The General Long-Baseline Experiment Simulator and applications

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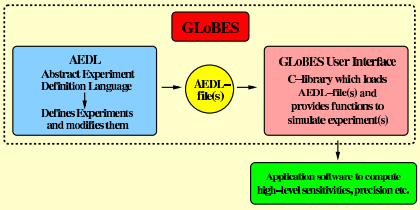
What is GLoBES ?

GLoBES is a multi-module software system to simulate Long-Baseline neutrino oscillation experiments. Experiments can be defined individually using the Abstract Experiment Definition Language (AEDL). One can use pre-defined experiments which also can be modified in AEDL. GLoBES contains a variety of functions that allow to simulate the experiments and investigate their capabilities in the GLoBES User Interface including:

- Systematics
  of the simulated experiments
- Correlations
  of different parameters in parameter-space
- Degeneracies
  i.e. disconnected solutions in parameter-space

Structure of GLoBES



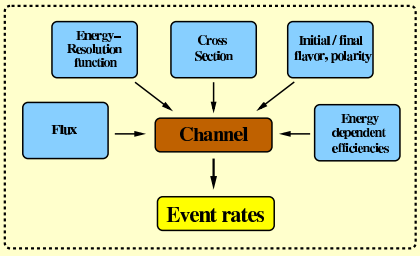
AEDL

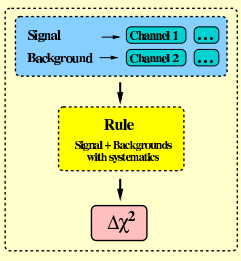
Abstract Experiment Definition Language

AEDL allows a modular definition of very different experiments, like conventional neutrino beam experiments (MINOS, ICARUS, OPERA) [?,?], Superbeams (JPARC-SK, NOνA [?]) [?, ?, ?, ?, ?], reactor experiments (e.g. Double-CHOOZ [?] etc.) [?,?] or neutrino factories (at different baselines) [?,?] etc.. All these experiments can be described in AEDL by a limited number of parameters including:

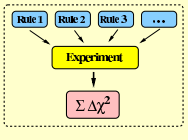
- Neutrino source
  Superbeam, neutrino factory, reactor experiment etc.
- Matter density profile and uncertainty
- Cross sections
- Detector simulation
  efficiencies, energy smearing, ...
- Systematical errors

The experiment definition is written to a text file which is then used by the application software to initialize the experiment. Additionally secondary files might be read for source fluxes, cross sections, energy resolution function etc.. These are then used to define a channel, which contains the oscillation of one neutrino flavor into another as well as detection effects.





A rule consists of the combination of signal and background, each composed of one or more channels and the appendant systematics.



Experiment definitions can contain several rules. Also, GLoBES can handle any number of experiments simultaneously, i.e. their χ^2's are added after minimization over systematics parameters but before minimization over the oscillation parameters.

AEDL Example: A simple neutrino factory

```
/*GLOBES
/* beam */
flux(@mu_plus)<
  @filename = 1
  @parent_energy = 50.0
  @stored_muons = 5.33e+20
  @time = 8.0 >
@target_mass = 50
@sizes = 20
@min = 4.0
@max = 50.0
/* cross section */
cross(@CC)<
  @cross_file = XX.dat >
/* baseline */
@baseline = 3000.0
@density_tab = {3.5}
@length_tab = {3000.0}
@density_error = 0.05
```

```
/* energy resolution */
energy(@MUONS)<
  @type = 1
  @sigma_e = {0.15,0.0,0.0}
/* channels */
channel(@disappearance)<
  @channel = @mu_plus: +: electron: muon: @CC: @MUONS >
channel(@disappearance)<
  @channel = @mu_plus: -: muon: muon: @CC: @MUONS >
/* rules */
rule(@rule1)<
  @signal = 0.45 @ appearance
  @signalerror = 0.001 : 0.0001
  @background = 1.0e-3 @ disappearance
  @backgroundcenter = 1 : 0.0
  @backgrounderror = 0.05 : 0.0001
  @errordim = 0
  @energy_window = 4.0 : 50.0 >
```

GLoBES User Interface

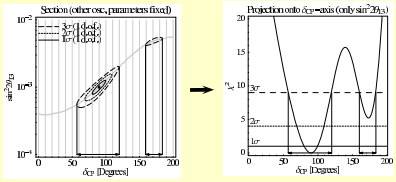
C-library which provides GLoBES functions to

- Calculate χ^2 including systematics
- Project χ^2 onto axes/hyperplanes
- Return low-level information
  (event rates, probabilities)
- Test various setups and modifications
  (single experiment or combination of experiments)

Example: From χ^2 to the precision of δ_{CP}

PROJECTION OF TWO-PARAMETER CORRELATION

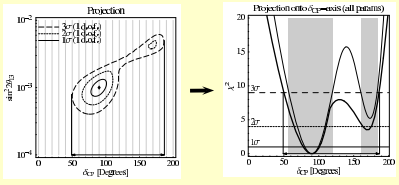
χ^2 with systematics — Projection



Chi — ChiDelta / ChiNP

PROJECTION OF SIX-PARAMETER CORRELATION

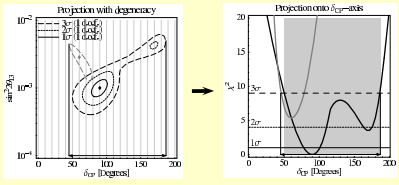
χ^2 with systematics — Projection



ChiThetaDelta — ChiDelta

INCLUSION OF SIGN-DEGENERACY

χ^2 with systematics — Projection



ChiAll — ChiDelta

INFORMATION

GLoBES and related material can be found at

`http://www.ph.tum.de/~globes`

Release date: August, 1st 2004

References

[1] P. Huber, M. Lindner, M. Rolinec, T. Schwetz and W. Winter, *Prospects of accelerator and reactor neutrino oscillation experiments for the coming ten years*, hep-ph/0403068.

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[3] D. Ayres, ..., P. Huber, M. Lindner, W. Winter et al. *Letter of intent to build an off-axis detector to study $\nu_\mu \to \nu_e$ oscillations with the NuMI neutrino beam*, hep-ex/0210005.

[4] P. Huber, M. Lindner and W. Winter, *Superbeams versus neutrino factories*, Nucl. Phys. B645, 3 (2002), hep-ph/0204352.

[5] P. Huber, M. Lindner and W. Winter, *Synergies between the first-generation JHF-SK and NuMI superbeam experiments*, Nucl. Phys. B654, 3-30 (2003), hep-ph/0211300.

[6] P. Huber, M. Lindner, T. Schwetz and W. Winter, *Reactor neutrino experiments compared to superbeams*, Nucl. Phys. B665, 487-519 (2003), hep-ph/0303232.

[7] F. Ardellier, ..., P. Huber, M. Lindner, T. Schwetz, W. Winter et al. *Letter of intent for double-CHOOZ: A search for the mixing angle θ_{13}*, hep-ex/0405032.

[8] P. Huber and W. Winter, *Neutrino factories and the "magic" baseline*, Phys. Rev. D68, 037301 (2003), hep-ph/0301257.

[9] P. Huber, M. Lindner and W. Winter, *GLoBES: User's and references manual*, http://www.ph.tum.de/~globes

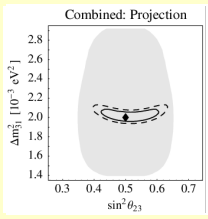
Applications

In Ref. [?] the prospects of accelerator and reactor neutrino oscillation experiments for the coming ten years have been investigated using GLoBES. The following experiments have been simulated:

- Conventional beam experiments:
  MINOS, ICARUS, OPERA (5 years running each)
- Reactor neutrino experiments:
  D-Chooz ($L_{FD} = 1.05$ km, $6 \cdot 10^4$ events in FD)
  Reactor-II ($L_{FD} = 1.7$ km, $6.4 \cdot 10^5$ events in FD)
- Super beam experiments: (5 years neutrino running)
  JPARC-SK (T2K), NuMI off-axis (NOνA, $L = 812$ km)

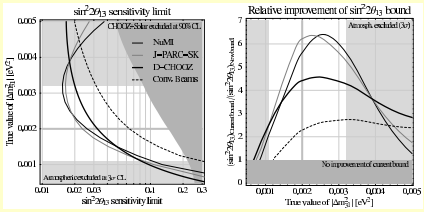
DETERMINATION OF THE 'ATMOSPHERIC' PARAMETERS

The plot shows the allowed region from combining the LBL experiments expected within the next ten years, in comparison to the current allowed region. The true values $\theta_{23} = \pi/4$ and $\Delta m^2_{31} = 2 \cdot 10^{-3}$ eV^2 have been assumed. The accuracy on $\sin^2\theta_{23}$ can be improved by a factor two, and on Δm^2_{31} by one order of magnitude.

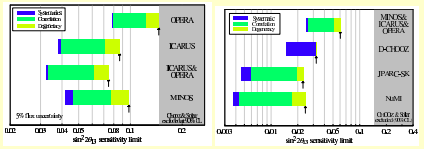


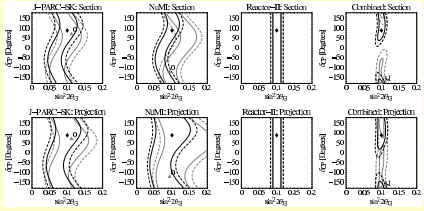
SENSITIVITY TO $\sin^2 2\theta_{13}$

The determination of θ_{13} is a very important issue for the upcoming experiments. The plot below compares the upper bound on $\sin^2 2\theta_{13}$ from the different experiments if no signal is observed as a function of the true value of Δm^2_{31}.



Below we show the impact of systematics, correlations, and degeneracies assuming a true value of $\Delta m^2_{31} = 2 \cdot 10^{-3}$ eV^2. One observes that beam experiments are strongly affected by parameter correlations (mainly by the correlation between θ_{13} and δ_{CP}), whereas the reactor experiments are dominated by systematics (and statistics).



POTENTIAL FOR LARGE θ_{13}

If θ_{13} is close to its current bound the next generation of experiments may provide some information on δ_{CP} and on the mass hierarchy. The plot below shows the allowed regions in the plane of $\sin^2 2\theta_{13}$ and δ_{CP} assuming the true values $\sin^2 2\theta_{13} = 0.1$ and $\delta_{CP} = \pi/2$. The grey curves correspond to the solution with the wrong sign of Δm^2_{31}. The upper panels are sections in the 6-dimensional parameters space (undisplayed parameters fixed at their true values), whereas in the lower panels the χ^2 is minimized in each point with respect to all parameters not shown.