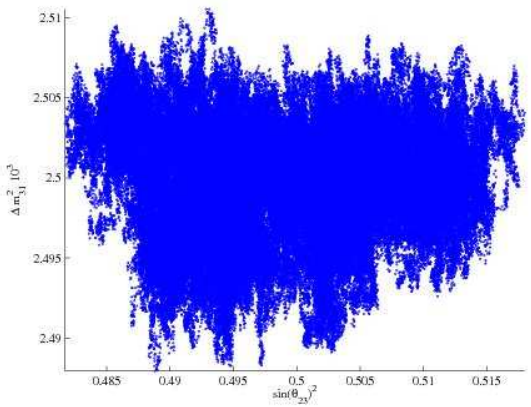
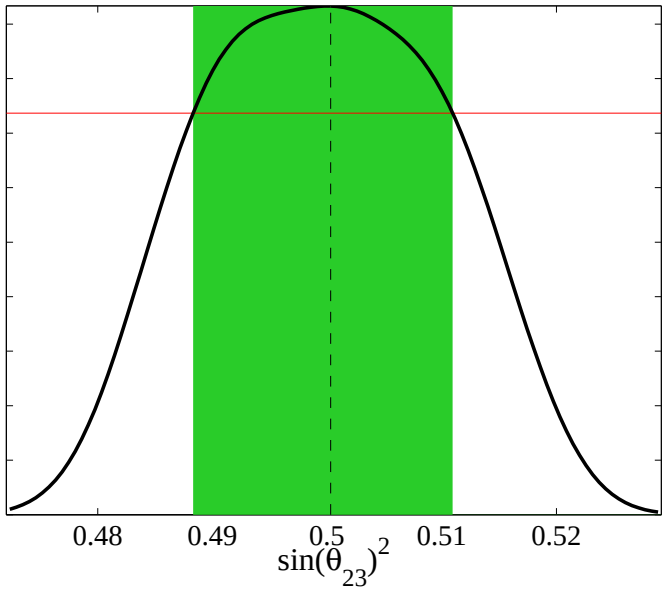




Result plots

Several different possibilities for result visualization:

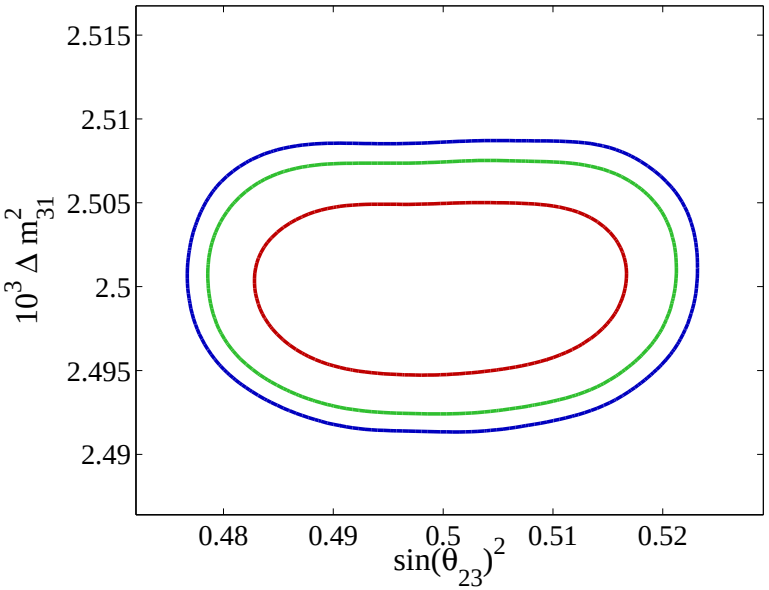
- 1D distributions



Result plots

Several different possibilities for result visualization:

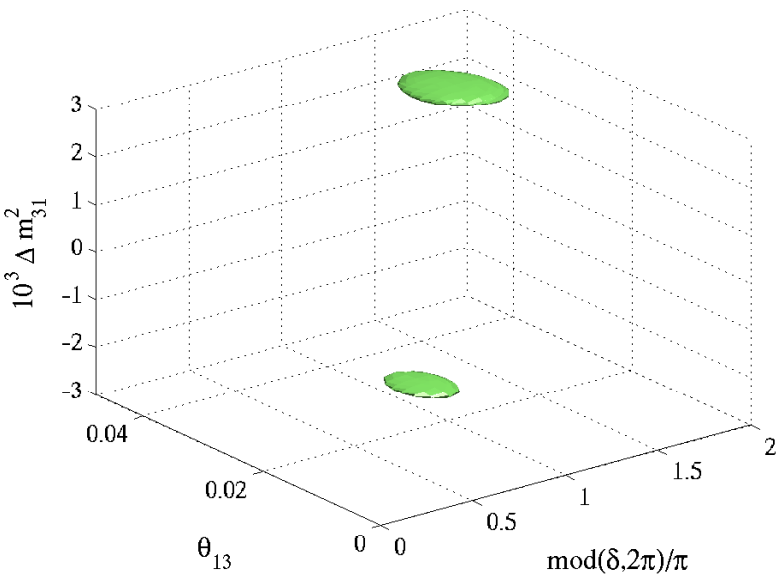
- 1D distributions
- 2D contours



Result plots

Several different possibilities for result visualization:

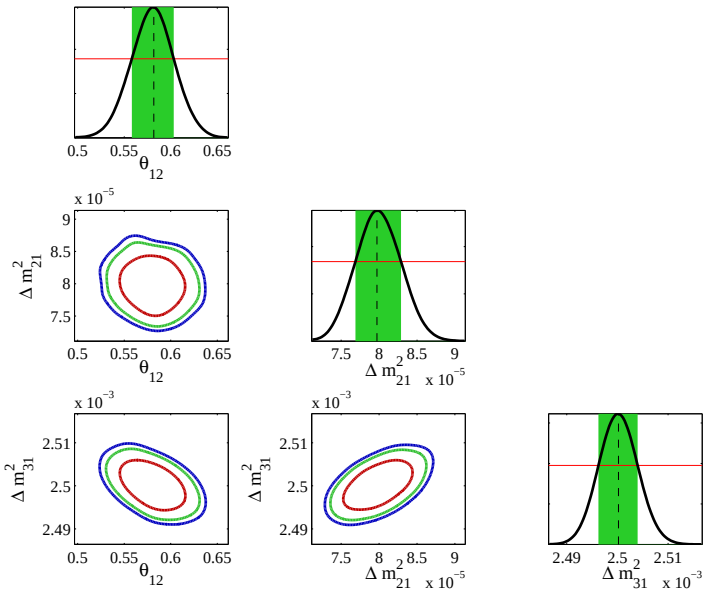
- 1D distributions
- 2D contours
- 3D surfaces



Result plots

Several different possibilities for result visualization:

- 1D distributions
- 2D contours
- 3D surfaces
- Triangle plots



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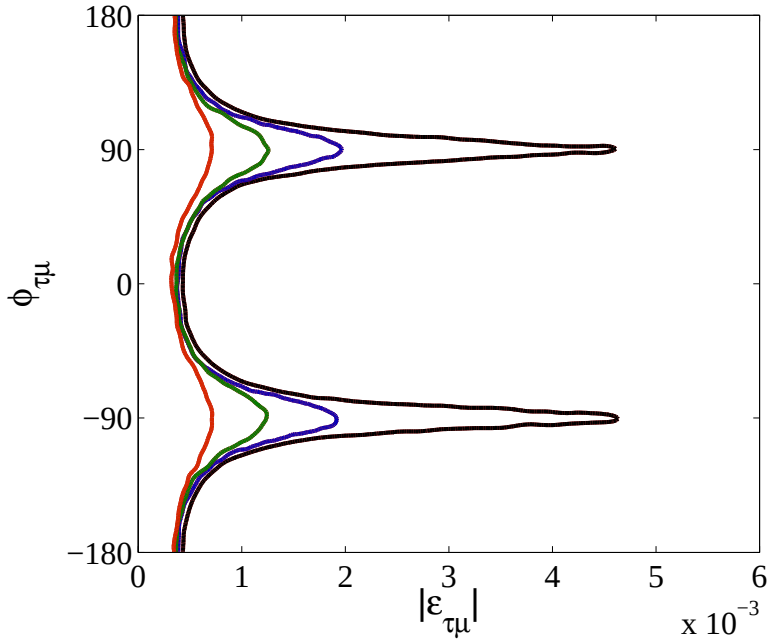
In addition:

- Plots customizable within Matlab
- Different simulations in same plot



Antusch, MB, Fernandez-Martinez, Lopez-Pavon, 0903.3986

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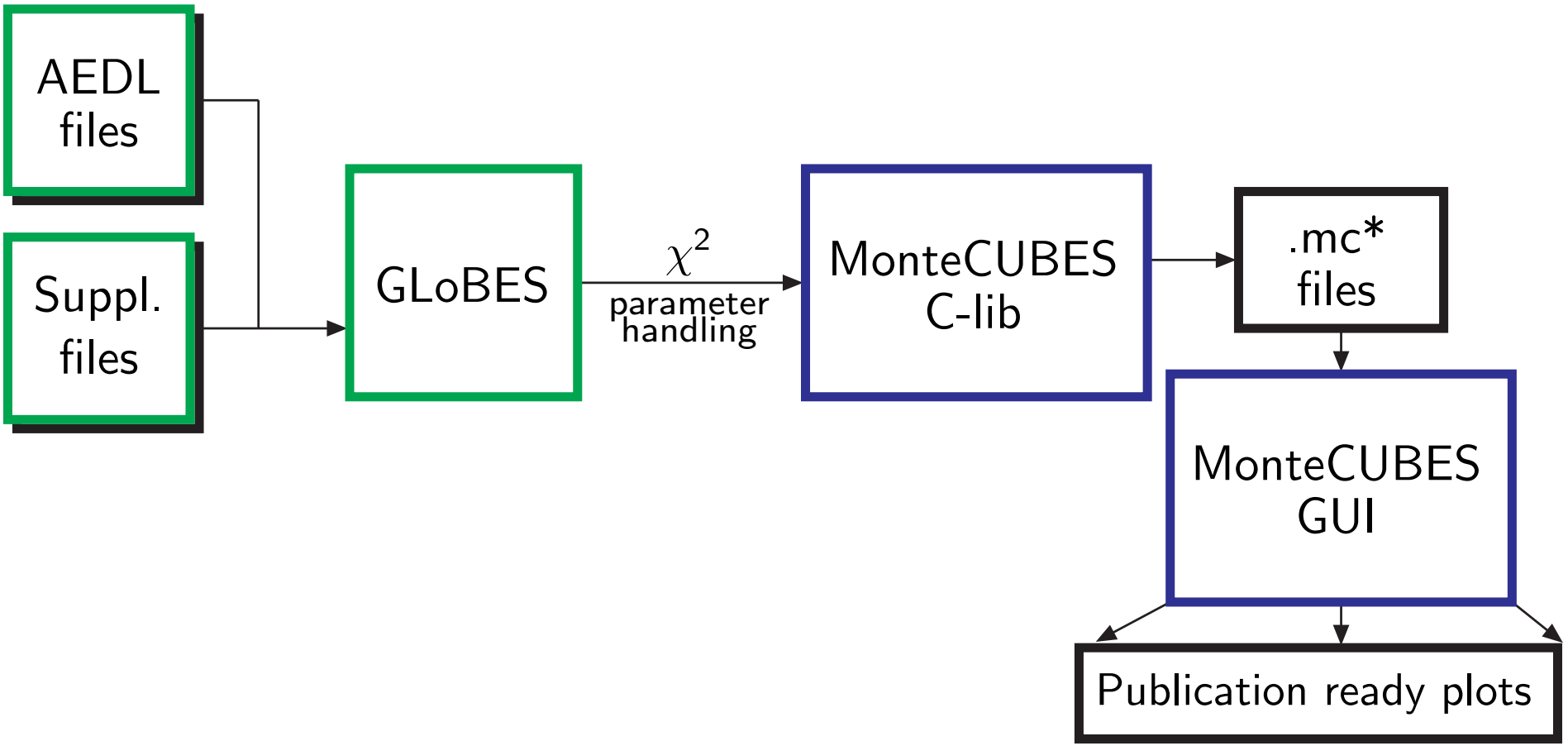

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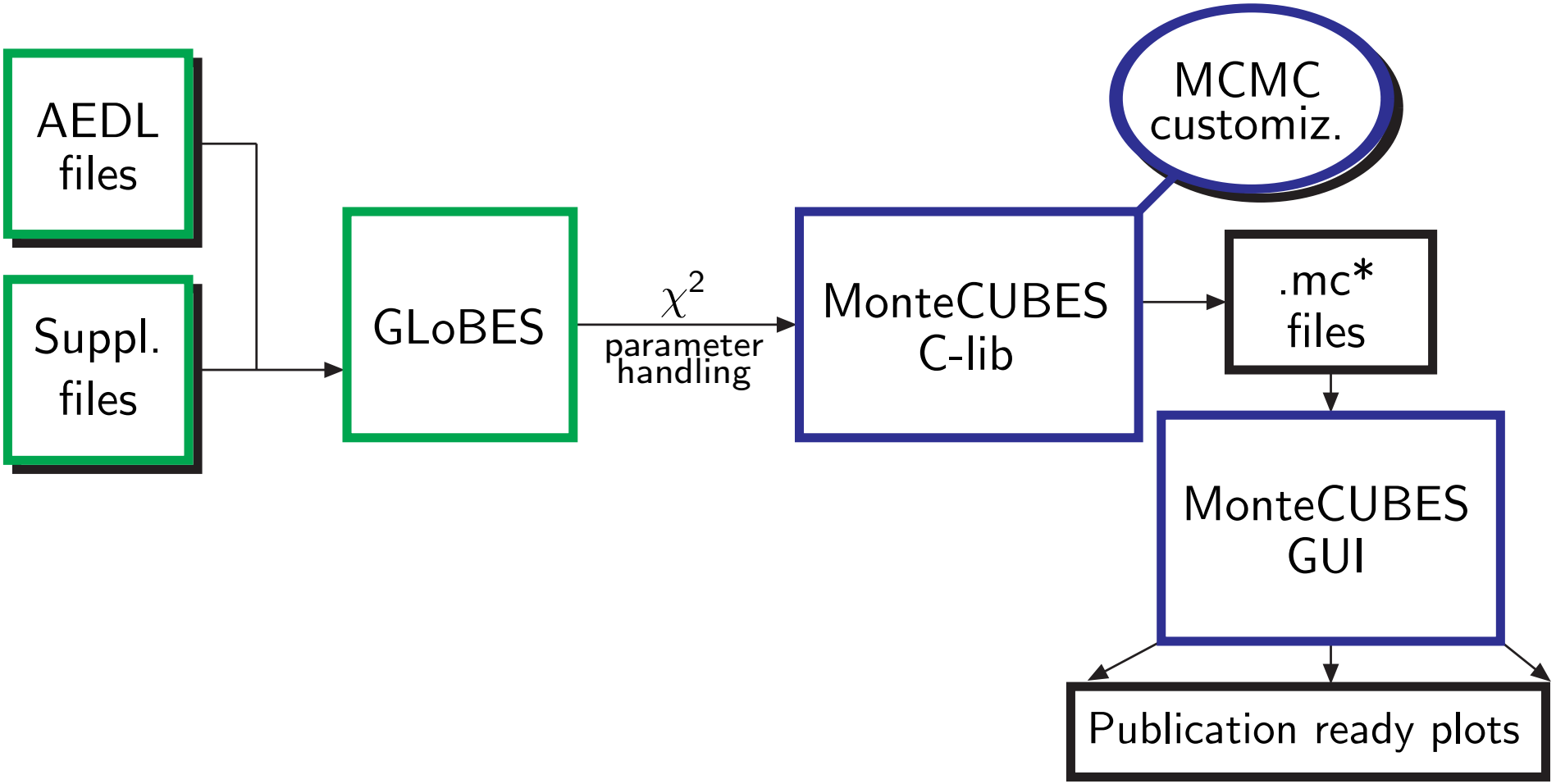
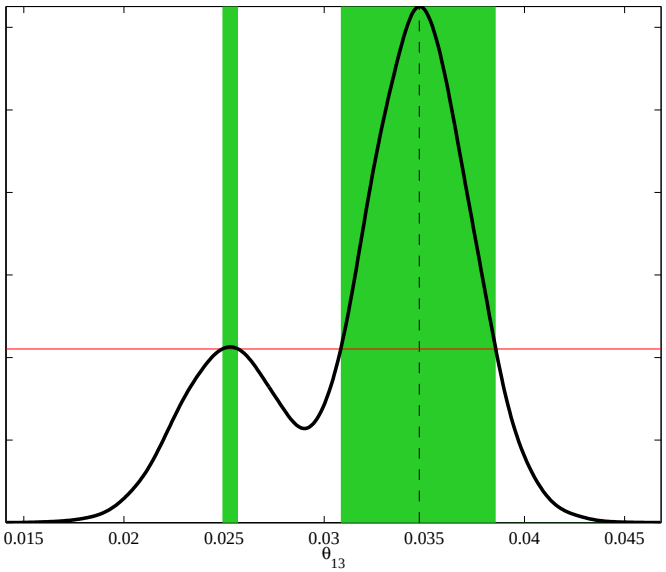


MCMC cutomization



The MCMC is highly modular:

- Find and explore degenerate solutions (with correct weights)
- Customization of step proposal function (Metropolis–Hastings algorithm)
- User can define new PRNG (default is Mersenne twister)

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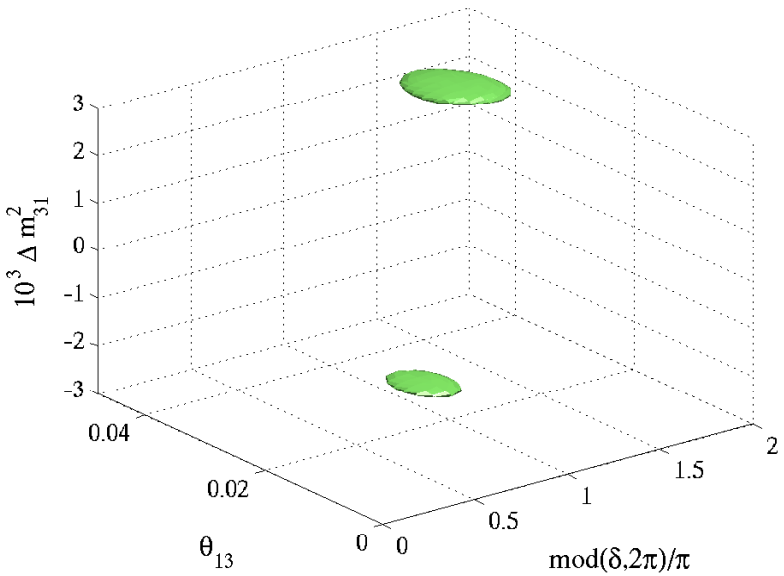

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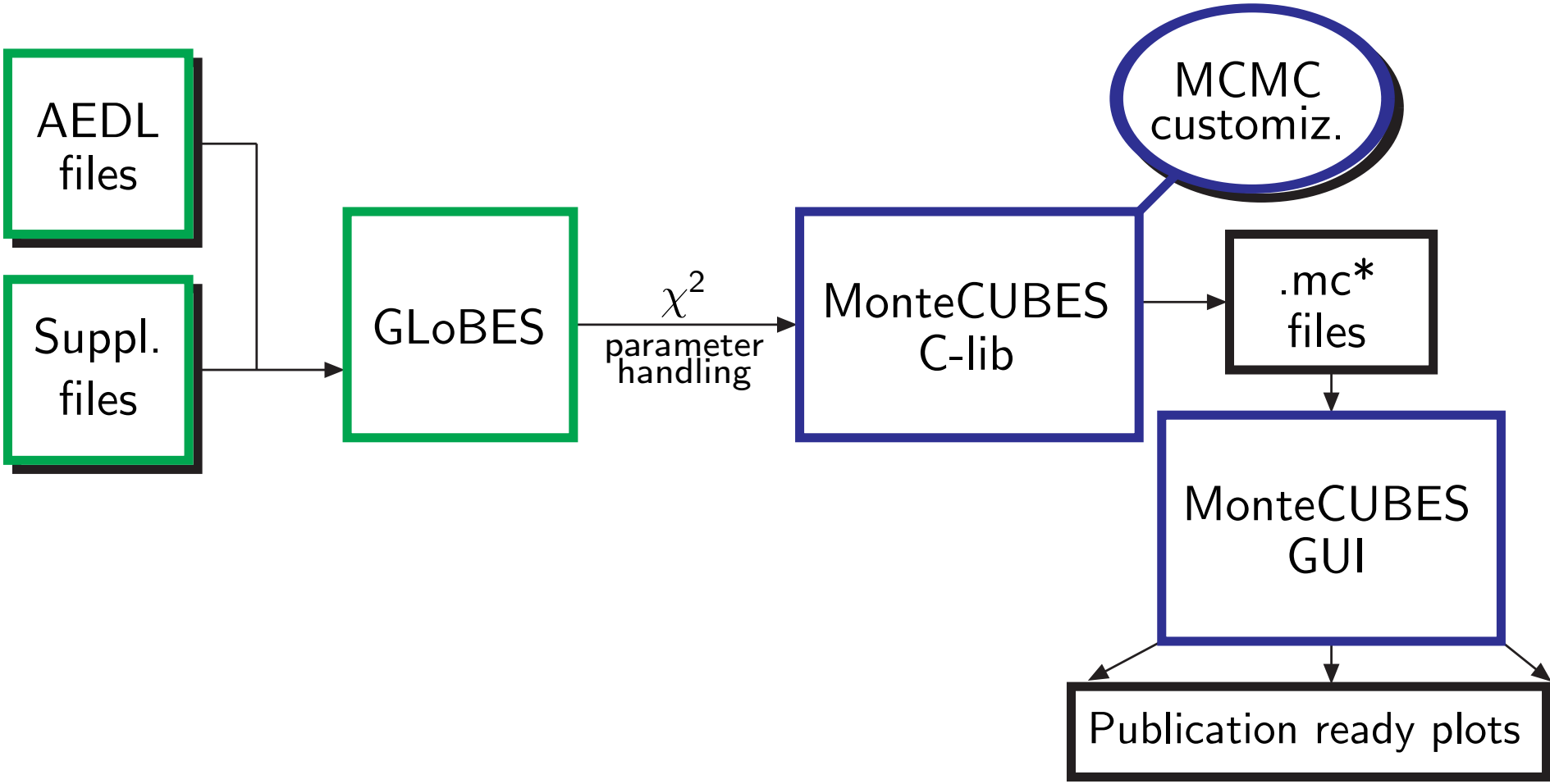

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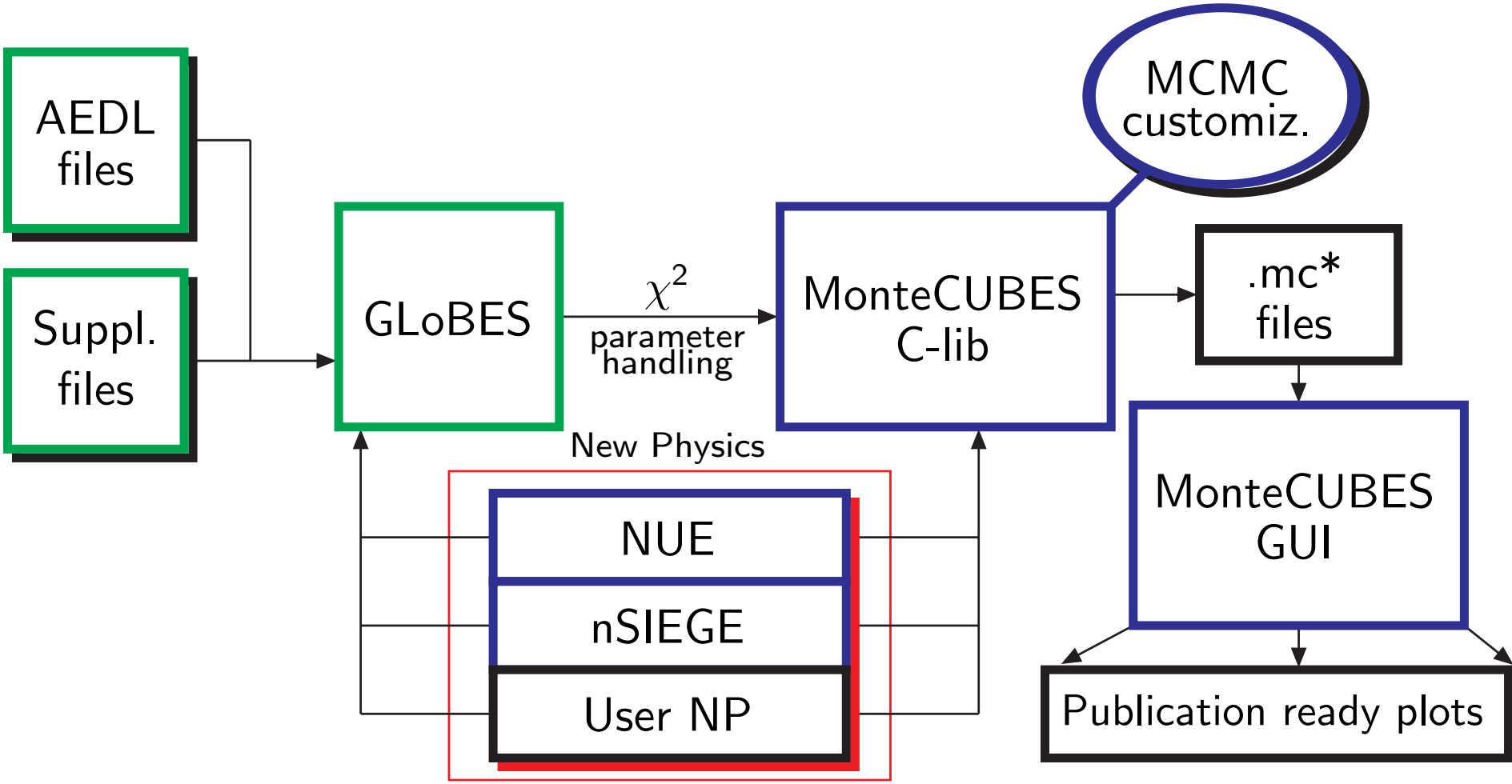
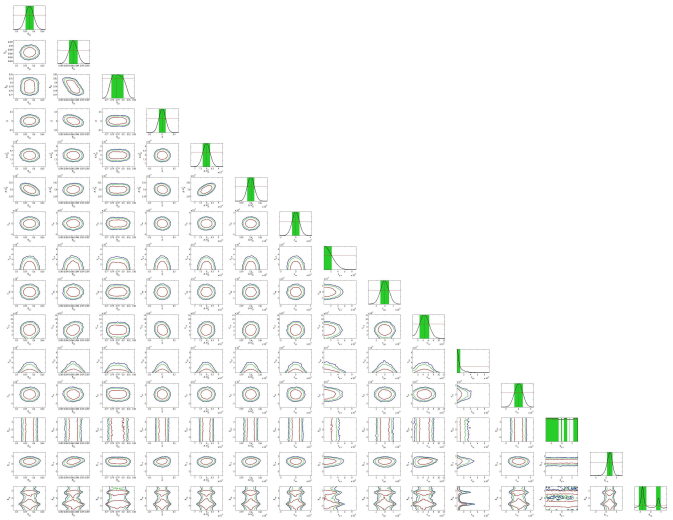


New physics

- Fully compatible with GLoBES 3.0 new physics (NP) extensions
- Includes NP extensions:
  - NUE – Minimal Unitarity Violation
  - nSIEGE – NSI
- MCMC methods powerful for high-dimensional parameter spaces $\Longrightarrow$ well suited for NP



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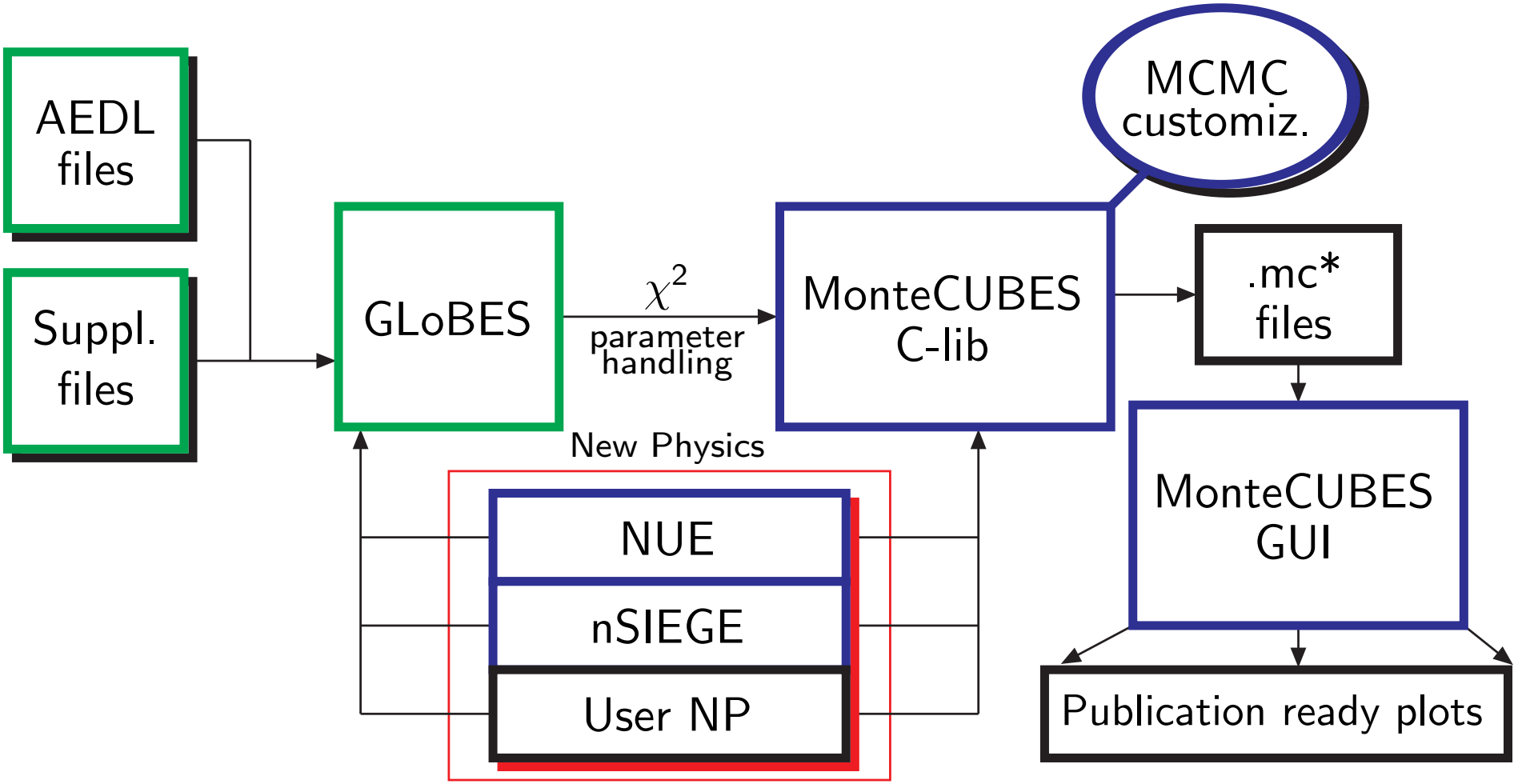

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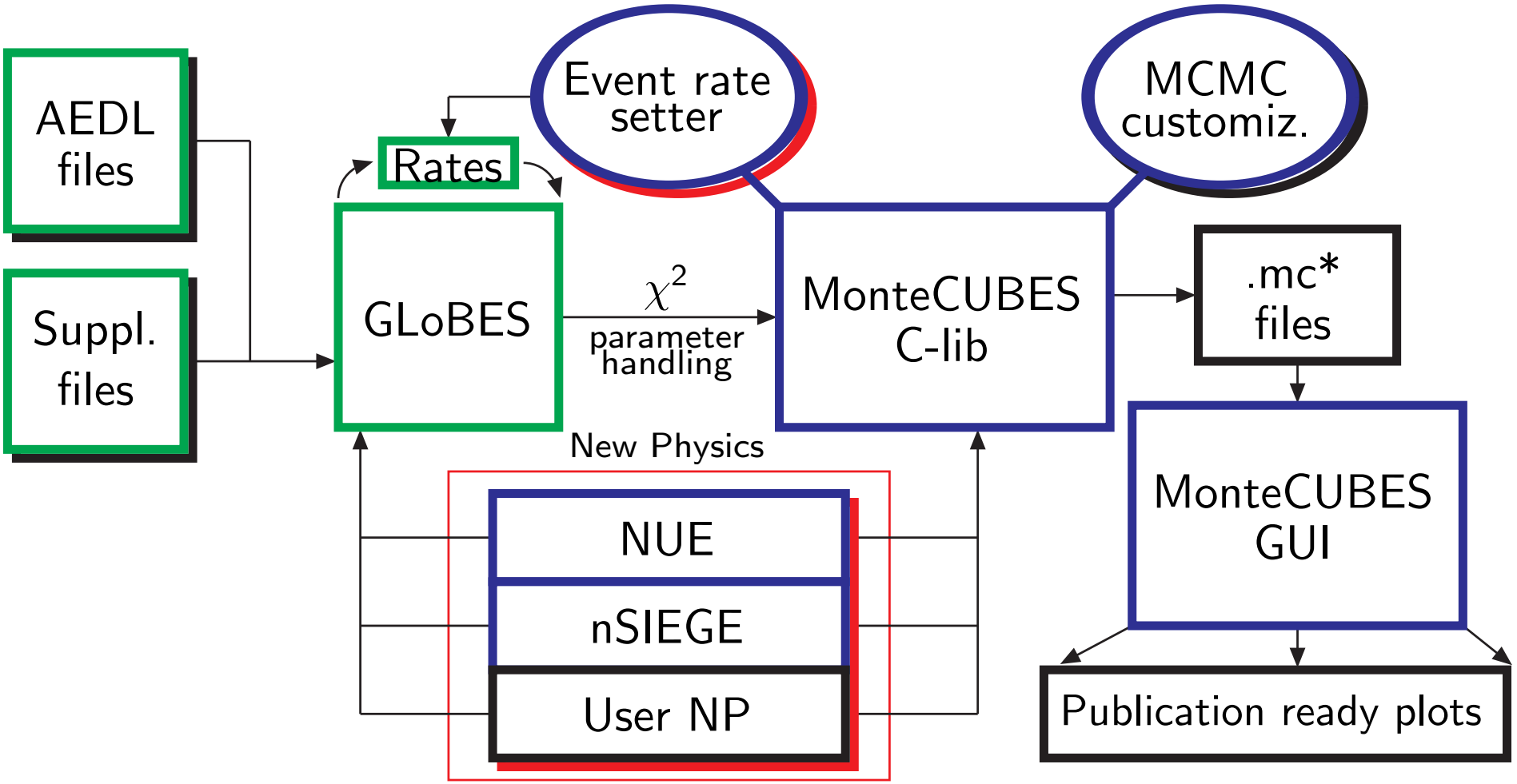
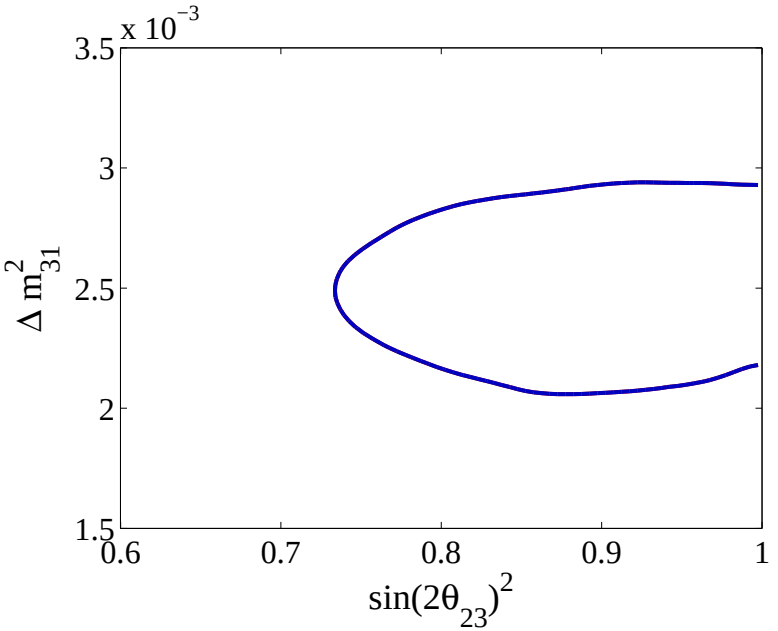


Event rate setting

- Possibility of easily setting event rates explicitly
- Can in principle be used for real data:
  - Great care is needed for experiment definitions (AEDL)
  - Compare no-oscillation hypothesis to experiment forecast
- K2K (without great care) $\longrightarrow$



Using the GUI without Matlab

- Essentially, Matlab can create stand-alone applications
- In order to run properly, these require the installation of the Matlab Compiler Runtime (MCR) for the appropriate Matlab version
- The MCR installer is $\mathcal{O}(200)$ MB

Summary

- MonteCUBES is a GLoBES plug-in
- Allows MCMC simulations for neutrino oscillation experiments
- Easy to use
- Compatible with standard experiment definition files
- Powerful for treating large parameter spaces