

# GLoBES

## General Long Baseline Experiment Simulator

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GLoBES is a modular open-source software library for simulating 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, super-beams, beta beams, neutrino factories, ...
- Perform sophisticated  $\chi^2$  analyses
- Adapt to the user's needs

### What GLoBES cannot (yet) do:

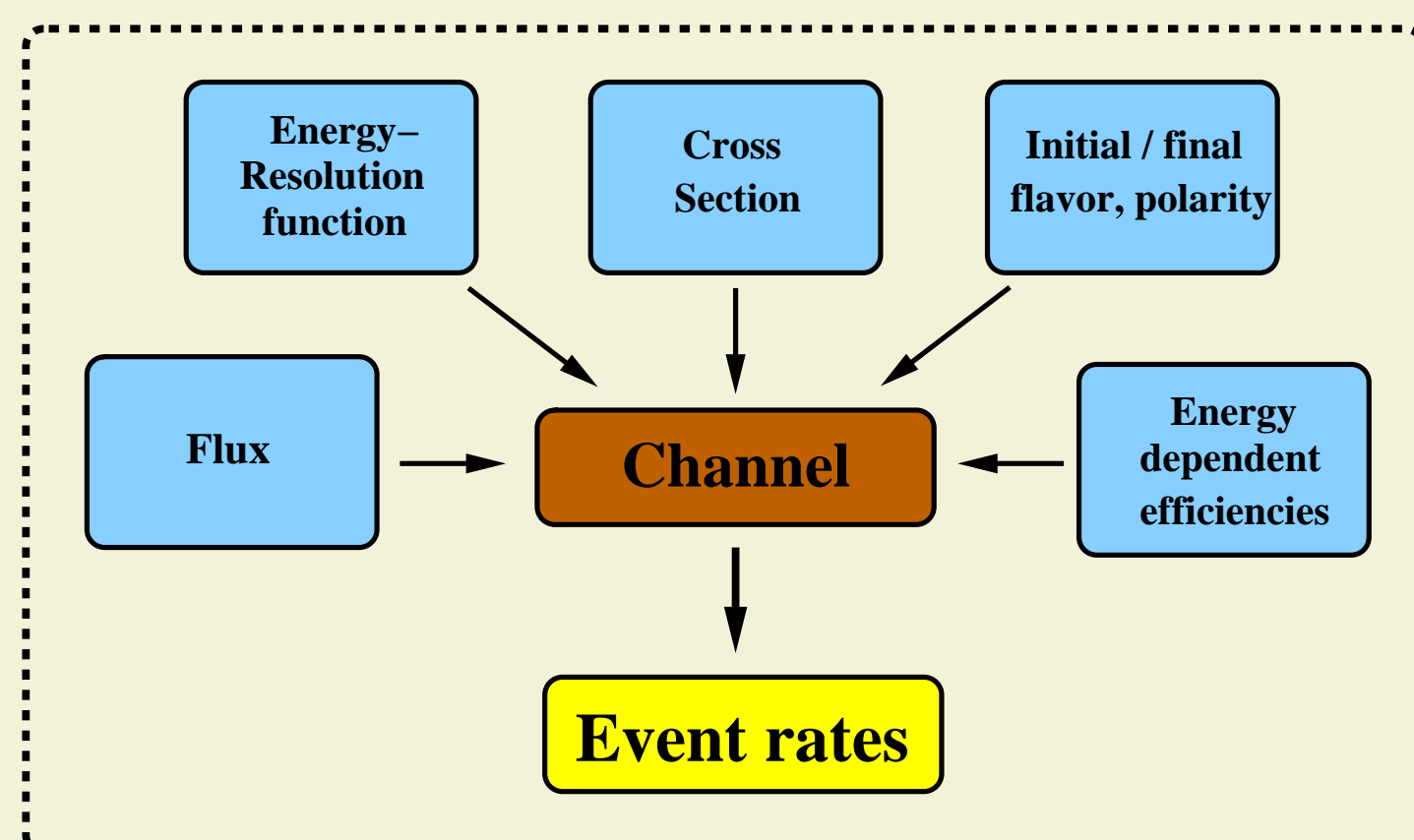
- Replace a detector Monte Carlo simulation
- Simulate solar and atmospheric neutrinos

## Experiment definition in GLoBES

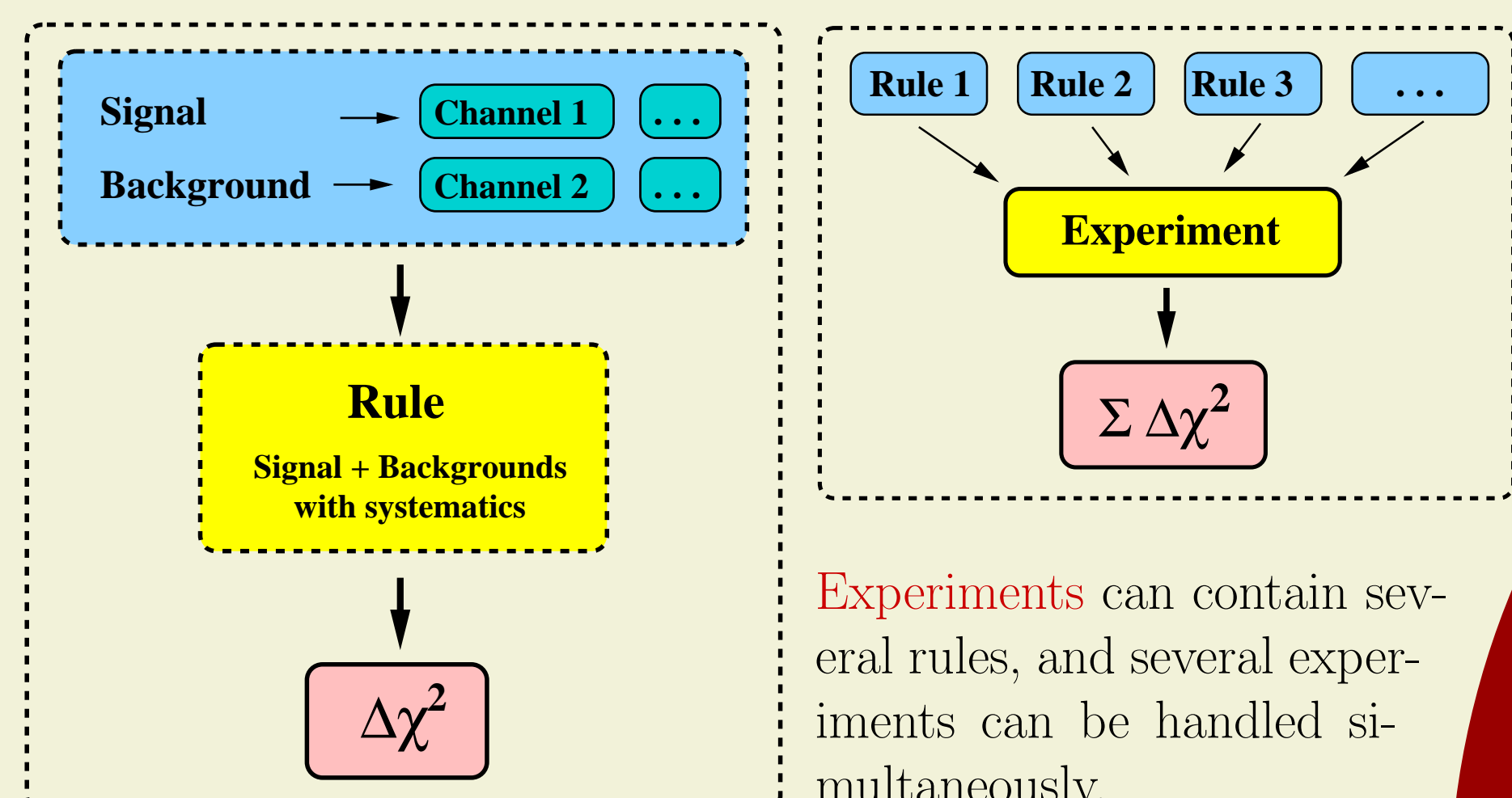
In GLoBES, experiments are described using **AEDL**, the **A**bstract **E**xperiment **D**efinition **L**anguage. AEDL files specify, for example

- 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  $\nu_\mu \rightarrow \nu_e$  oscillations in a superbeam, with contamination from  $\nu_e \rightarrow \nu_e$ ).



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

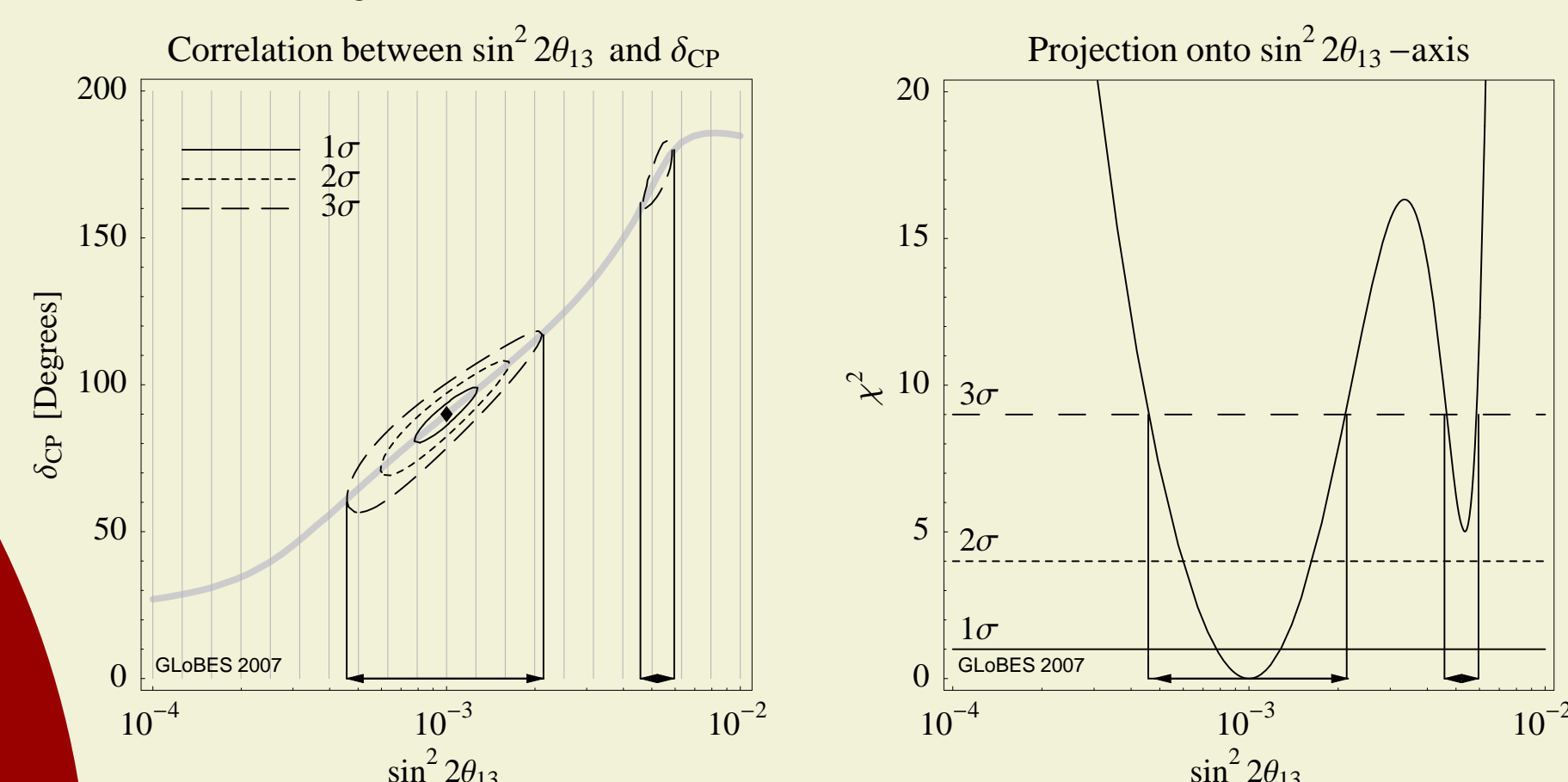
- **Cuts and projections** of the multi-dimensional  $\chi^2$  manifold (“marginalization”)
- Inclusion of **systematical uncertainties** (fully customizable)
- Inclusion of **correlations and degeneracies**
- Inclusion of **external priors** (fully customizable)
- Supports setups with **Multiple sources**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

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

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

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
$semin = 4
$semax = 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 theta_12 and Delta m^2_21 */
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(sin^2 2theta_13) */
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 delta_CP marginalization */
    glbSetOscParams(test.values, 200.0/2*(x+4)*M.PI/180, GLB.DELTA.CP);

    /* Compute chi^2 and marginalize over all parameters except theta_13 */
    chi2 = glbChiTheta13(test.values, NULL, GLB.ALL);
}
```

# GLoBES

GLoBES website:

[www.mpi-hd.mpg.de/~globes/](http://www.mpi-hd.mpg.de/~globes/)

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

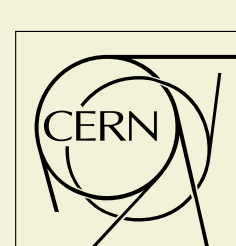
GLoBES publications:

CPC 167, 195 (2005), [hep-ph/0407333](http://arxiv.org/abs/hep-ph/0407333)

CPC 177, 432 (2007), [hep-ph/0701187](http://arxiv.org/abs/hep-ph/0701187)

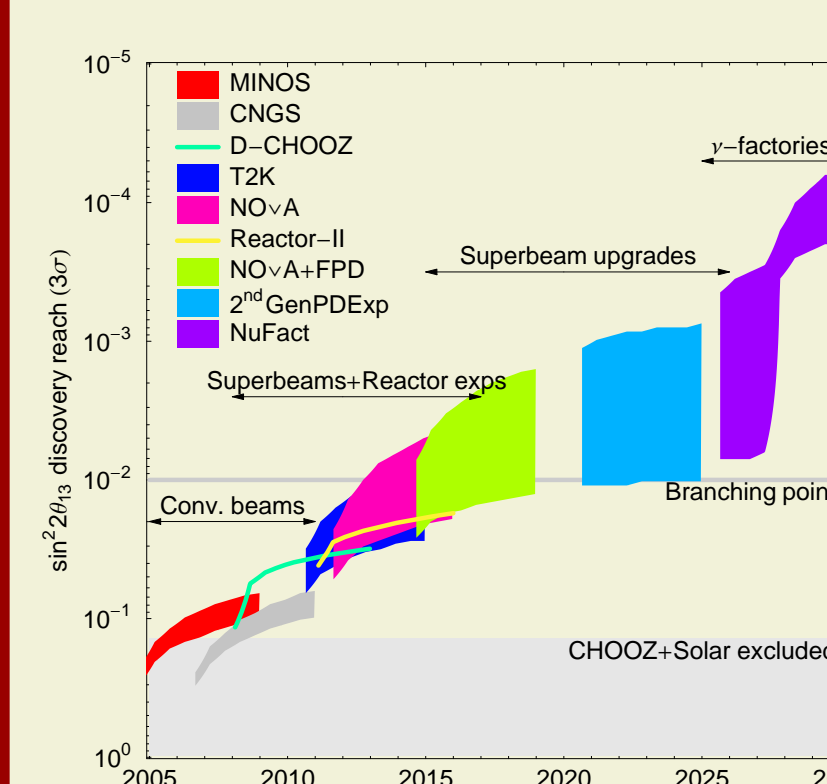
Contact the authors:

[globes@mpi-hd.mpg.de](mailto:globes@mpi-hd.mpg.de)

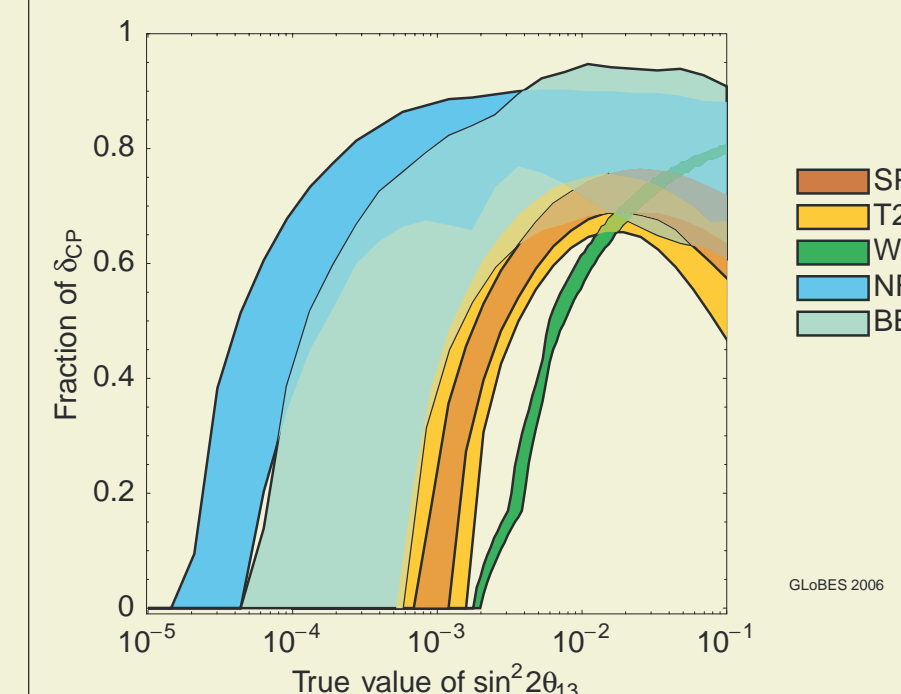


## Recent GLoBES results

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



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



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

