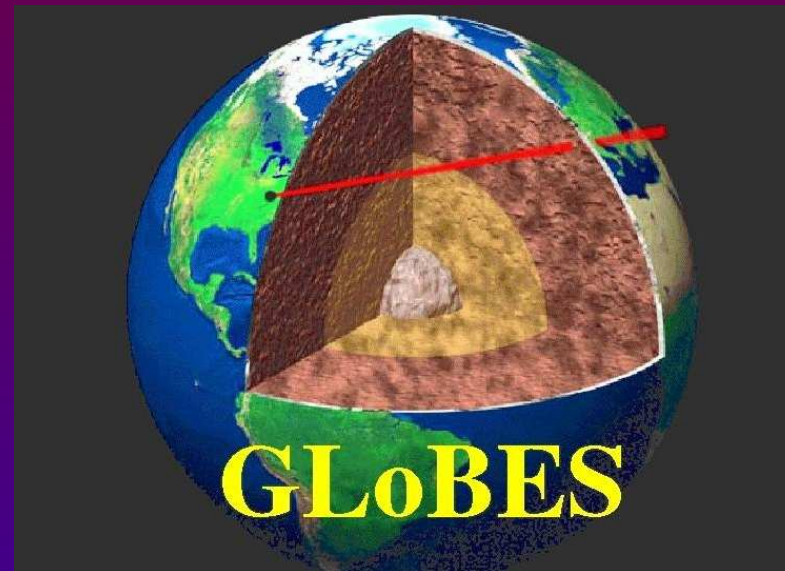


# The **G**eneral **L**ong **B**aseline **E**xperiment **S**imulator



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# Outline

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- Basic Structure

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- AEDL-File Example

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- $\chi^2$ -Projections
- Examples of Applications

# Part I

## GLOBES - General Features

# GLOBES - Purpose

The **G**eneral **L**ong **B**aseline **E**xperiment **S**imulator

**GLOBES** is a software package designed for

- Simulation
- Analysis
- Comparison

of neutrino oscillation long baseline experiments

# GLOBES - Availability

GLOBES can be downloaded as tar-ball together with a detailed manual from

<http://www.ph.tum.de/~globes/>

since August 2004.

The software is developed, documented, maintained and supported by the GLOBES-Team:

- Patrick Huber (UW)
- Joachim Kopp (TUM)
- Manfred Lindner (TUM)
- Mark Rolinec (TUM)
- Walter Winter (IAS)

# GLOBES - Features

- Accurate treatment of systematical errors
- Arbitrary matter density profile & uncertainties
- Arbitrary energy resolution function
- Single and multiple experiment simulation
- Output of oscillation probabilities
- Output of event rates
- Simple  $\chi^2$  calculation
- Inclusion of external input
- Projection of  $\chi^2$  (minimization)

# GLOBES - Experiments

GLOBES has been used for simulating:

- MINOS, ICARUS and OPERA
- Reactor experiments, Double-CHOOZ
- T2K
- NO $\nu$ A
- SPL CERN-Fréjus [J.E. Campagne, hep-ex/0510029](#)
- JHF-HK (T2K upgrade)
- Neutrino factories
- $\beta$ -beams
- BNL neutrino beam

# GLOBES - Basic Structure

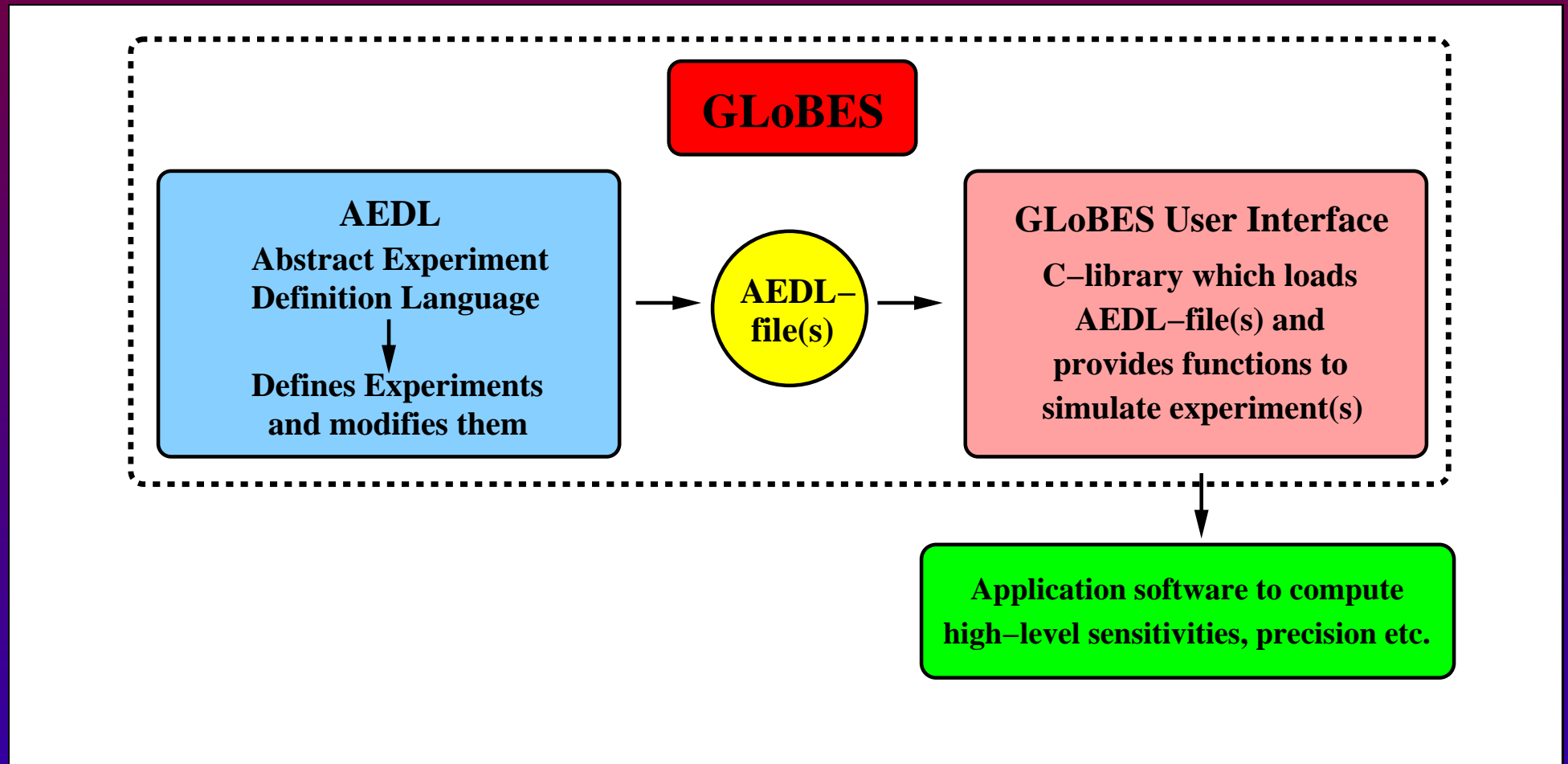


Figure taken from P. Huber, M. Lindner and W. Winter, *Comput. Phys. Commun.* **167** (2005) 195

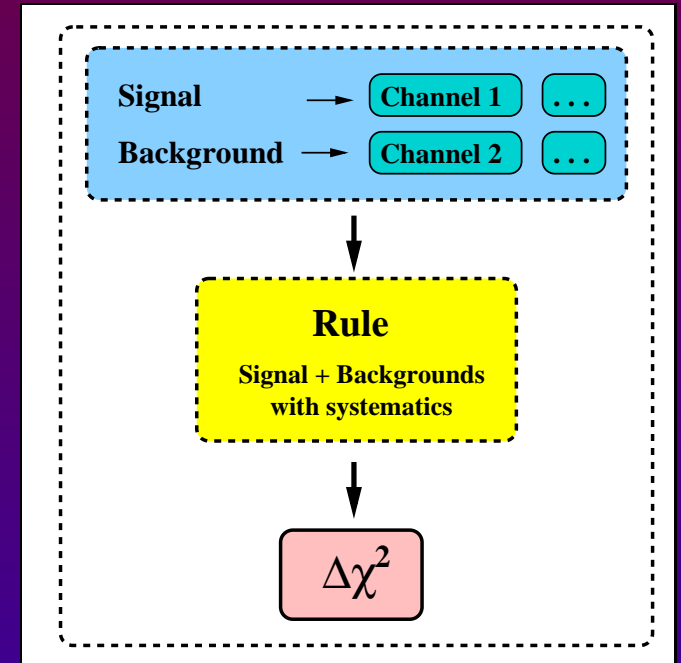
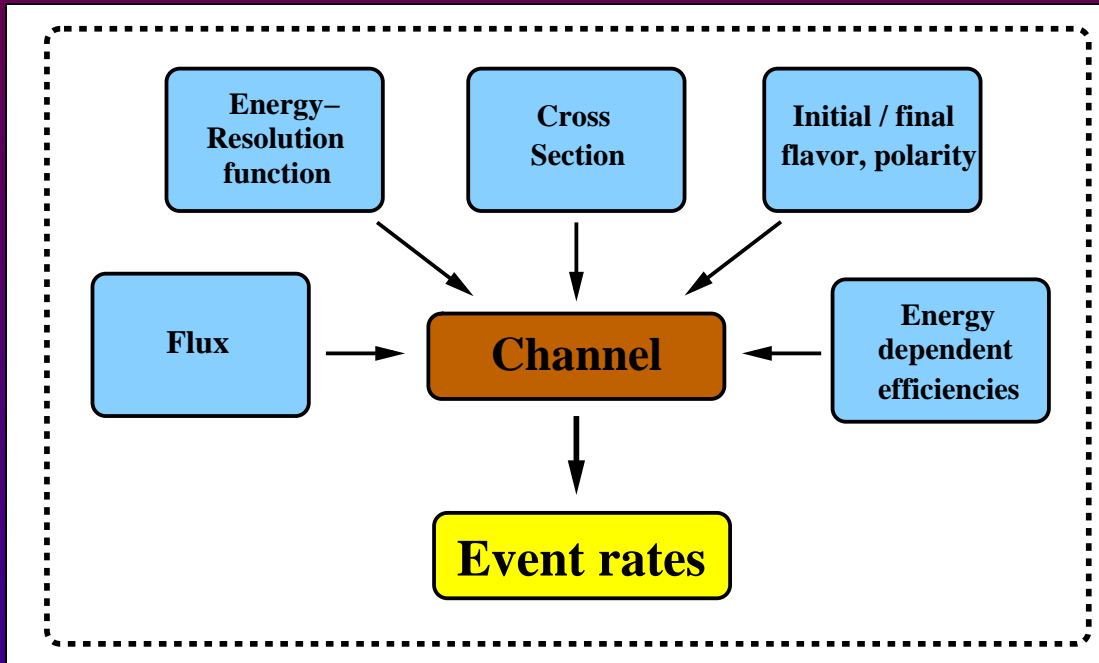


# Part II

## Experiment Description in AEDL

# AEDL - Features

The experiment is described within one file: `Name.glb`



Figures taken from P. Huber, M. Lindner and W. Winter, *Comput. Phys. Commun.* **167** (2005) 195

- Experiments can contain an arbitrary number of rules
- GLoBES can handle any number of experiments

# AEDL-File - Example

Flux and cross sections can be loaded from external files:

```
flux(#user_flux)<
@flux_file = "user_flux_file.dat"
@time = 5.0 /* years */
@power = 4.0 /* MW */
@norm = 1.0
>
```

```
cross(#CC)<
@cross_file = "XCC.dat"
>
cross(#NC)<
@cross_file = "XNC.dat"
>
```

For the case of a neutrino function GLoBES provides a builtin flux:

```
flux(#nf_flux_mu_plus)<
@builtin = 1
@parent_energy = 50.0 /* GeV */
@stored_muons = 5.33e+20
@time = 8.0 /* years */
>
```

# AEDL-File - Example continued

## Basic characteristics of Experiment:

```
$target_mass = 50.0 /* kt */
```

Mass of Detector (fiducial volume)

```
$profiletype = 1
```

Baseline and

```
$baseline = 3000.0 /* km */
```

Density Profile

```
$density = 2.7 /* g cm-3 */
```

(average density, PREM or manually defined)

```
$bins = 20
```

Energy window:

```
$emin = 4.0 /* GeV */
```

Reconstructed neutrino energy

```
$emax = 50.0 /* GeV */
```

Analysis level (after energy smearing)

```
$sampling_points = 20
```

Energy window:

```
$sampling_min = 4.0
```

True neutrino energy

```
$sampling_max = 50.0
```

Integral Evaluation (before energy smearing)

# AEDL-File - Example continued

## Description of energy resolution:

```
energy(#ERES)<  
@type = 1  
@sigma_e = (alpha,beta,gamma)  
>
```

```
energy(#manual_smearing_matrix)<  
@energy =  
{0,2,0.863,0.182,0.00267}:  
{0,3,0.151,0.697,0.151,0.00101}:  
...  
{16,19,0.00936,0.278,0.483,0.136};  
>
```

Gaussian energy resolution function  
with width  $\sigma$ :

$$\sigma(E) = \alpha \times E + \beta \times \sqrt{E} + \gamma$$

Manual energy smearing:

energy smearing matrix  $M_{ij}$

- number of rows:  
\$bins
- number of columns:  
\$sampling\_points

# AEDL-File - Example

## Defining different channels:

```
channel(#nu_mu_dissappearance)<  
@channel = #user_flux : +: m: m: #CC: #ERES  
@pre_smearing_efficiencies = {0.333,0.666,0.999,1.,1., ... ,1.,1.}  
>
```

```
channel(#nu_mu_NC_bckg)<  
@channel = #user_flux : +: NOSC_m: NOSC_m: #NC:  
#manual_smearing_matrix  
>
```

## Additional features:

- @post\_smearing\_efficiencies
- @pre\_smearing\_background
- @post\_smearing\_background

# AEDL-File - Example continued

## Defining the Rules:

```
>rule(#Nu_Mu_DIS)<
@signal = 0.86@#nu_mu_dissappearance
@signalerror = 0.04 : 0.0001

@background = 0.11@#nu_mu_NC_bckg : 0.11@#nu_e_NC_bckg : 0.05@#BCKG_3
@backgrounderror = 0.05 : 0.0001

@errordim_sys_on = 2
@errordim_sys_off = 0

@energy_window = 4.0 : 50.0
>
```

# Part III

## GLOBES - C-API and Applications



# GLOBES - Basics

Alays to be done:

```
glbInit(argv[0]);

glbClearExperimentList();

glbDefineAEDLVariable("Variable",
    double value);

glbInitExperiment("Name.glb",
    &glb_experiment_list[0],
    &glb_num_of_exps);
```

Initialize the GLOBES Library

Delete earlier loaded AEDL-Files

Define Variables within the AEDL-File  
(has to be set in `Name.glb`)

Load the experiment described in  
`Name.glb` to the experiment list  
(arbitrary number possible)

# GLoBES - Reference Rates

Set the simulated "Data" - Event Rates:

```
glb_params true_values = glbAllocParams();

glbDefineParams(true_values, th12, th13,
               th23, delta, sdm, ldm);

glbSetOscillationParameters(true_values);

glbSetRates();

...

glbFreeParams(true_values);
```

Initialize a parameter vector

Assign parameter values for the  
parameter vector `true_values`

$(\theta_{12}, \theta_{13}, \theta_{23}, \delta, \Delta m_{21}^2, \Delta m_{31}^2)$

Set `true_values` to be the "True Values"

Let **GLoBES** calculate the  
reference event rate vector

Free the parameter vector  
`true_values` at the end

# GLoBES - $\chi^2$ Calculation

## Simple $\chi^2$ including systematics

```
glb_params fit_values = glbAllocParams();

glbDefineParams(fit_values, th12', th13',
               th23', delta', sdm', ldm');

glbSwitchSystematics(GLB_ALL,
                    GLB_ALL, GLB_ON);

double chi =
    glbChiSys(fit_values, GLB_ALL, GLB_ALL);

glbFreeParams(fit_values);
```

Initialize another parameter vector

Assign parameter values for the parameter vector `fit_values`  
( $\theta_{12}'$ ,  $\theta_{13}'$ ,  $\theta_{23}'$ ,  $\delta'$ ,  $\Delta m_{21}^2$ ,  $\Delta m_{31}^2$ )

Switch on systematical errors

Calculate the  $\chi^2$  at the parameter vector `fit_values`

Free the parameter vector `fit_values` at the end

# GLoBES - Projection of $\chi^2$

## Including parameter correlations by projection of $\chi^2$

```
glbDefineParams(in_error, d_th12, d_th13,  
               d_th23, d_delta, d_sdm, d_ldm);  
  
glbSetDensityParams(in_error,  
                   d_rho, GLB_ALL);  
  
glbSetStartingValues(start);  
  
glbSetInputErrors(in_error);  
  
double chiProj = glbChiTheta(fit_values,  
                             minimum, GLB_ALL);
```

Define the errors on oscillation parameters (external input)

Give the error on the matter density  $\rho$

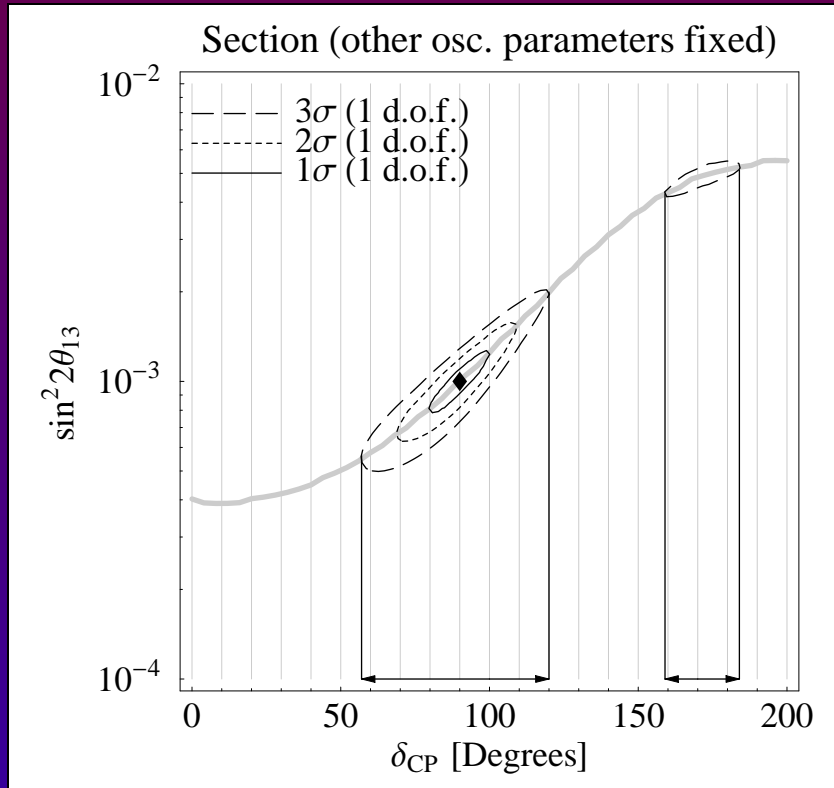
Set center values for defined errors

Set all errors as defined before

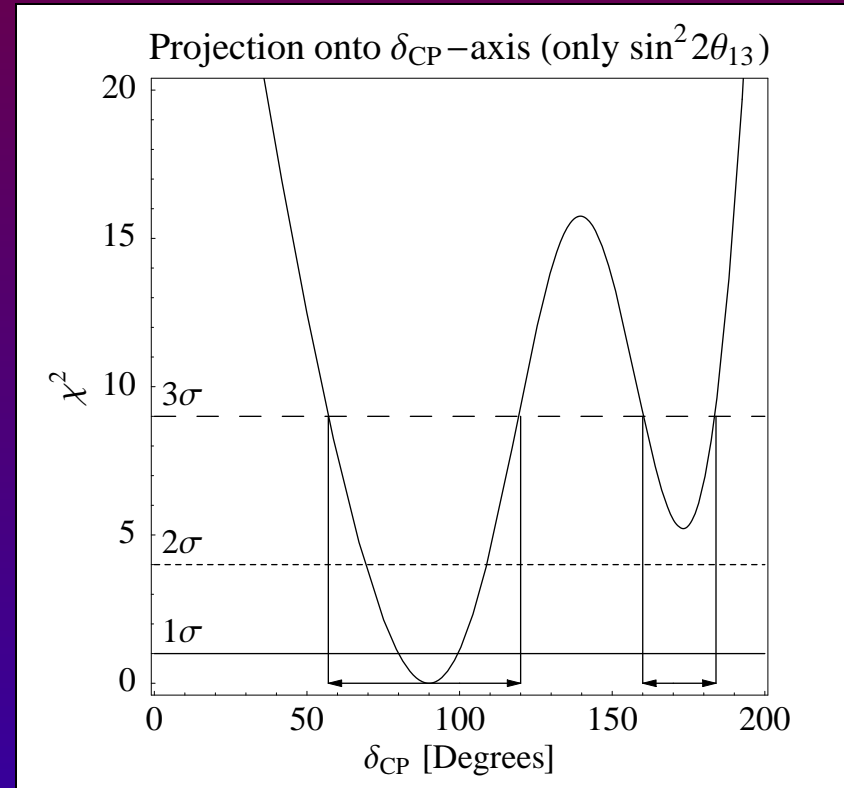
Calculate a projection with respect to  $\sin^2 2\theta_{13}$

# GLOBES - Applications I

Projection of two-parameter correlations (Here  $\delta$  -  $\sin^2 2\theta_{13}$ )



glbChiSys

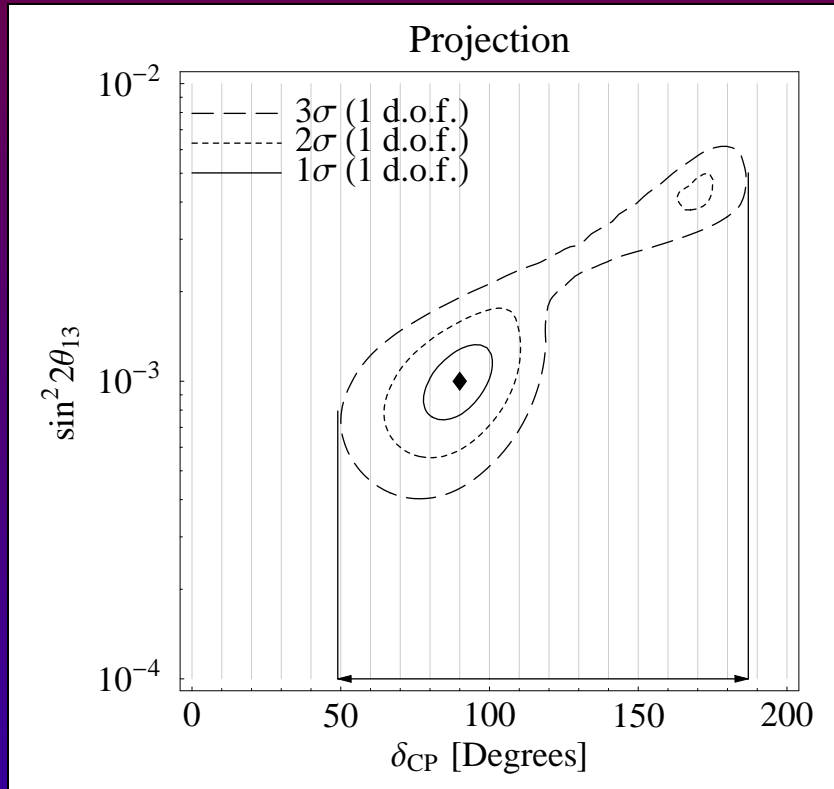


glbChiDelta

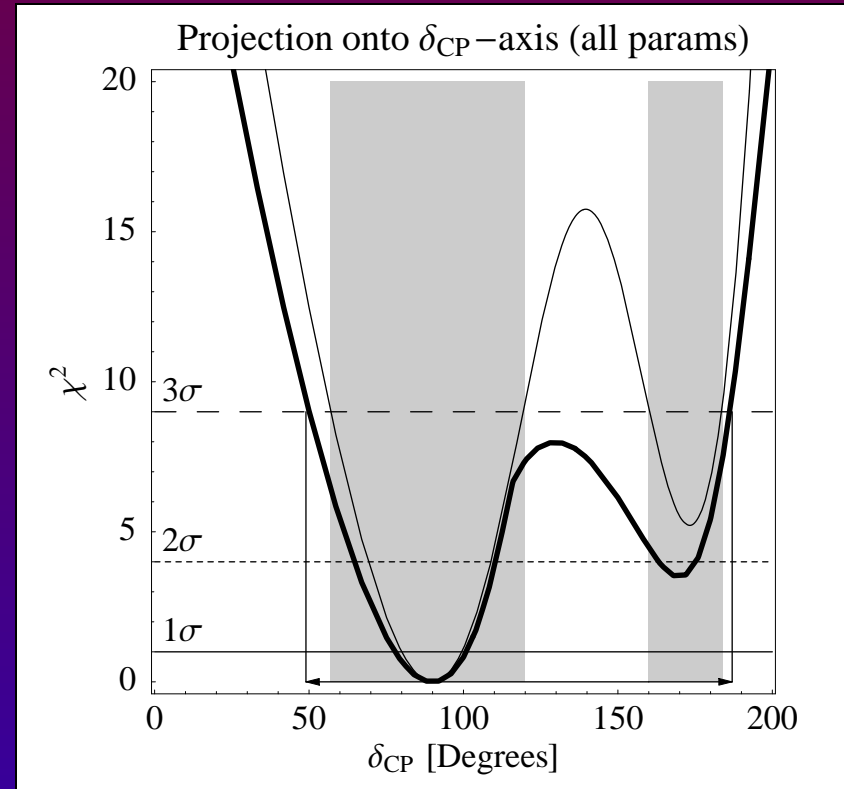
Figures taken from P. Huber, M. Lindner and W. Winter, Comput. Phys. Commun. **167** (2005) 195

# GLOBES - Applications II

## Projection of six-parameter correlations



glbChiThetaDelta

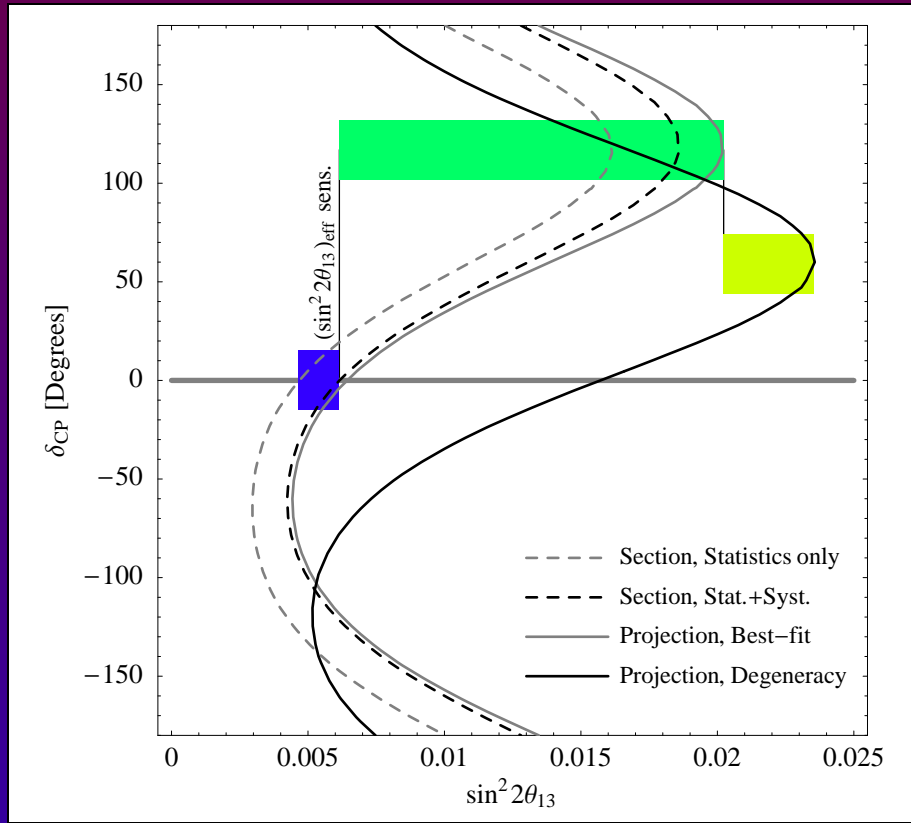


glbChiDelta

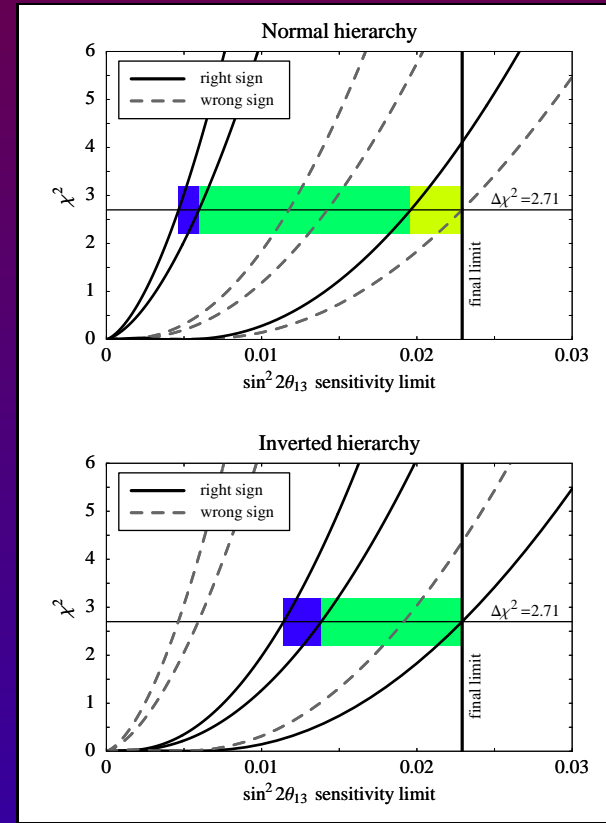
Figures taken from P. Huber, M. Lindner and W. Winter, Comput. Phys. Commun. **167** (2005) 195

# GLOBES - Applications III

Sensitivity to  $\sin^2 2\theta_{13}$  (true value  $\sin^2 2\theta_{13} = 0$ )



`glbChiSys`

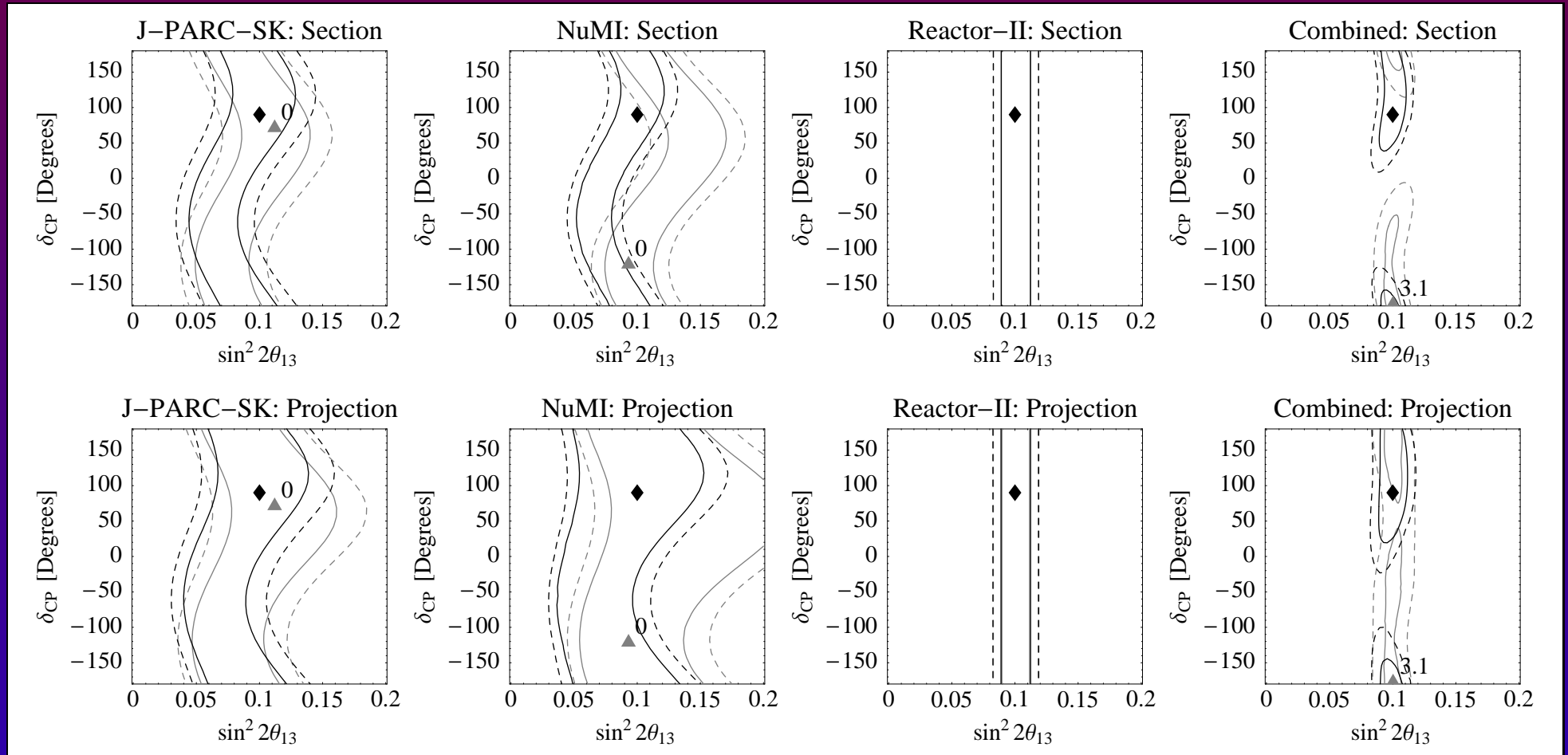


`glbChiTheta`

Figures taken from P. Huber, M. Lindner, MR, T. Schwetz and W. Winter, Phys. Rev. D 70 (2004) 073014

# GLOBES - Applications IV

Assume large true value  $\sin^2 2\theta_{13} = 0.1$



Figures taken from P.Huber, M.Lindner, MR, T.Schwetz, W.Winter, Phys. Rev. D 70 (2004) 073014



# Conclusions

GLoBES is a

- well tested
- powerful
- flexible

software package for the

- Simulation
- Analysis
- Comparison

of neutrino oscillation  
experiments

So remember: [www.ph.tum.de/~globes/](http://www.ph.tum.de/~globes/)

