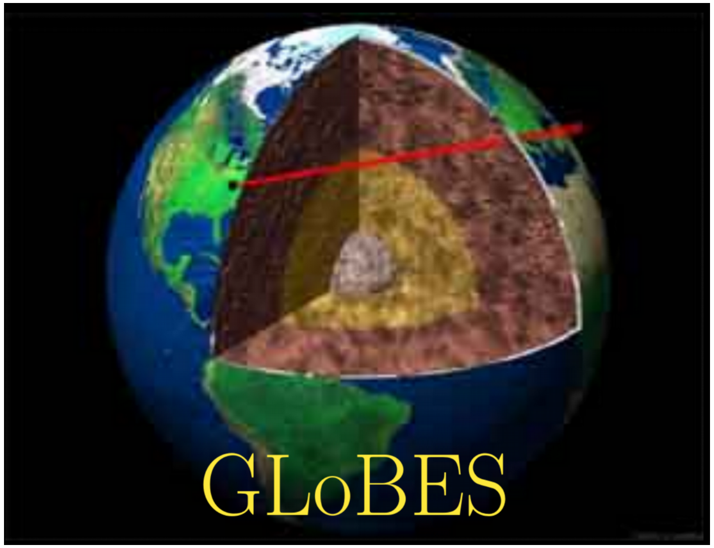
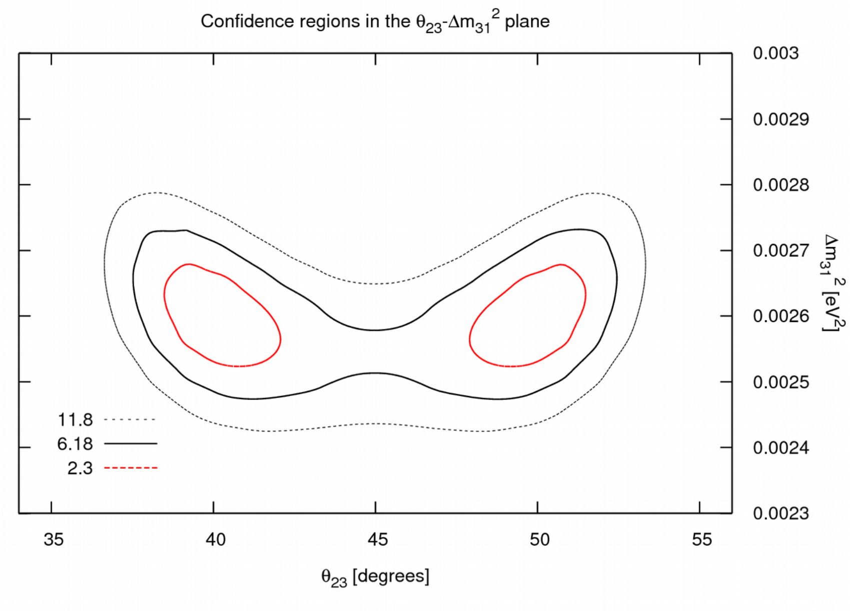
GLoBES

General Long Baseline Experiment Simulator





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Introduction

- GLoBES is a sophisticated software package for
  the simulation of long baseline neutrino oscillation experiments
- It calculates
    - χ^2
    - sensitivity of experiments
    - oscillation probabilities
- Observables in GloBES:
    - Reconstructed neutrino energy
    - Neutrino flavor
- Applied to:
    - Conventional beams
    - Super beam
    - Neutrino factories
    - B-beam
    - Reactor experiment

Introduction

- GLoBES is a package based on C-libraries

- Each library consist of different functions
  - Functions are different for vacuum and matter

- Data analysis of experiment
  - It can be added up to 32 experiments at the same time

- Simulation of future experiments
  - Simulation is based on 2 types of values
    - True parameter values
    - Fit parameter values

GLoBES tutorials

- Four tutorials available on:
  https://www.mpi-hd.mpg.de/personalhomes/globes/documentation.html

1. **Simulating T2K** entry-level
2. **AEDL features** intermediate level
3. **Advanced features** advanced level
4. **Degeneracy finding** advanced level

- None of us had any experiences with GLoBES so far
  → started with '**Simulating T2K**'
  (will present you the results from this tutorial only)
  → continued with '**AEDL features**'

Simulating T2K

- Study the sensitivity of the T2K experiment
- Simulation based on the T2K Letter of Intent
  (results will differ from actual T2K performance)

- **Part 1**:

  Precision measurement of the leading
  atmospheric oscillation parameters θ_{23} and Δm_{31}^2

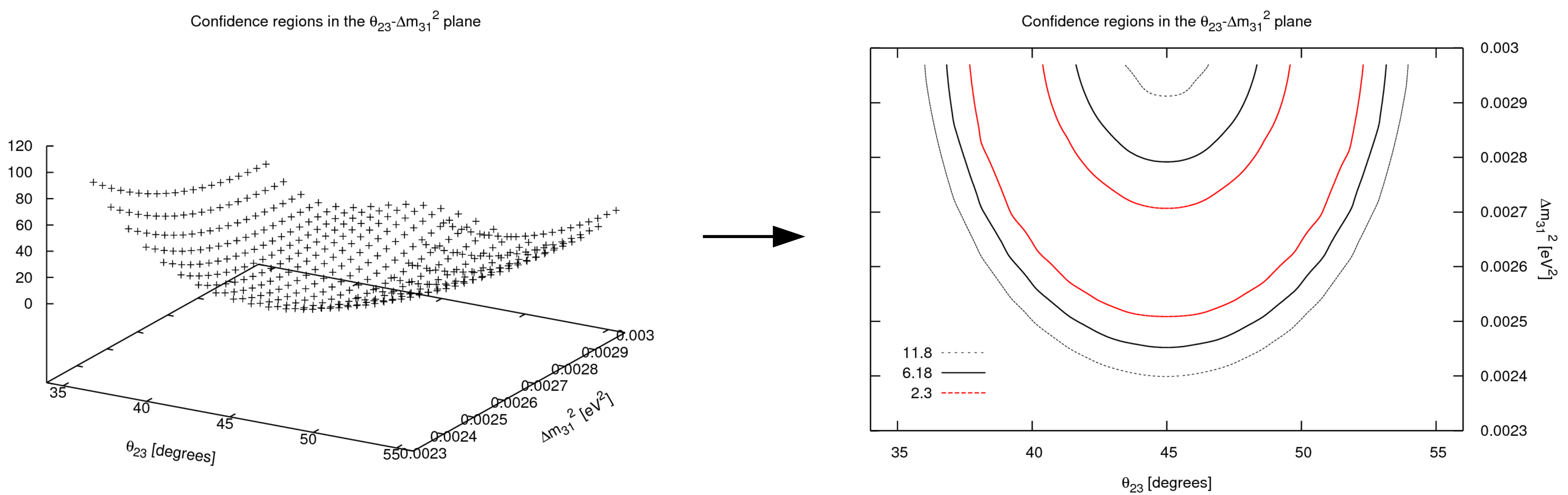
- **Part 2**:

  Possible detection of non-zero θ_{13} and δ_{CP}

Precision Measurement of θ_{23} and Δm_{31}^2

χ^2 contour-plot

(predicted values: θ_{12}= 33.21°, θ_{13}= 0°, θ_{23}= 45°, Δm_{21}^2= 7.9e-5 eV, Δm_{31}^2= 2.6e-3 eV , δ_{CP}= 0)

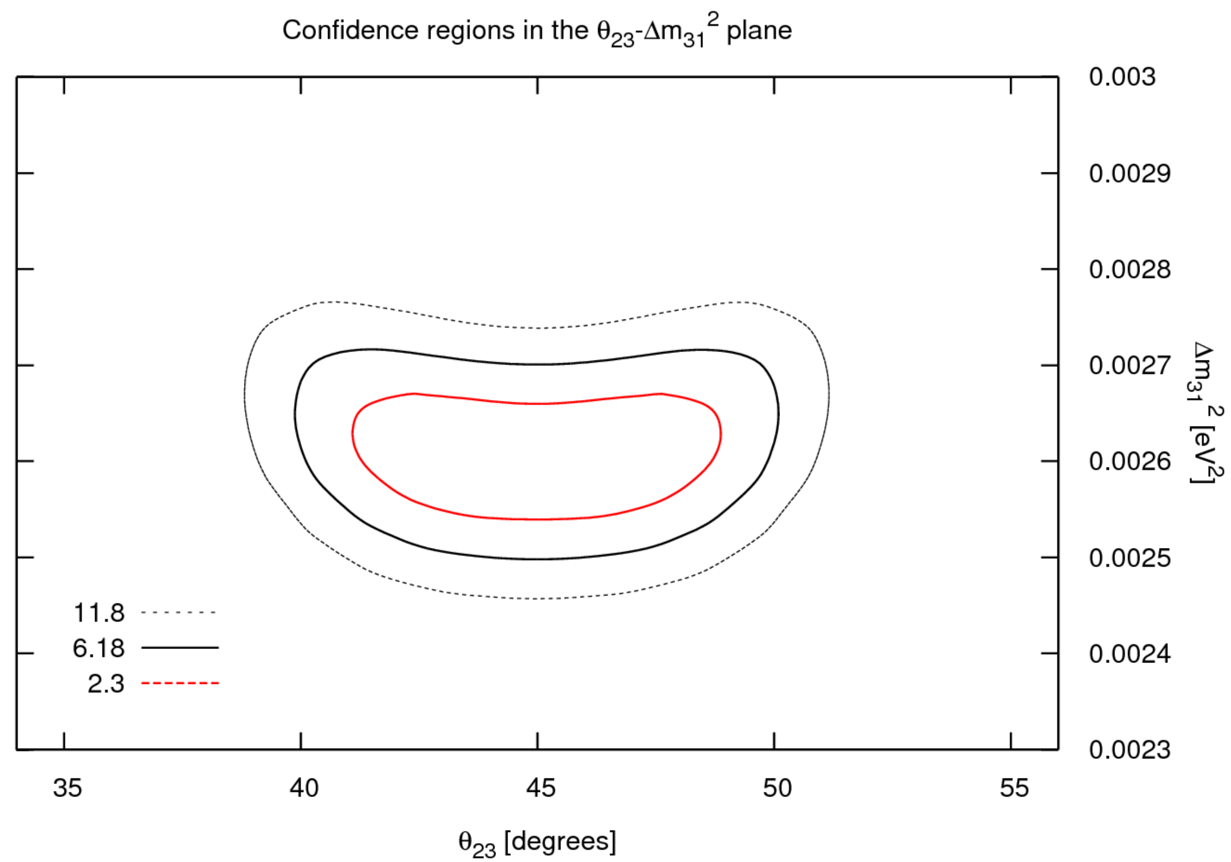


- **χ^2-distribution (2 d.o.f.)**: 2.3 ≙ 1σ, 6.18 ≙ 2σ, 11.8 ≙ 3σ
- **Contour-plot**: intersection lines of surface plot with planes at χ^2 = 2.3, 6.18 and 11.8 projected onto $\theta_{23}/\Delta m_{31}^2$ – plane
- **Problem**: strong correlation between θ_{23} and Δm_{31}^2

Precision Measurement of θ_{23} and Δm_{31}^2

Spectral analysis vs. total rates

- So far: only total rates
- Now: improve sensitivity of the analysis with spectral information
  → change the number of analysis bins from 1 to 20

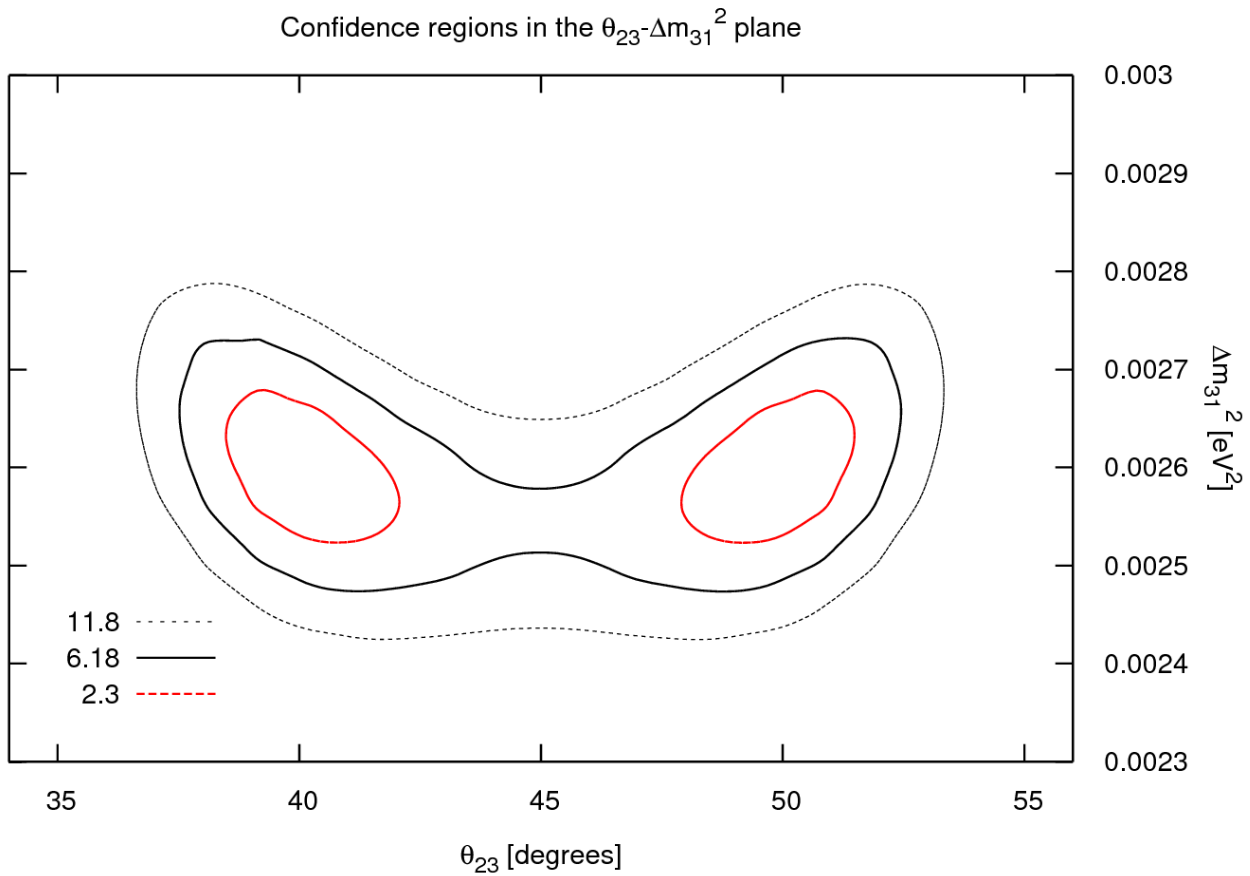


Precision Measurement of θ_{23} and Δm_{31}^2

Octant degeneracy

$\sin^2(2\theta_{23}) = \sin^2(180° - 2\theta_{23}) = \sin^2(2(90° - \theta_{23})) \rightarrow$ degeneracy at $90° - \theta_{23}$

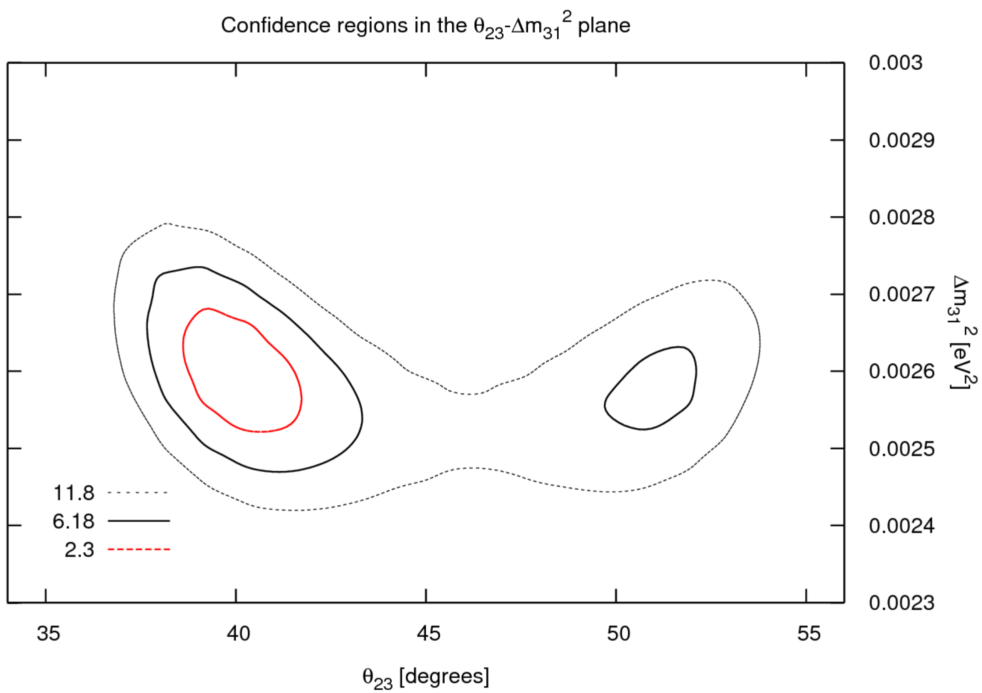
- So far: $\theta_{23} = 45°$ (no degeneracy)
- Now: $\theta_{23} = 40°$ (introducing degenerated solution at $\theta_{23} = 50°$)



Precision Measurement of θ_{23} and Δm_{31}^2

Incorporation of θ_{13}

- So far: $\theta_{13} = 0$
- Now: $\theta_{13} = 9.22°$



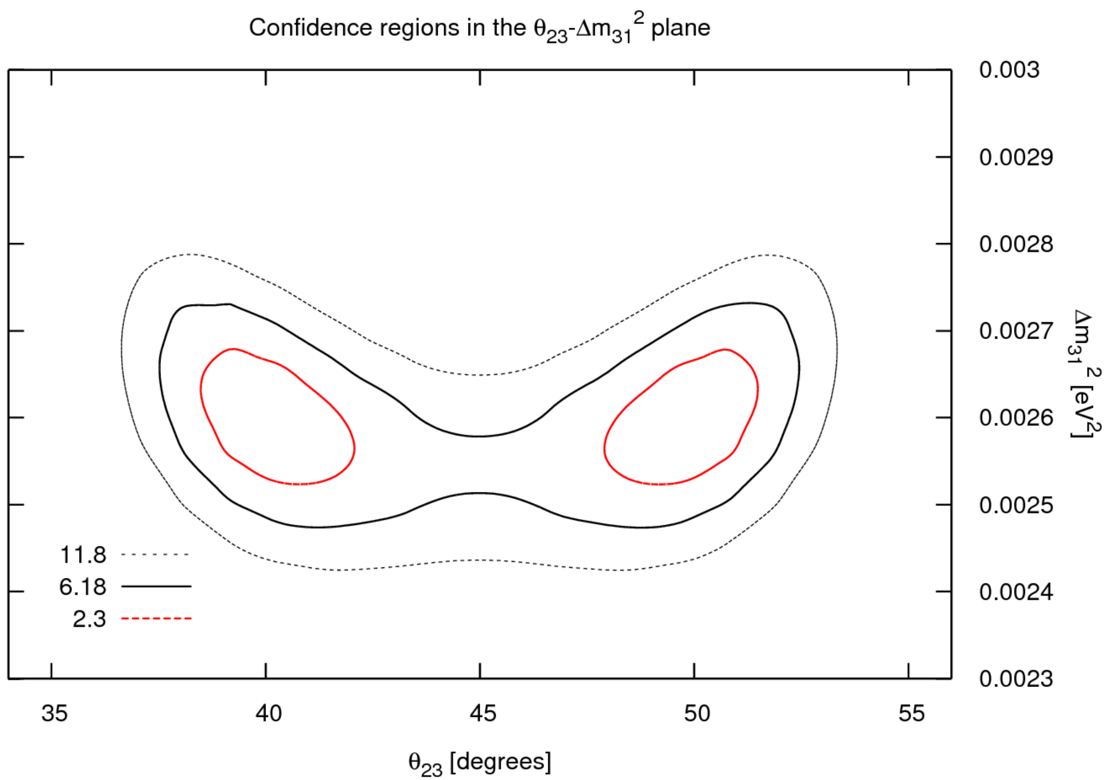
→ degenerated solution is excluded at > 1σ

Problem: Do not expect T2K to have the capability to resolve octant degeneracy
→ have to take into account correlations with θ_{13} and δ_{CP}

Precision Measurement of θ_{23} and Δm_{31}^2

Correlations with θ_{12} and δ_{CP}

- So far: θ_{13} and δ_{CP} fixed
- Now: also marginalize over θ_{12} and δ_{CP} (within allowed ranges)

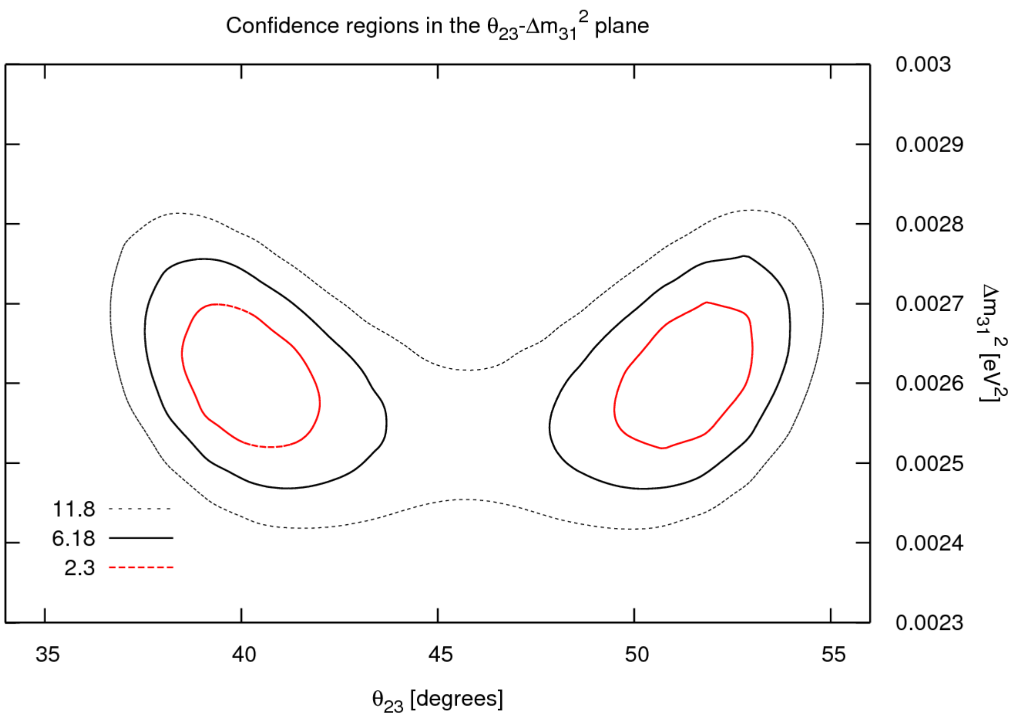


→ Sensitivity decreases due to uncertainties in predicted values

→ Degeneracy looks as expected again

Mass hierarchy: sgn(Δm_{31}^2) degeneracy

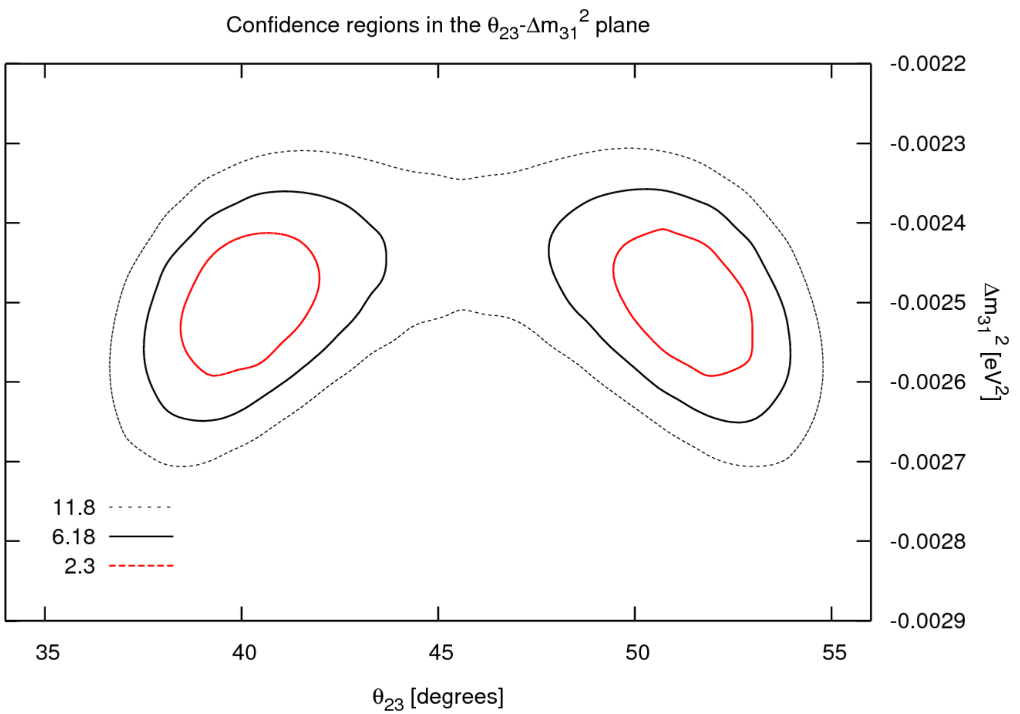
Normal mass hierarchy



$\theta_{23} \cong 40.0$ and 51.3

$\Delta m_{31}^2 \cong 2.6$ e-3

Inverted mass hierarchy



$\theta_{23} \cong 39.8$ and 51.2

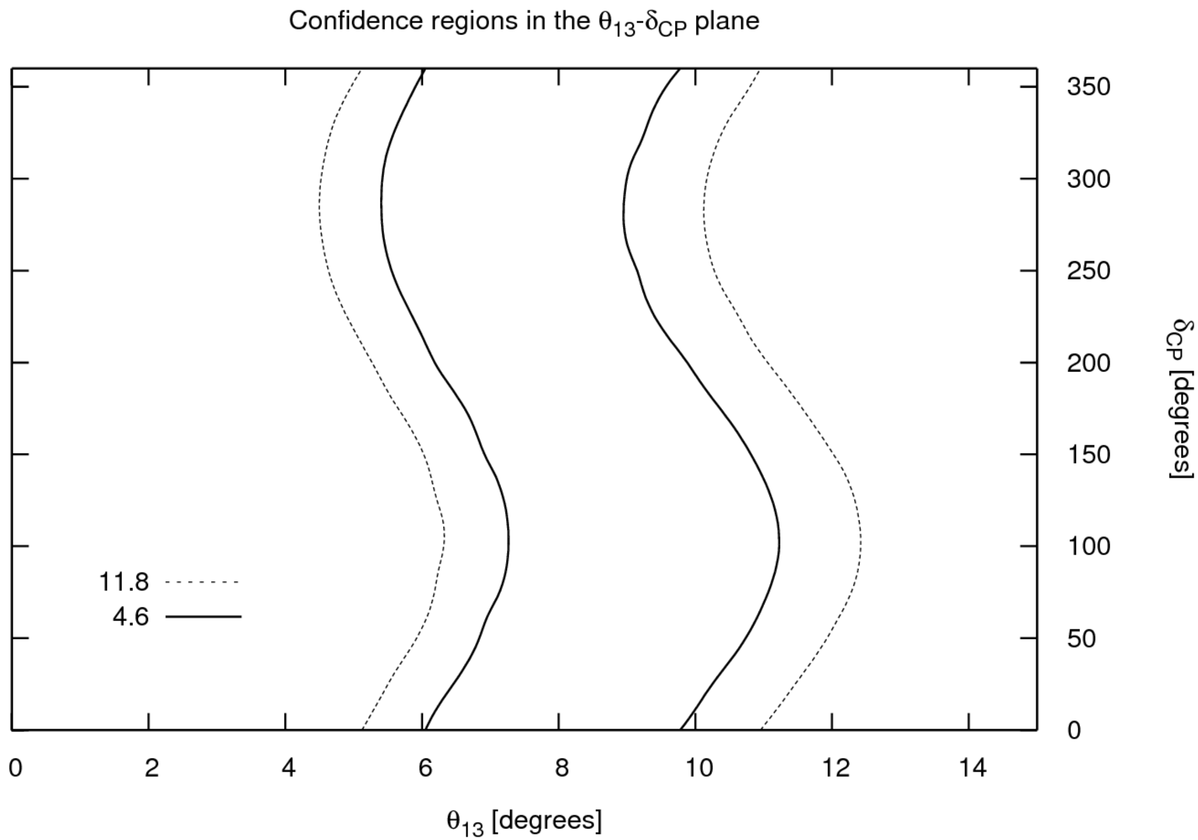
$\Delta m_{31}^2 \cong -2.5$ e-3

Note: $|\Delta m_{31}^2|_{NH} > |\Delta m_{31}^2|_{IH}$

Measurement of θ_{13} and δ_{CP}

Now: $\theta_{23} = 45°$ (assuming NH)

Simulating 3 years of ν data (no $\bar{\nu}$ data added yet)



→ impossible to constrain the CP phase

→ strong correlation between θ_{13} and δ_{CP}

Measurement of θ_{13} and δ_{CP}

Become sensitive to δ_{CP}

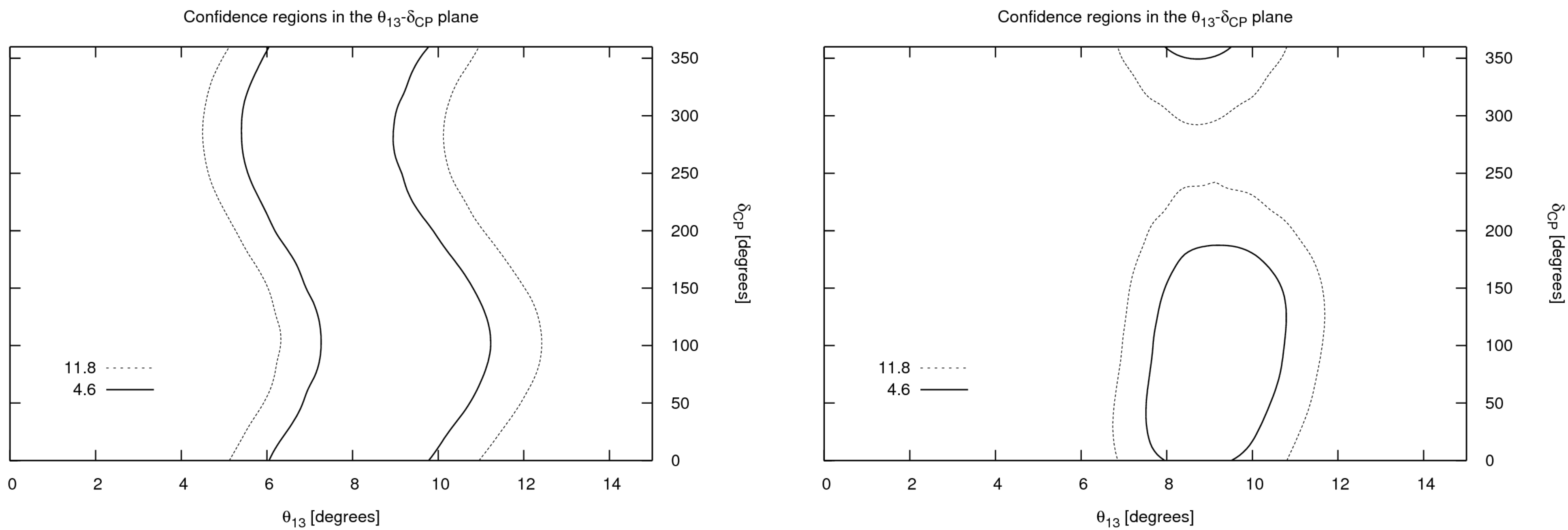
- Add T2K $\bar{\nu}$ beam data
- Include reactor results

Measurement of θ_{13} and δ_{CP}

Become sensitive to δ_{CP}

- Add T2K $\bar{\nu}$ beam data
- Include reactor results

→ add 6 years $\bar{\nu}$ data (remind: $\sigma_{\bar{\nu}} < \sigma_{\nu}$)



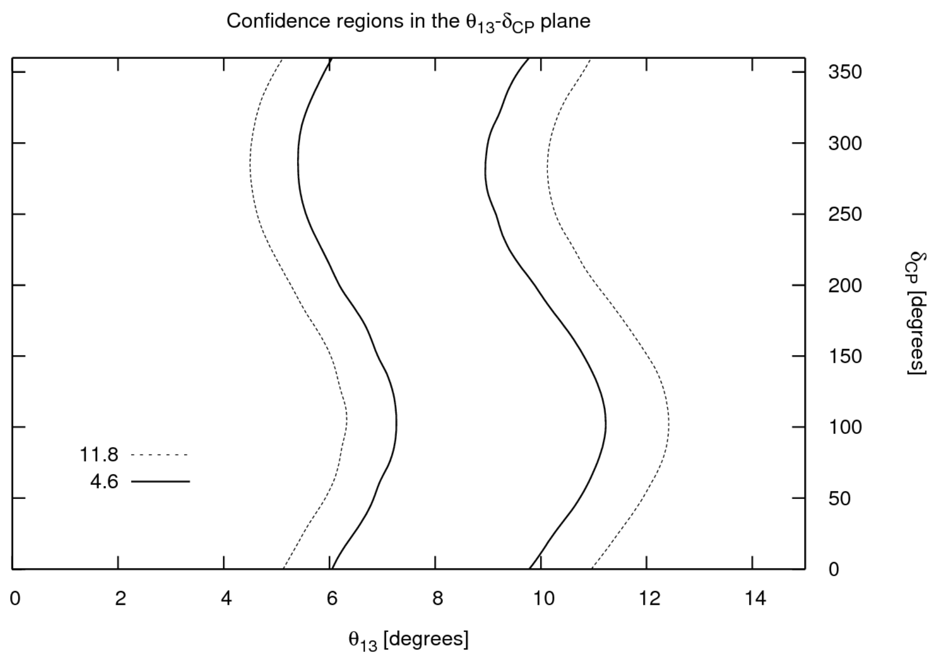
~50% of the δ_{CP} plane is excluded at 90% C.L.

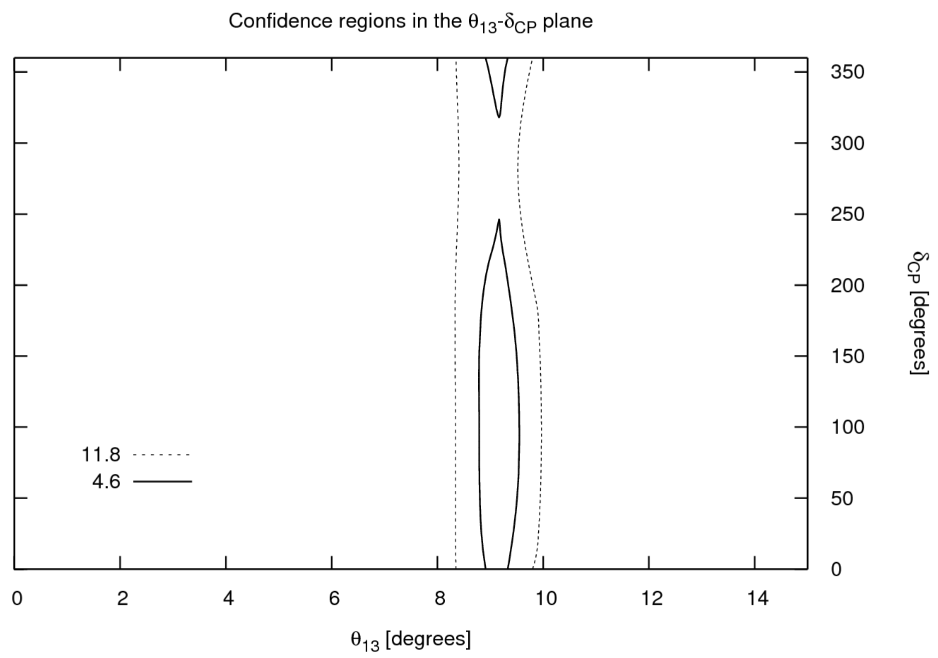
Measurement of θ_{13} and δ_{CP}

Become sensitive to δ_{CP}

- Add T2K $\bar{\nu}$ beam data
- Include reactor results

→ reactor experiment can measure Θ_{13} with great precision





~50% of the δ_{CP} plane is excluded at 90% C.L.

Conclusions

- GLoBES provides a nice platform to study LBNO experiments
- Easy to combine results from different experiments to produce significance plots
- Easy way to implement new experiments
- Several predefined experiments and tutorials available on the GLoBES webpage