# Working Status

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IFIRSE - ICISE

NuGroup Meeting, 3rd February, 2018

# Outlines

# Neutrino-Nucleus interactions

**Quasi-elastic scattering**

- Charge current elastic quasi-elastic (CCQE) scattering and neutral current elastic scattering (CC) dominate at the enegy of around $1 GeV$.

$$\nu_l + n \rightarrow l^- + p$$

$$\nu_l + N \rightarrow \nu_l + N$$

- Where $l^- = e^-, \mu^-, \tau^-$ and $N$ is the nuclon

# Neutrino-Nucleus interactions

**CC1$\pi$ and NC1$\pi$ interactions**

- In a few GeV region, the intermediate state is dominated by the $\Delta(1232)$ resonance, which mainly decay into a nucleon and a pion

$$\nu_l + N \to l^- + \Delta \to l^- + N' + \pi$$

$$\nu_l + N \to \nu_l + \Delta \to \nu_l + N' + \pi$$

# Neutrino-Nucleus interactions

**Coherent pion production**

- Momentum tranfer from neutrinos can exite the nucleus. Then the nucleus decays and leaves a pion

$$\nu_l + A \rightarrow l^- + A + \pi^+$$

$$\nu_l + A \rightarrow \nu_l + A + \pi^0$$

# Neutrino-Nucleus interactions

**Deep inelastic scattering**

- At high energy ($> 5 GeV$), neutrino interaction is dominated by deep inelastic scattering

$$\nu_l + N \rightarrow l^- + N' + hadrons$$

$$\nu_l + N \rightarrow \nu_l + N' + hadrons$$

# T2K.glb modification

- The modifications of event rates and systematic errors are based on arXiv:1409.7469v2[hep-ex]
- Systematic errors of appearance and disappearance are 9.7% and 13.3%, respectively.
- For $\nu_e$ and $\bar{\nu}_e$ appearance:

| | $\delta_{CP}$ | Total | Signal $\nu_\mu \to \nu_e$ | Signal $\bar{\nu}_\mu \to \bar{\nu}_e$ | Beam CC $\nu_e + \bar{\nu}_e$ | Beam CC $\nu_\mu + \bar{\nu}_\mu$ | NC |
|---|---|---|---|---|---|---|---|
| 100% $\nu$-mode | 0° | 291.5 | 211.9 | 2.4 | 41.3 | 1.4 | 34.5 |
| 100% $\nu$-mode | -90° | 341.8 | 262.9 | 1.7 | | | |
| 100% $\bar{\nu}$-mode | 0° | 94.9 | 11.2 | 48.8 | 17.2 | 0.4 | 17.3 |
| 100% $\bar{\nu}$-mode | -90° | 82.9 | 13.1 | 34.9 | | | |

# T2K.glb modification

- The modifications of event rates and systematic errors are based on arXiv:1409.7469v2[hep-ex]
- Systematic errors of appearance and disappearance are 9.7% and 13.3%, respectively.
- For $\nu_\mu$ and $\bar{\nu}_\mu$ disappearance:

| | Total | CCQE $\nu_\mu(\bar{\nu}_\mu)$ | CC non-QE $\nu_\mu(\bar{\nu}_\mu)$ | CC $\nu_e + \bar{\nu}_e$ CC $\nu_\mu(\bar{\nu}_\mu) \to \nu_e(\bar{\nu}_e)$ | NC |
|---|---|---|---|---|---|
| 100% running in $\nu$-mode | 1,493 | 782(48) | 544 (40) | 4 | 75 |
| 100% running in $\bar{\nu}$-mode | 715 | 130(263) | 151(138) | 0.5 | 33 |

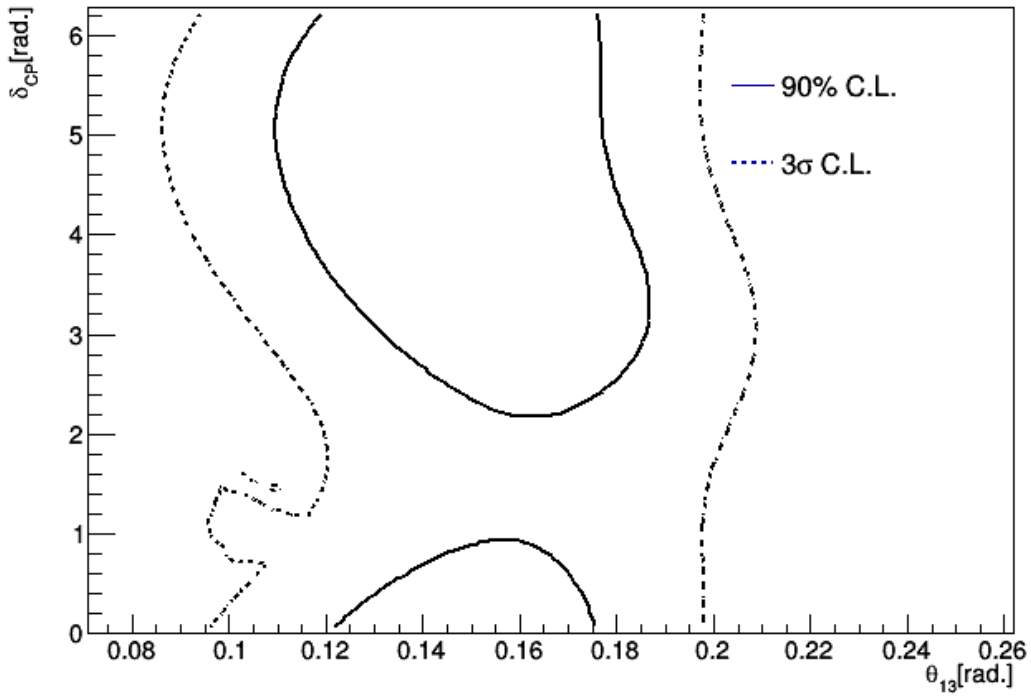
# Updated "true" values of oscillation parameters

- The updated values are based on pdg.lbl.gov/2017/reviews/rpp2017-rev-neutrino-mixing.pdf

| Parameter | best-fit | $3\sigma$ |
|---|---|---|
| $\Delta m^2_{21}$ $[10^{-5}$ eV $^2]$ | 7.37 | $6.93 - 7.96$ |
| $\Delta m^2_{31(23)}$ $[10^{-3}$ eV $^2]$ | 2.56 (2.54) | $2.45 - 2.69$ $(2.42 - 2.66)$ |
| $\sin^2\theta_{12}$ | 0.297 | $0.250 - 0.354$ |
| $\sin^2\theta_{23}$, $\Delta m^2_{31(32)} > 0$ | 0.425 | $0.381 - 0.615$ |
| $\sin^2\theta_{23}$, $\Delta m^2_{32(31)} < 0$ | 0.589 | $0.384 - 0.636$ |
| $\sin^2\theta_{13}$, $\Delta m^2_{31(32)} > 0$ | 0.0215 | $0.0190 - 0.0240$ |
| $\sin^2\theta_{13}$, $\Delta m^2_{32(31)} < 0$ | 0.0216 | $0.0190 - 0.0242$ |
| $\delta/\pi$ | 1.38 (1.31) | $2\sigma$: (1.0 - 1.9) ($2\sigma$: (0.92-1.88)) |

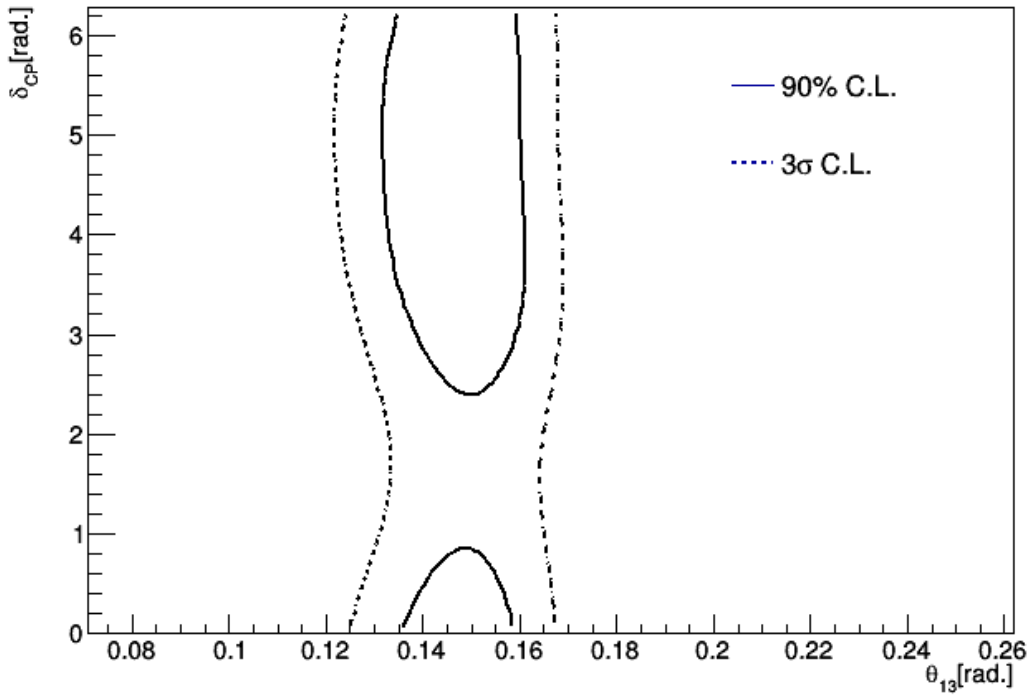
# Made the plots by root with T2K.glb

**th13delta.c**



# Made the plots by root with T2K.glb

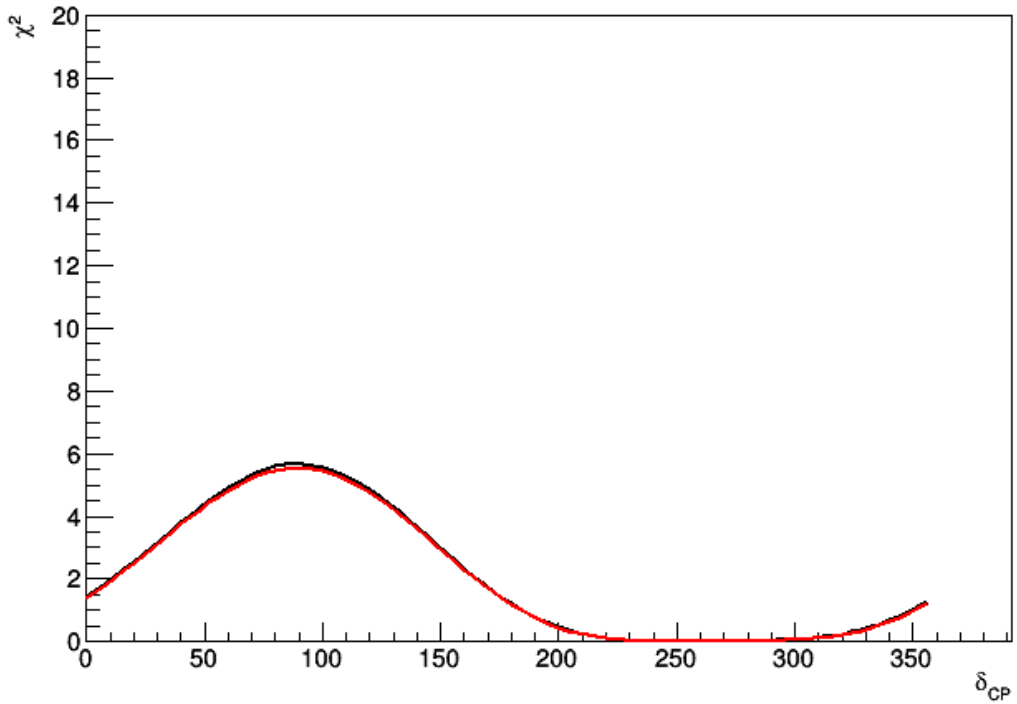
**th13delta_wreactor.c**



# Made the plots by root with T2K.glb

**deltacp_proj.c**

- Black line: Chi2 for two-parameter correlation
- Red line: Ch2 for full correlation: minimize over all but theta13



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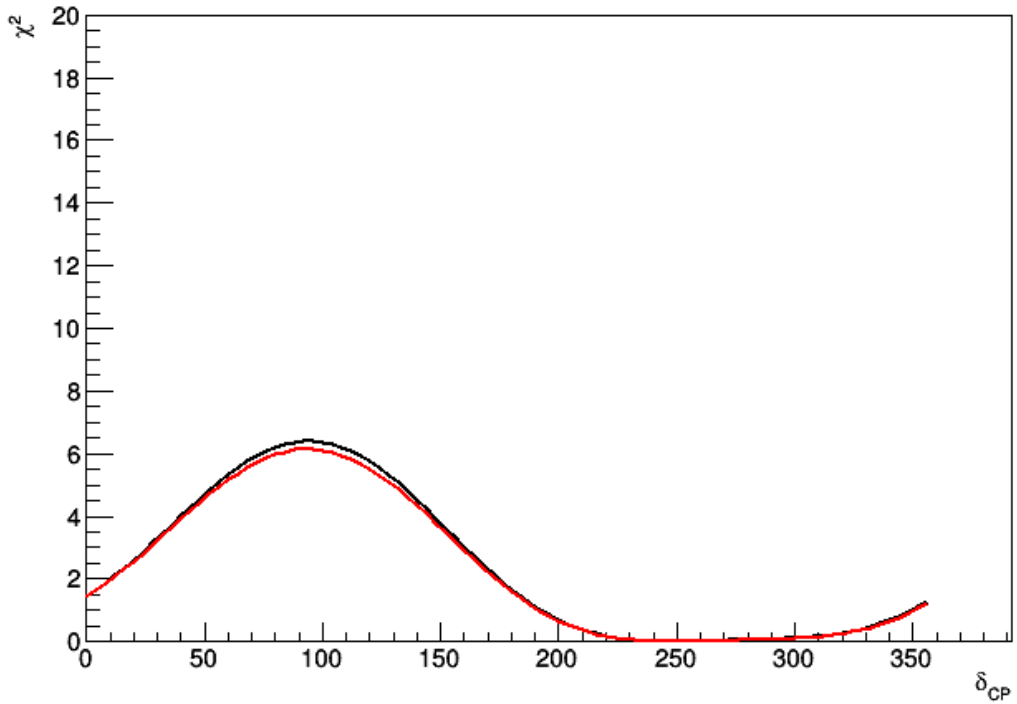

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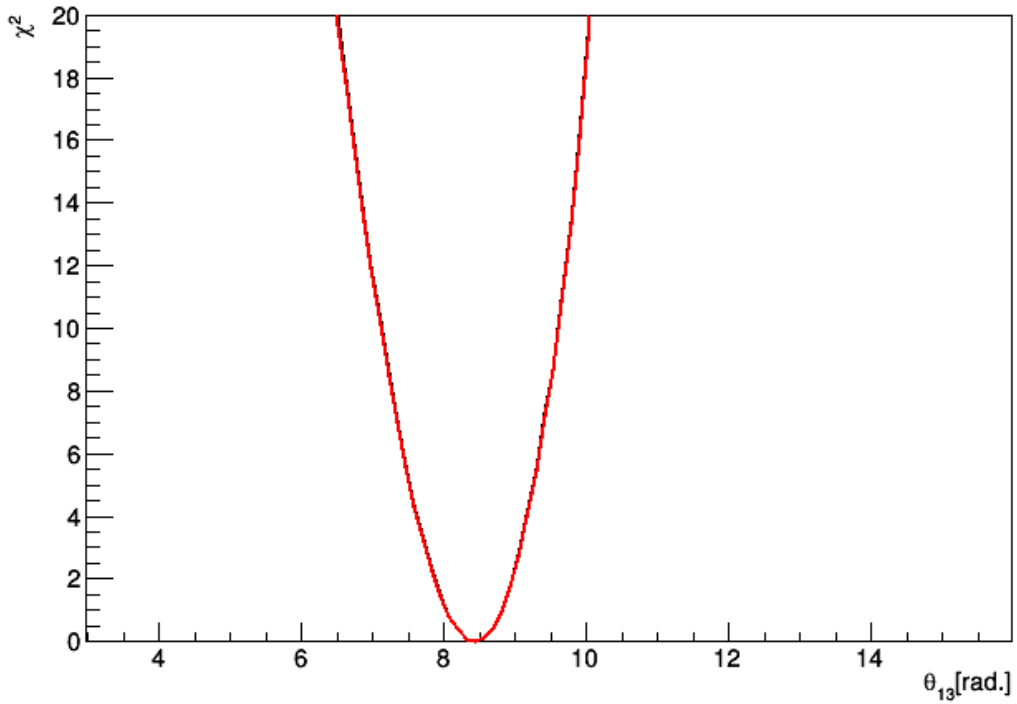
**theta13_proj_wreactor.c**

- Black line: Chi2 for two-parameter correlation
- Red line: Ch2 for full correlation: minimize over all but theta13



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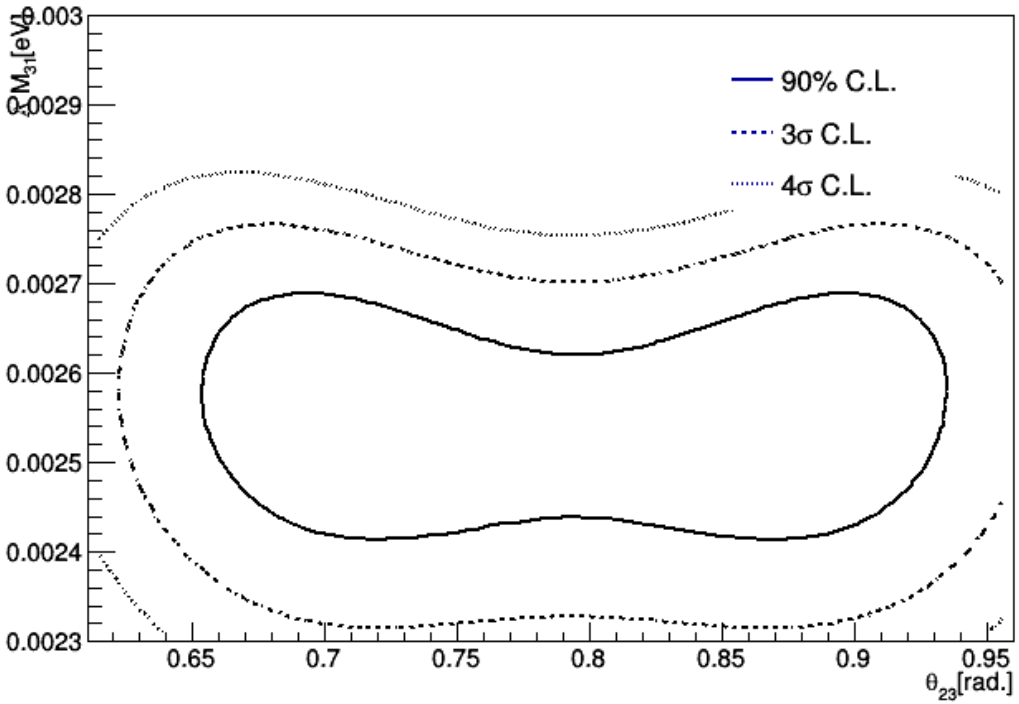
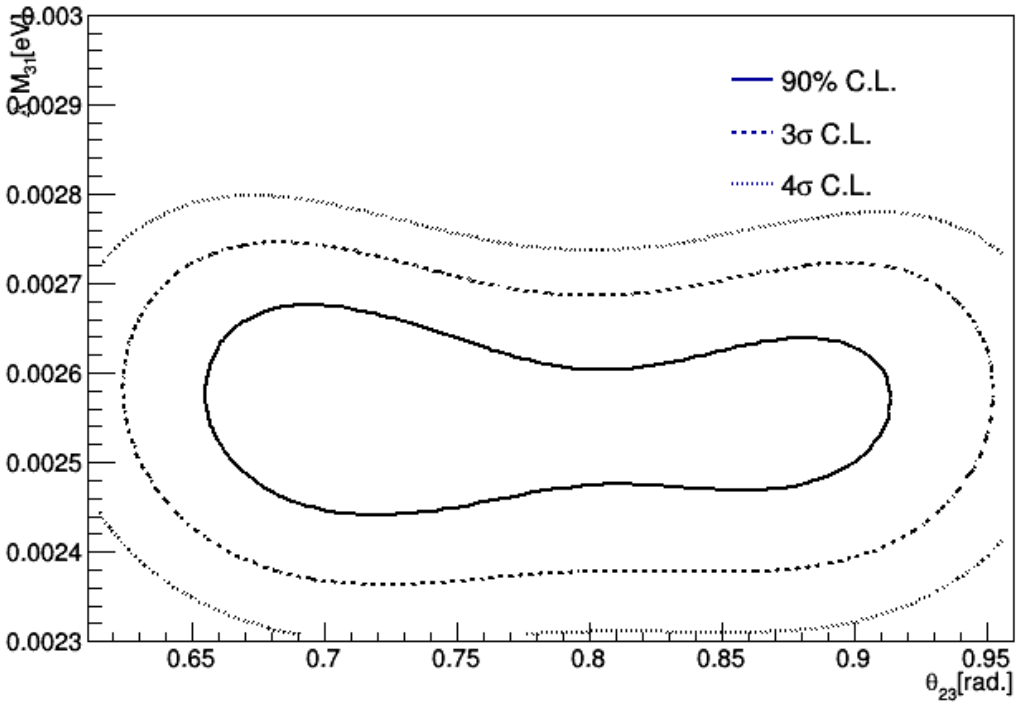
**th23dm.c**



# Made the plots by root with T2K.glb

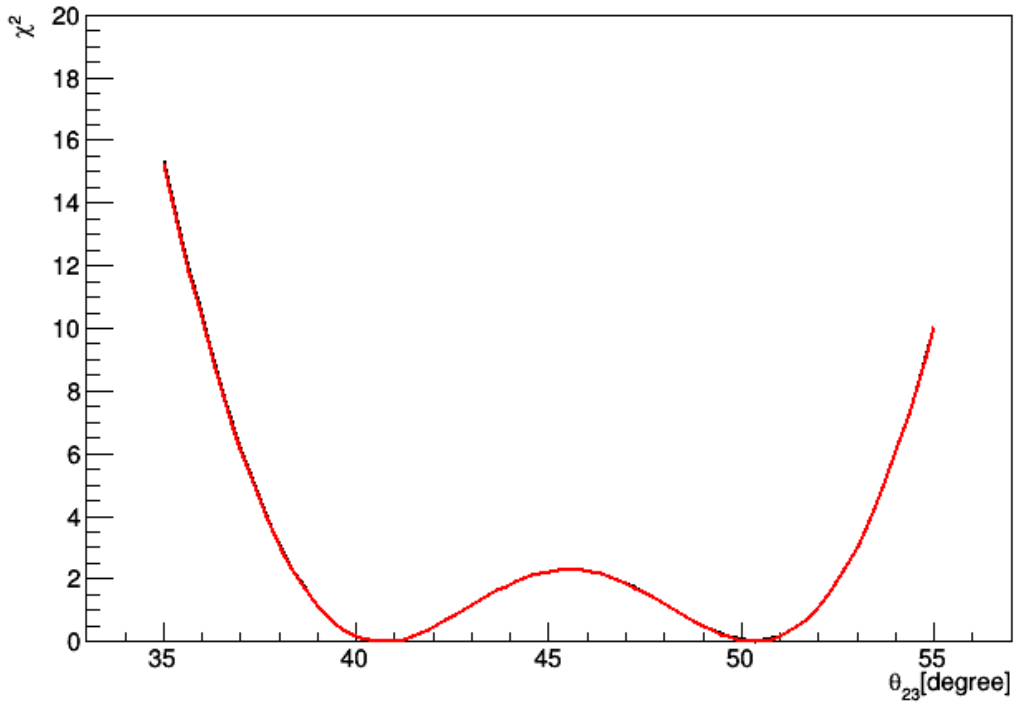
**th23dm_wreactor.c**



# Made the plots by root with T2K.glb

**theta23_proj.c**

- Black line: Chi2 for two-parameter correlation
- Red line: Ch2 for full correlation: minimize over all but dm31



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- Black line: Chi2 for two-parameter correlation
- Red line: Ch2 for full correlation: minimize over all but dm31