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# GLoBES

## General Long Baseline Experiment Simulator

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GLoBES is a modular open-source software library for simulating of short- and long-baseline neutrino oscillation experiments, and for studying the oscillation phenomenology.

**What GLoBES can do:**

- Compute 3-flavour oscillation probabilities in matter
- Simulate event spectra for reactor experiments, superbeams, beta beams, neutrino factories, …
- Peform sophisticated $\chi^2$ analyses
- Adapt to the user's needs

**What GLoBES cannot (yet) do:**

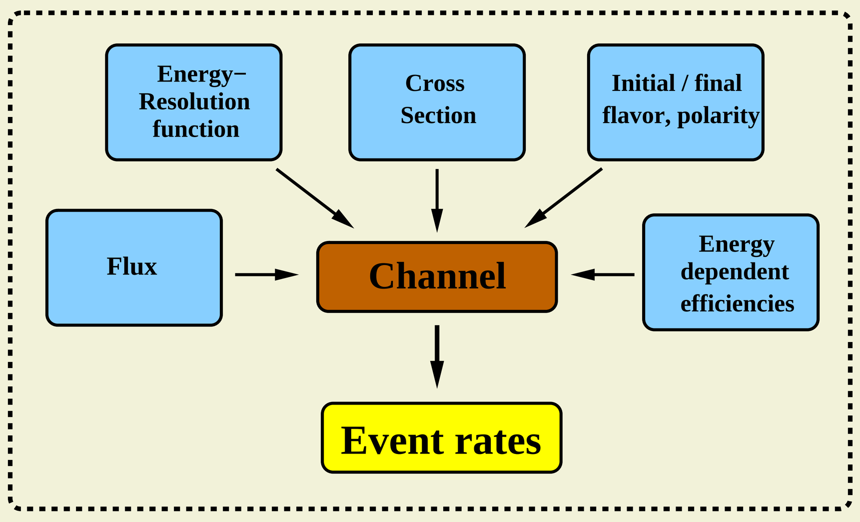
- Replace a detector Monte Carlo simulation
- Simulate solar and atmospheric neutrinos

## Experiment definition in GLoBES

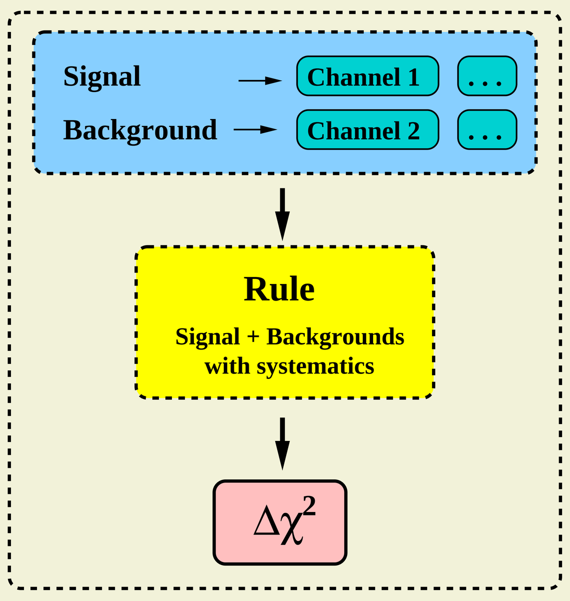
In GLoBES, experiments are described using AEDL, the Abstract Experiment Definition Language. AEDL files specify, for example

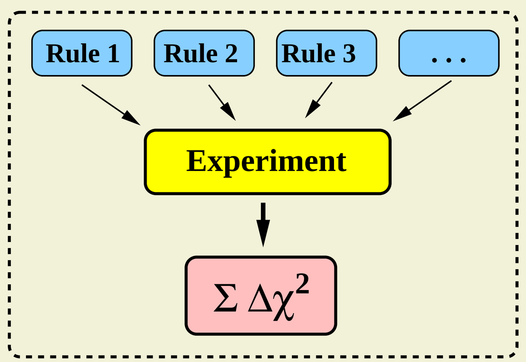
- Source types and spectra
- Matter density profiles
- Cross sections
- Detector properties: Efficiencies, resolutions, backgrounds, …
- Systematical uncertainties

A channel corresponds to oscillations from one flavour into another:




A rule consists of the combination of all signal and background channels in an experimental data sample (e.g. $\nu_e$ appearance from $\nu_\mu \to \nu_e$ oscillations in a superbeam, with contamination from $\nu_e \to \nu_e$).




Experiments can contain several rules, and several experiments can be handled simultaneously.

## Oscillations

The oscillation engine is the heart of the software. Its main features are

- Full three-flavour treatment
- Arbitrary (non-adiabatic) matter profiles
  The PREM (Preliminary Reference Earth Model) matter profile is hard-coded in GLoBES. The user can choose approximations to this profile (e.g. constant density, mantle-core-mantle profile, etc.) or define completely new profiles.
- High numerical efficiency
  GLoBES uses specifically designed numerical algorithms to ensure an excellent performance, which is, for the specific problem of neutrino oscillations, far superior to that of "black box" libraries.
- Extensibility
  The user has the possibility to modify or completely replace the GLoBES oscillation engine, e.g. to include sterile neutrinos, non-standard interactions, and other kinds of "new physics".

## $\chi^2$ analysis

GLoBES uses the $\chi^2$ method to extract physical information from the simulated event spectra. Main features are

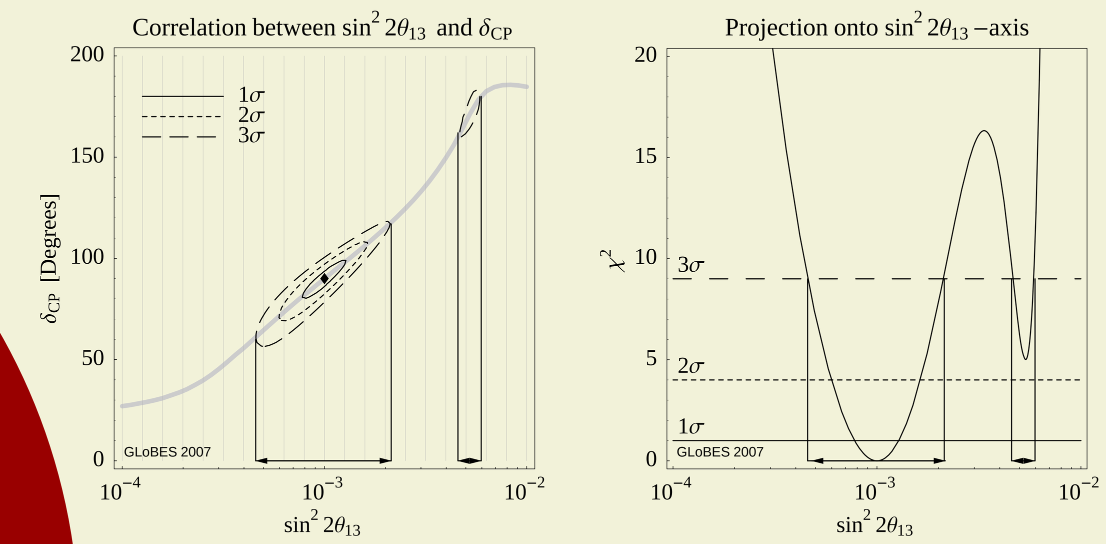
- Cuts and projections of the multi-dimensional $\chi^2$ manifold ("marginalization")
- Inclusion of systematical uncertainties (fully customizable)
- Inclusion of correlations and degeneracies
- Inclusion of external priors (fully customizable)
- Supports setups with Multiple sources and multiple detectors
- Excellent numerical efficiency

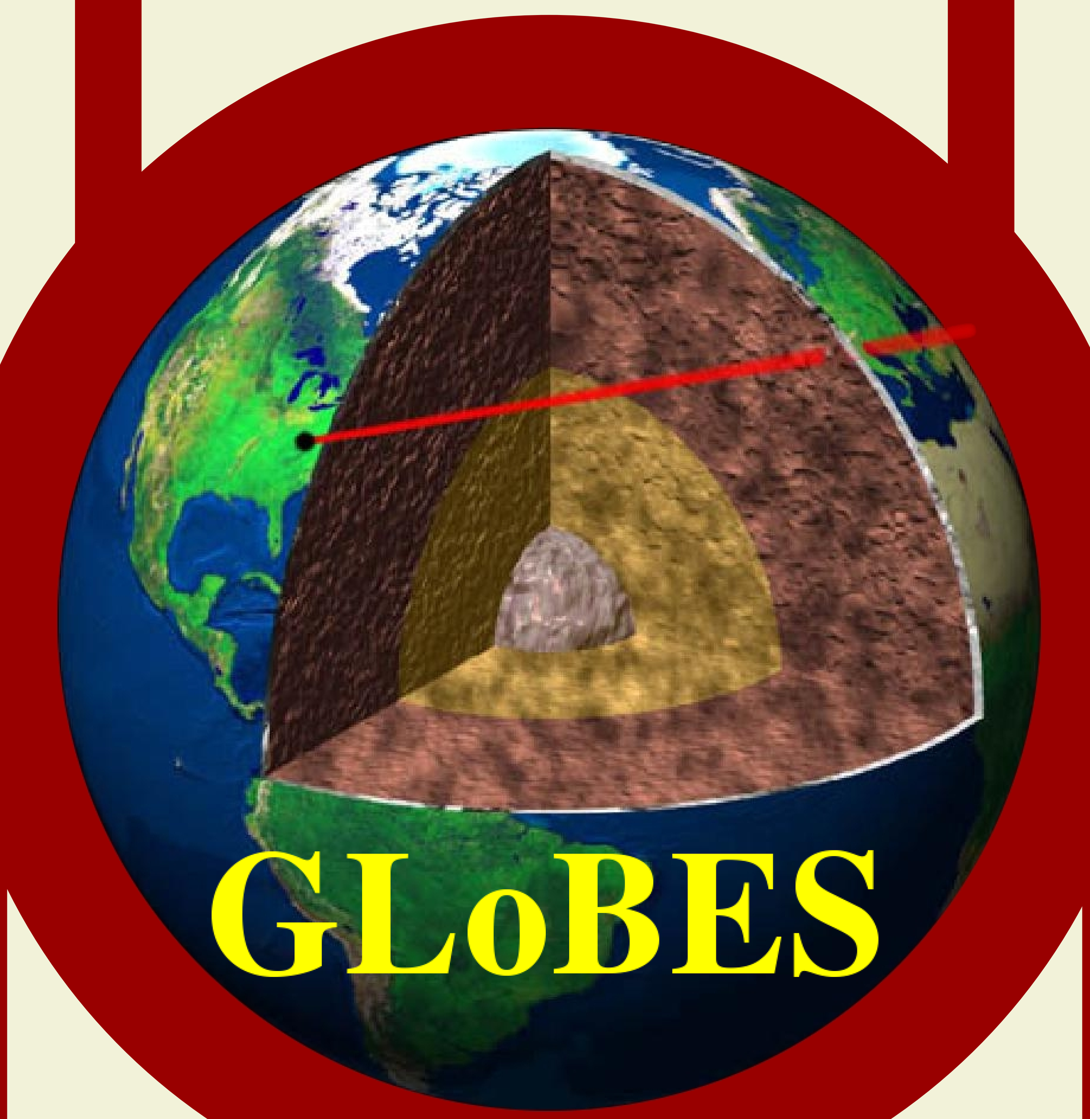
The builtin $\chi^2$ functions of GLoBES have the Poissonian form

$$\chi^2(\vec{\lambda},\vec{a}) = 2\sum_{\text{exp's}}\sum_{\text{rules}}\sum_{\textit{bins}}\left[N^{\text{th}}(\vec{\lambda},\vec{a}) - N^{\text{obs}} + N^{\text{obs}}\log\frac{N^{\text{obs}}}{N^{\text{th}}(\vec{\lambda},\vec{a})}\right] + \chi^2_{\text{prior}}(\vec{\lambda}) + \chi^2_{\text{pull}}(\vec{a}),$$

where $N^{\text{obs}}$ and $N^{\text{th}}$ are the "observed" and theoretically predicted event rates, respectively. The vector $\vec{\lambda}$ contains the oscillation parameters, and $\vec{a}$ are the systematical biases. $\chi^2_{\text{prior}}(\vec{\lambda})$ and $\chi^2_{\text{pull}}(\vec{a})$ implement external input on these parameters. Note that GLoBES allows also for arbitrary, user-defined $\chi^2$ functions.

**Example:** $\theta_{13}$–$\delta_{\text{CP}}$ correlation and intrinsic degeneracy in a $\nu$-fact.




## GLoBES example

**The AEDL file:** A simple neutrino factory

```
$version="3.0.0"
nuflux(#mu_plus)<
  @builtin = 1
  @parent_energy = 50
  @stored_muons = 10.66e+20
  @time = 4
>
$target_mass = 50
$bins = 20
$emin = 4
$emax = 50
$profiletype = 1
$baseline = 3000
energy(#ERES)< /*E res.*/
  @type = 1
  @sigma_e = {0.15, 0, 0}
>
```

```
cross(#CC)< /* Cross sections */
  @cross_file = "XCC.dat"
>
channel(#nu_mu_app)<
  @channel = #mu_plus:+:e:m:#CC:#ERES
>
channel(#nu_mu_bar_disapp)<
  @channel = #mu_plus:-:m:m:#CC:#ERES
>
rule(#Nu_Mu_Appearance)<
  @signal = 0.45@#nu_mu_app
  @signalerror = 0.025 :  0.0001
  @background = 5e-6@#nu_mu_bar_disapp
  @backgrounderror = 0.2 :  0.0001
  @sys_on_function = "chiSpectrumTilt"
  @sys_off_function = "chiNoSysSpectrum"
>
```

**Application code snippet:** Project $\chi^2$ onto $\theta_{13}$ axis

```
/* Define priors for θ12 and Δm²21 */
glbDefineParams(input_errors, theta12*0.1, 0, 0, 0, sdm*0.1, 0);
glbSetDensityParams(input_errors, 0.05, GLB_ALL);
glbSetCentralValues(true_values);
glbSetInputErrors(input_errors);

/* Loop over log(sin² 2θ13) */
double theta13, x;
for (x=-4; x < -2.0+0.001; x+=2.0/50)
{
  theta13 = asin(sqrt(pow(10,x)))/2;

  /* Choose starting value for δCP marginalization */
  glbSetOscParams(test_values, 200.0/2*(x+4)*M_PI/180, GLB_DELTA_CP);

  /* Compute χ² and marginalize over all parameters except θ13 */
  chi2 = glbChiTheta13(test_values, NULL, GLB_ALL);
}
```

**GLoBES website:**

www.mpi-hd.mpg.de/∼globes/

- Software download
- Many predefined AEDL files
- Extensive documentation
- Examples and tutorials

**GLoBES publications:**

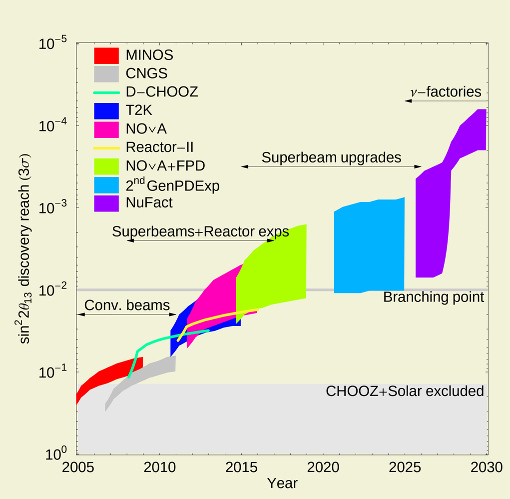
CPC **167**, 195 (2005), hep-ph/0407333
CPC **177**, 432 (2007), hep-ph/0701187

**Contact the authors:**

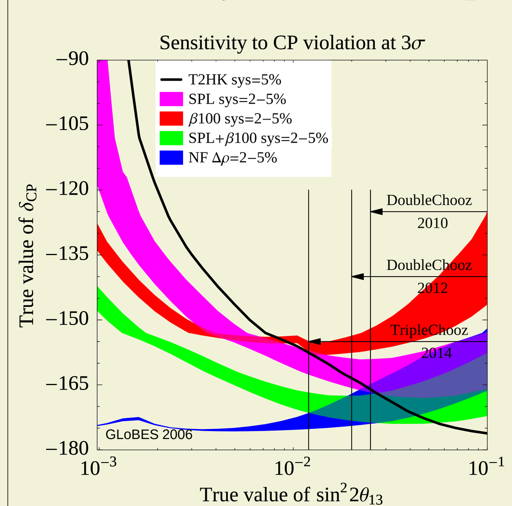
globes@mpi-hd.mpg.de

## Recent GLoBES results

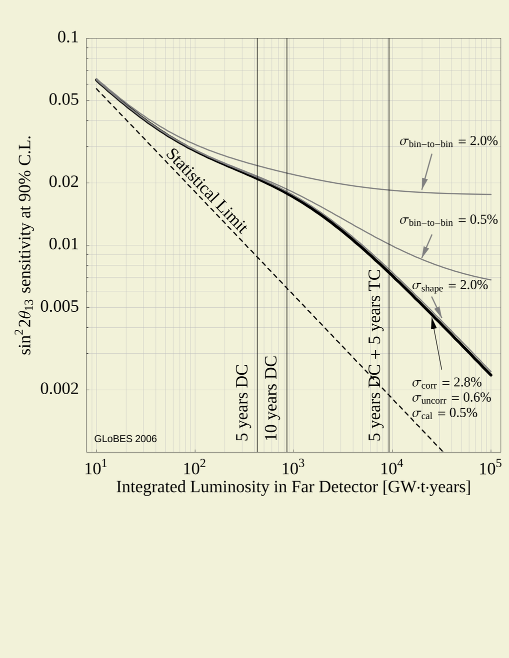
**Evolution of $\sin^2 2\theta_{13}$ disc. reach**




**$\delta_{CP}$ sensitivity of different exp's**




**Impact of systematical errors in a reactor experiment**




**Sensitivity of $\nu$-fact to standard and non-standard physics**