An alternative approach to extraction of oscillation parameters

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Abstract

We discuss a method to extract neutrino oscillation parameters based on the directly observable quantities, without reconstruction of neutrino energy.

Motivation

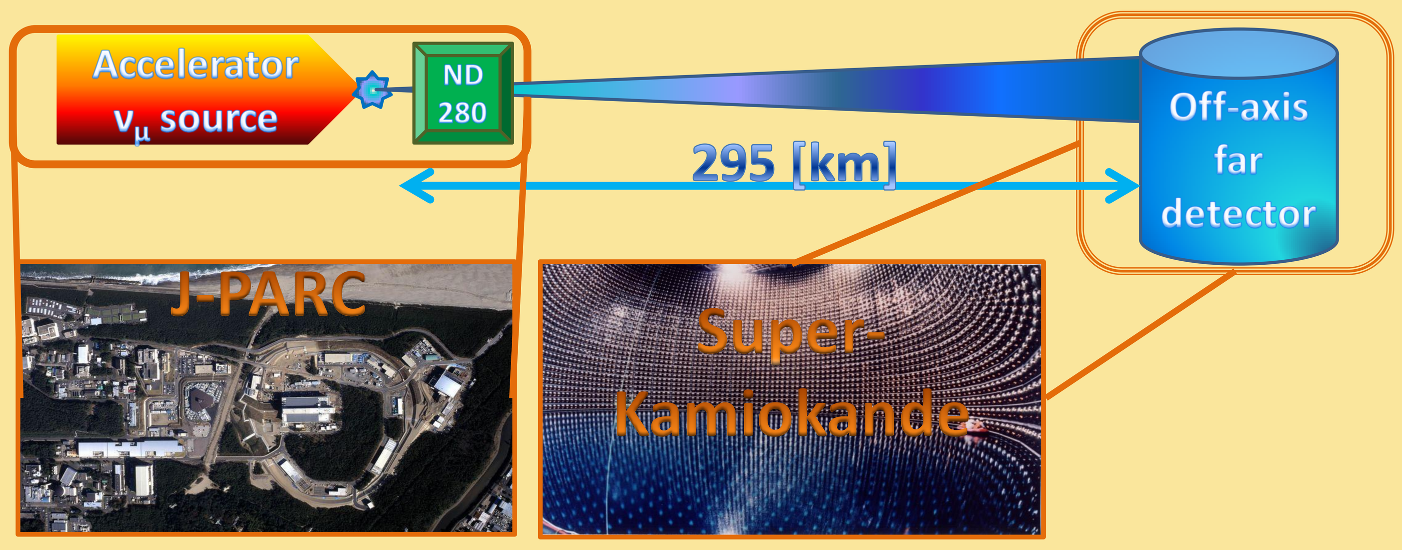
The traditional method of determination of neutrino oscillation parameters requires reconstruction of the neutrino energy for each measured event. One assumes the target nucleon to be at rest and uses the knowledge of the charged lepton kinematics and beam direction. The interaction is assumed to be pure charged-current (CC) and quasi-elastic (QE) type. However at low energies (e.g. T2K) the Fermi motion of nucleons and non-QE interactions are of significant meaning.

What if we omit the neutrino energy reconstruction and use only the direct observables (muon momenta, scattering angles, signal from pions)?
Actually, what we observe are only muons and (sometimes) pions !

The T2K experiment

Long baseline accelerator neutrino oscillation experiment in Japan

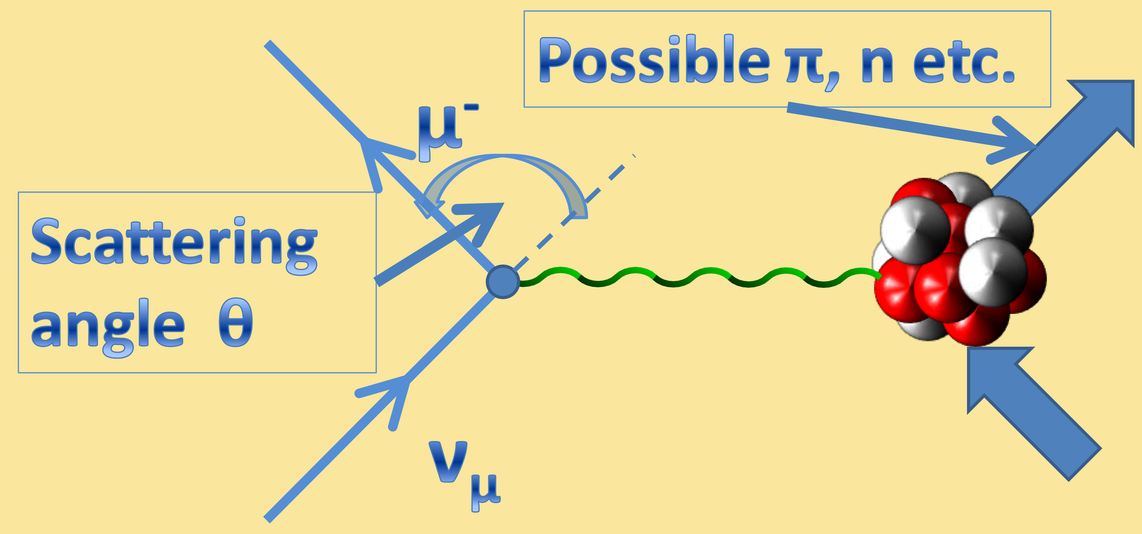
- Precise measurement of the ν_μ disappearance→ determination of Δm^2_{23} and Θ_{23}.
- Search for the ν_e appearance→ measurement of Θ_{13}.
- High statistics, over 10000 neutrino events in 5 years of operation→ small measurement uncertainties!
  $\delta(\Delta m^2_{23}) \approx 4\%$, $\delta(\sin^2(2\Theta_{23})) \approx 1\%$



What do we „see" in SuperKamiokande?

Super Kamiokande is a water Cherenkov detector

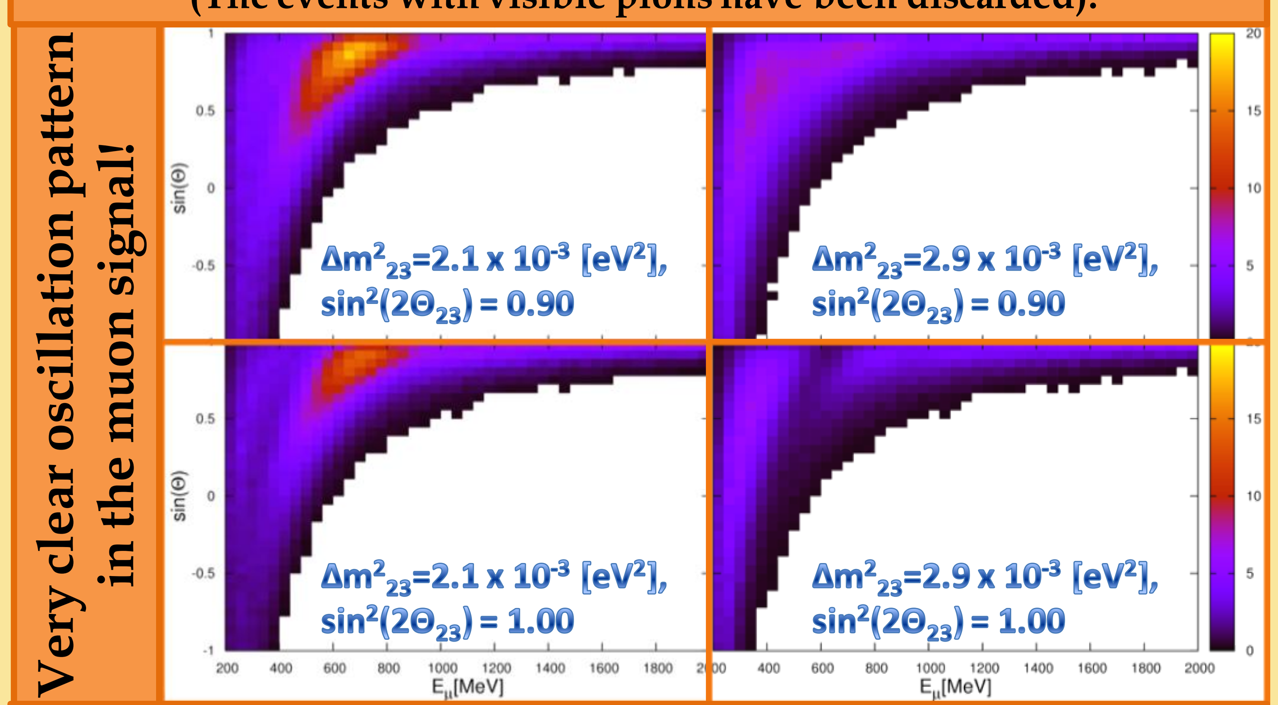
- Charged particles above the Cherenkov threshold (e.g. e±, μ±, π±).
- $\pi^0 \to \gamma\gamma$ decays.



The Alternative Method for data analysis in T2K

- Generate a large number of CC neutrino events (here- 1000000) with a Monte Carlo generator (here- **NuWro**) for the given neutrino beam.
- Create the reference oscillation samples for a set of different (Δm^2_{23}, $\sin^2(2\Theta_{23})$) using $P(\nu_\mu \to \nu_\mu)$.
- Make histograms in muon energy and scattering angle from the experimental data and reference samples, discarding events with visible pions.

Oscillation signal seen as an effect on observed distribution of muon scattering angles and energies.
(The events with visible pions have been discarded).



Muon distribution is a very good observable in a disappearance experiment.

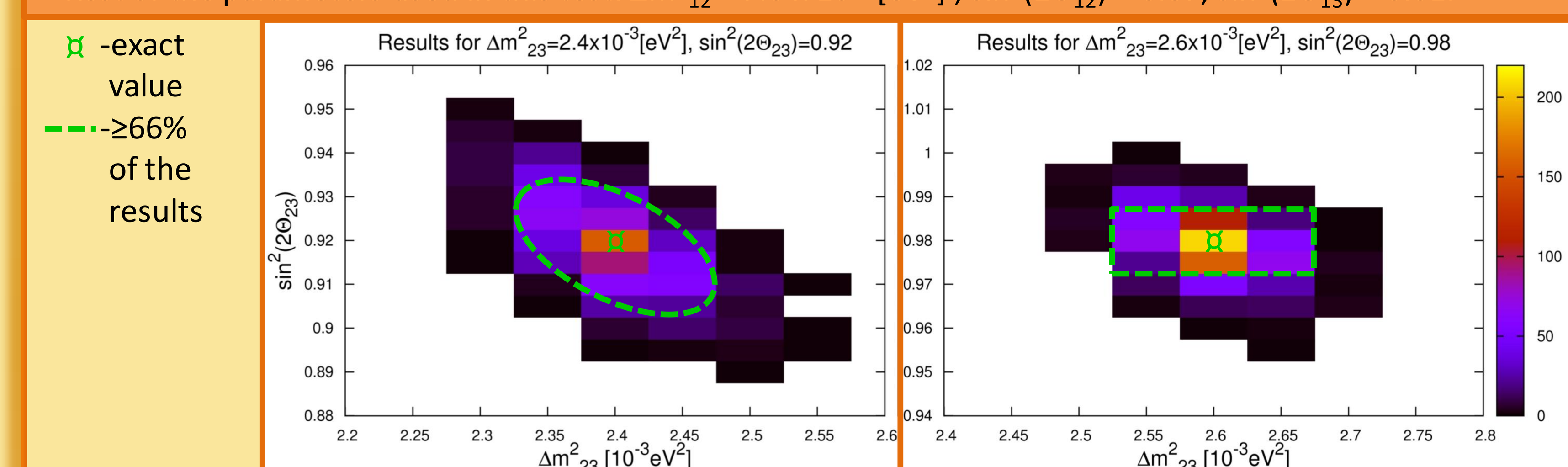
- With an experimentally measured distribution -> Find most probable (Δm^2_{23}, $\sin^2(2\Theta_{23})$) by minimizing the Chi^2.

Performance of the method

- Instead of the experimental data for different values of (Δm^2_{23}, $\sin^2(2\Theta_{23})$) 1000 MC samples have been created. The numbers of events correspond to about 6 years of data collecting.
- Histograms with uniform bins of the size 100 [MeV] in muon energy and π/4 in muon scattering angle have been used.
- For each sample the most probable parameters (Δm^2_{23}, $\sin^2(2\Theta_{23})$) have been found by minimizing the Chi^2.

Description:

These plots shows the results of Chi^2 test made for two different oscillation parameter values:(**Δm^2_{23} = 2.4 x 10^{-3} [eV^2], $\sin^2(2\Theta_{23})$ = 0.92)** and **Δm^2_{23} = 2.6 x 10^{-3} [eV^2], $\sin^2(2\Theta_{23})$ = 1.00)***.
Each bin gives the number of MC muon signal samples, which have been identified with a pair of oscillation parameters (Δm^2_{23}, $\sin^2(2\Theta_{23})$).
*Rest of the parameters used in this test: Δm^2_{12} = 7.6 x 10^{-5} [eV^2] , $\sin^2(2\Theta_{12})$ = 0.87, $\sin^2(2\Theta_{13})$= 0.01.



The results are strongly concentrated around the expectation value, as it should be!

Conclusions

- The proposed method gives good precision in the search for Δm^2_{23} and $\sin^2(2\Theta_{23})$ values. 1σ areas are not bigger,than 1x10^{-4} [eV2] (around 4%) in Δm^2_{23} and 0.01-0.02 in $\sin^2(2\Theta_{23})$ (around 2-3%),depending on the area, but without inclusion of the systematic errors.
- One can make an extra effort to find optimal muon bin distribution. A compromise must be found: to have many bins in the region sensitive to oscillation signal but also to keep high statistics.
- The systematic errors will clearly add some uncertainty.

Is this approach interesting enough to continue work in this direction?

Acknowledgements

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