Analysis and Background Aspects in Large Water Cerenkov Detectors

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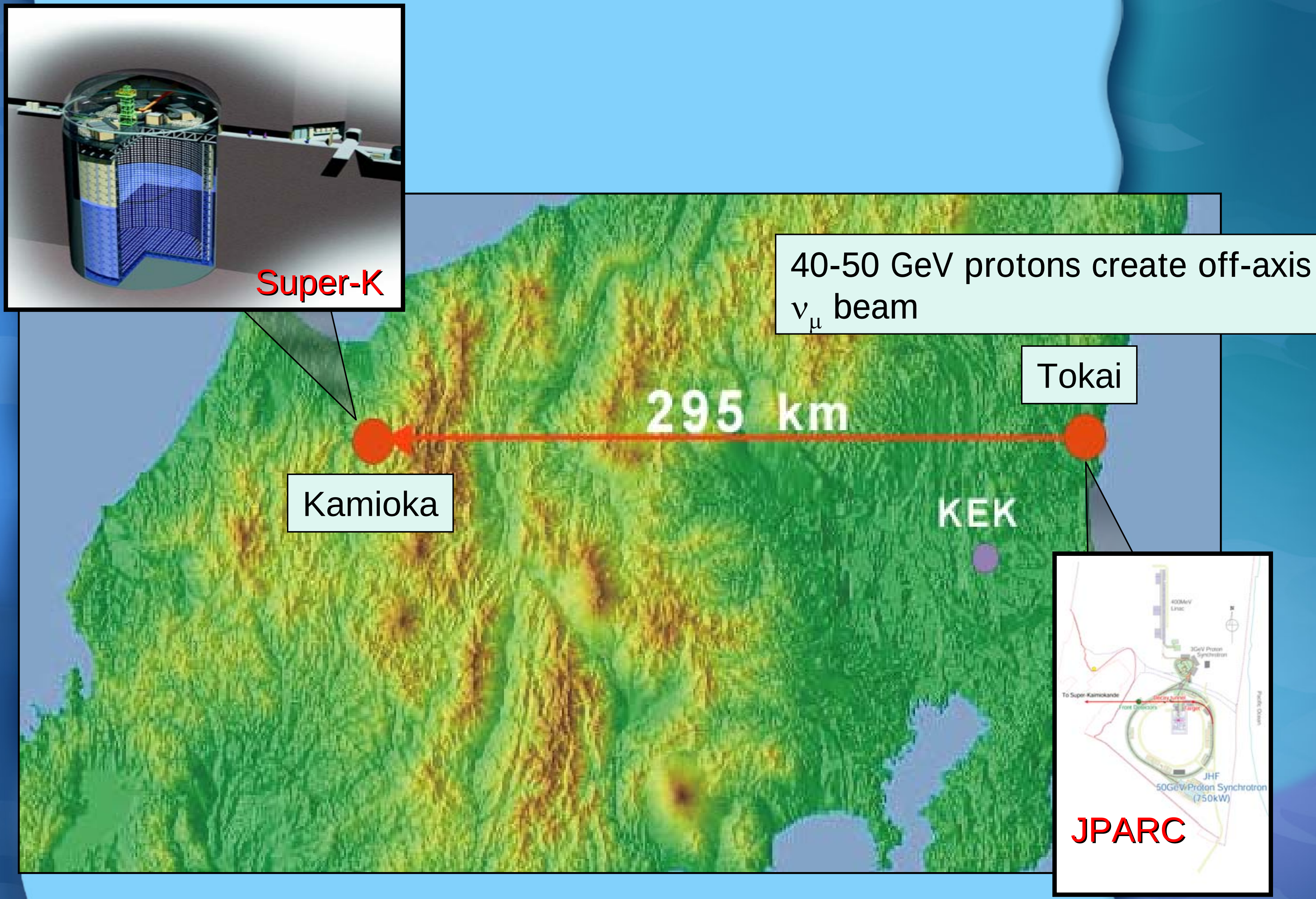
Outline

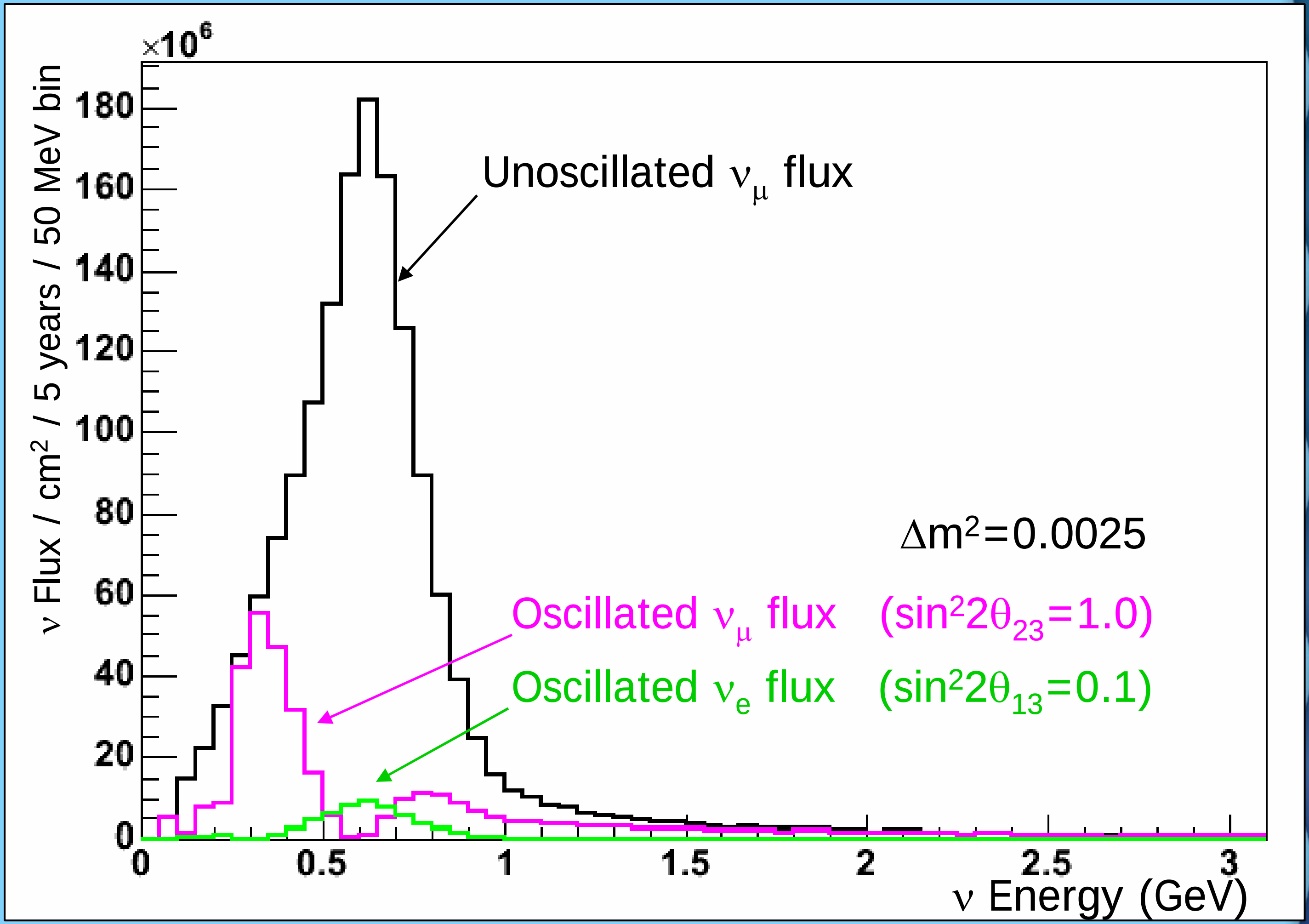
- T2K signal and background rates
- Water Čerenkov response model
  - Cross-sections and efficiencies
  - Neutrino energy reconstruction
  - Background rejection
- Systematic uncertainties
  - Near detector(s)
  - Fast global fit technique

T2K Experiment



Neutrino flux at Super-K

(2.5° off-axis beam from 0.75 MW, 40 GeV protons, assumes 5 years x 10^{21} POT)



Signal and Backgrounds

- **From off-axis ν_μ beam at Super-K**

	Disappearance Experiment	Appearance Experiment
Selection:	Fully contained, single-ring, μ-like events	Fully contained, single-ring, e-like (showering) no decay electron
Signal:	CCQE: $\nu_\mu + n \rightarrow p + \mu^-$	$\nu_\mu \rightarrow \nu_e + n \rightarrow p + e^-$

Backgrounds:

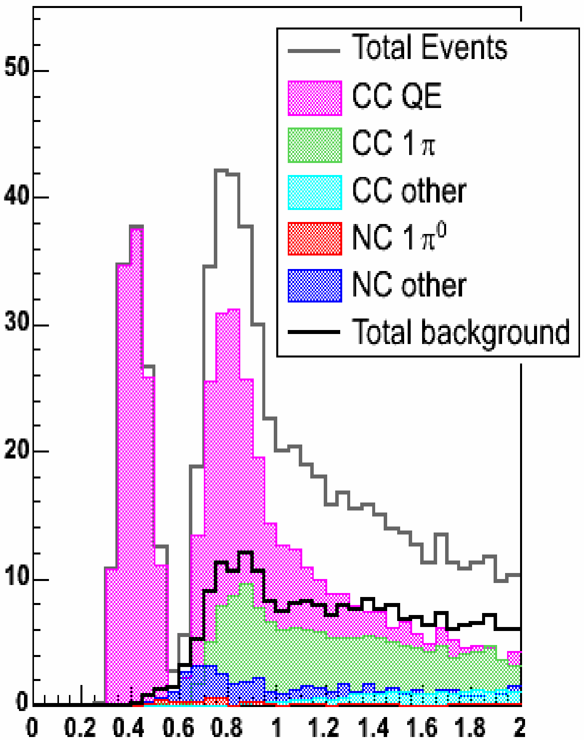
Disappearance	Appearance
CC single π: $\nu_\mu + N \rightarrow N' + \mu^- + \pi$	NC: $\nu + N \rightarrow N' + \nu + \pi^0$
CC multi π's: $\nu_\mu + N \rightarrow N' + \mu^- + \pi\ldots$	Beam ν_e
NC: $\nu + N \rightarrow N' + \nu + \pi\ldots$	Misidentified muons

Reconstructing ν_μ Energy

For T2K disappearance

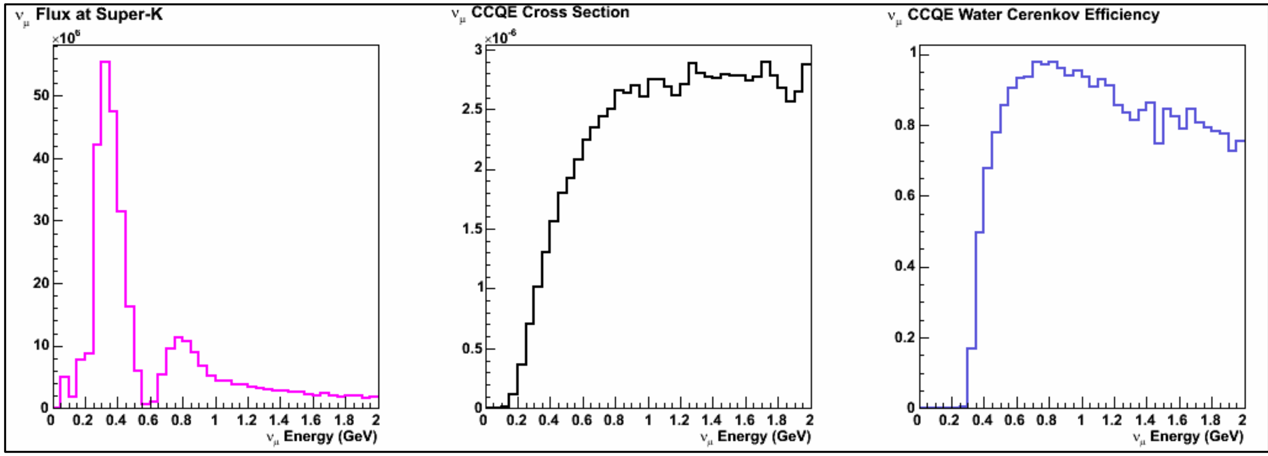
True Neutrino Energy

(1.0,0.0025)



ν_μ Energy (GeV)

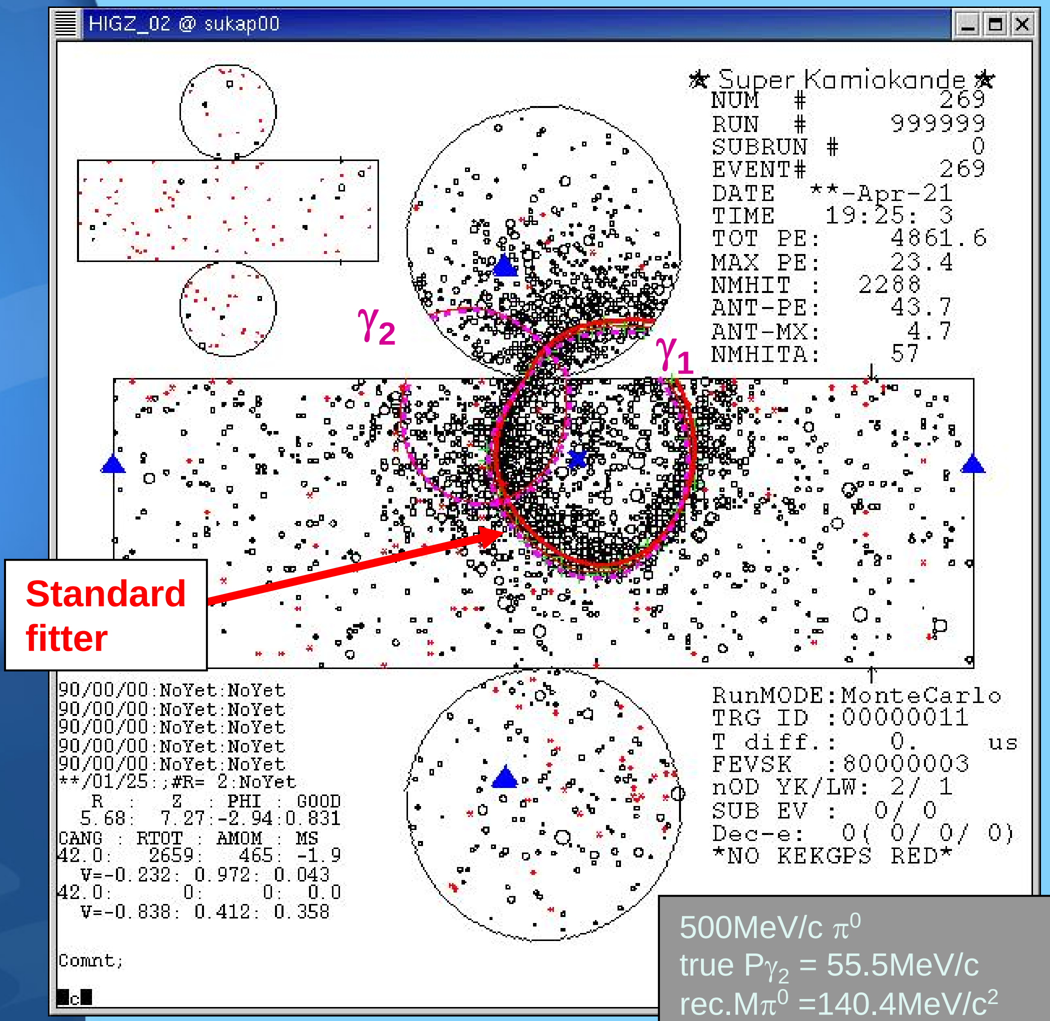
Interaction spectrum =
Flux x Cross section x Efficiency



y-axis: Events / 5 years / 22.5 kton / 50 MeV bin

ν_e Appearance Background

- **Largest background is from NC π^0 production**



- The π^0 fitter (POLfit) finds a second ring by testing:

  Likelihood(2γ) vs. Likelihood(1e)

  Then fits direction and energy fraction of 2nd ring

Plot from S. Mine

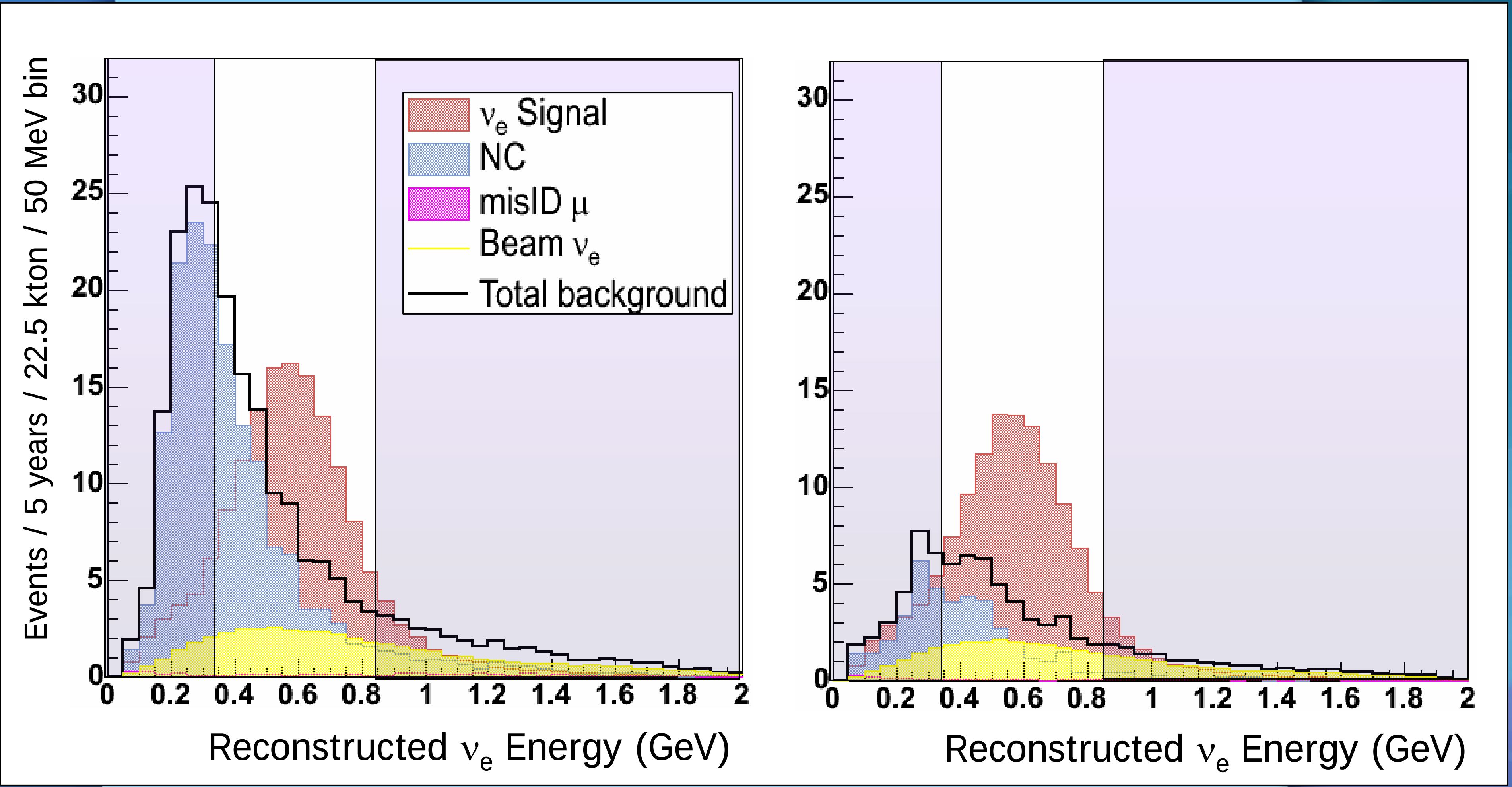
ν_e signal vs. background after π^0 fitter

(For $\Delta m^2=0.0025$ $\sin^2 2\theta_{23}=1.0$ $\theta_{13}=9°$)

Background estimates by M. Fechner

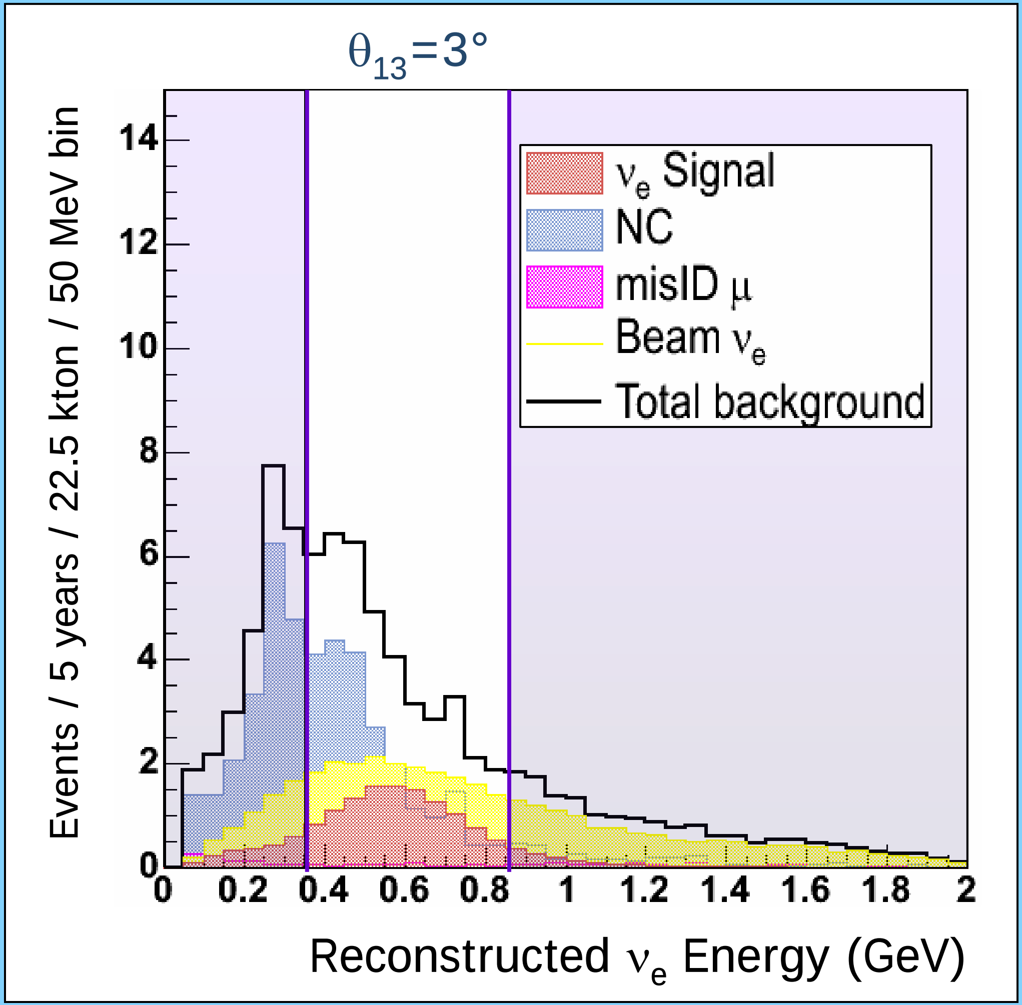
Before π^0 fitter:
NC background ~ 40 events

After π^0 fitter:
NC background ~ 10 events



ν_e signal for varied θ_{13} values

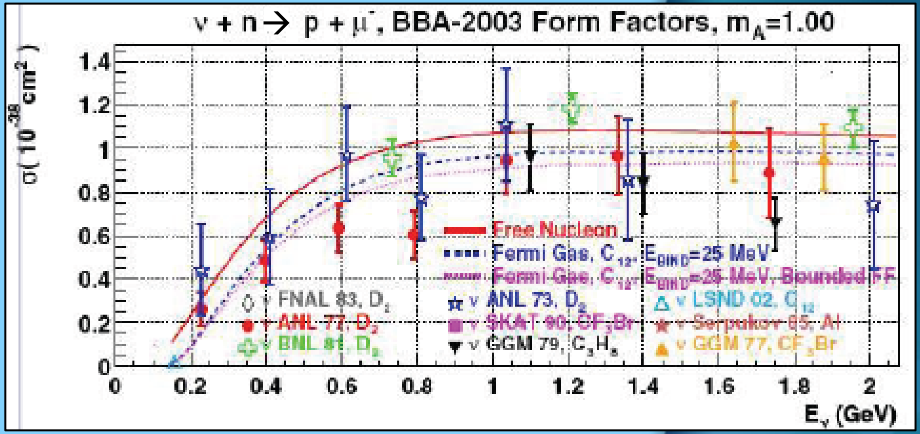
(For $\Delta m^2 = 0.0025$ $\sin^2 2\theta_{23} = 1.0$)

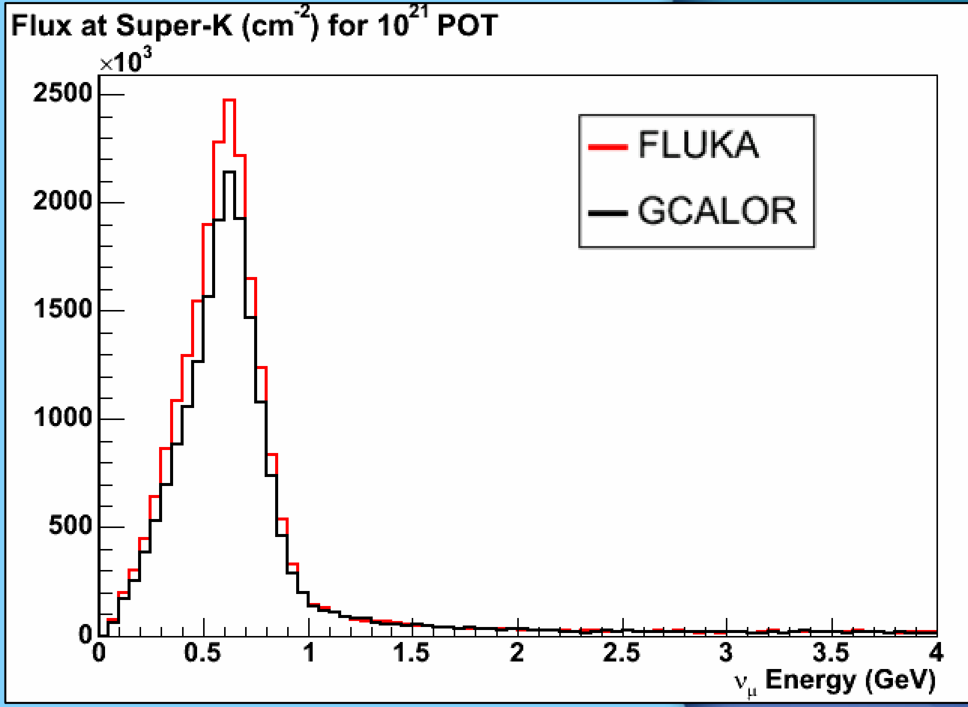


($\sin^2 2\theta_{13} = 0.01$)

Systematic uncertainties

- **Precision measurement of θ_{23} and Δm^2_{23} and appearance background subtraction require careful control of systematic uncertainties.**
  - **Čerenkov detector reconstruction:**
    - **Energy scale (~3%)**
    - **Fiducial volume (~3%)**
  - **Cross sections**
    - **CCQE (~10-20%)**
    - **Other (~20-50%)**
  - **Flux normalization and shape**
    - **Hadron production model**
    - **Beam geometry**
    - **Beam ν_e**





Near Detector(s)

- Systematics may be controlled by using one or more near detectors.
- Fine-grained detector placed near the target.
  - Ability to measure relative amounts of CCQE and nonQE interactions
- Water Cerenkov 2km away from target.
  - Flux shape matches that at far detector.
  - Close to identical response at both near and far detectors.

Global oscillation fit

- **A fit has been developed to determine oscillation parameters with the following capabilities:**
  - **varying systematic effects**
  - **inclusion of near and far detectors**
  - **inclusion of both signal and background**
  - **parameterized detector response** **(cross-sections, efficiency, reconstruction)**

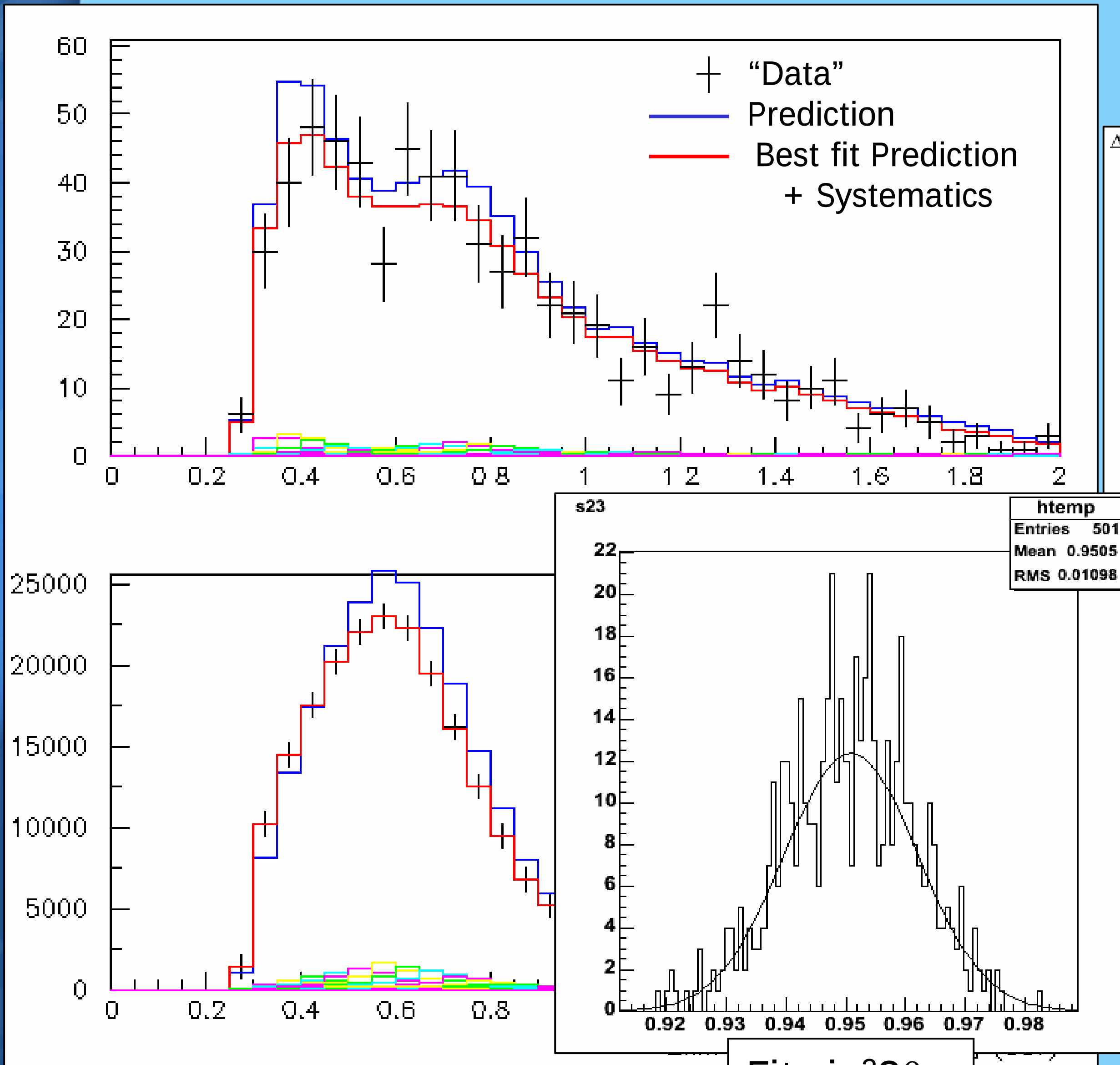
A similar approach has been used in the Super-K atmospheric neutrino oscillation analysis.

References:

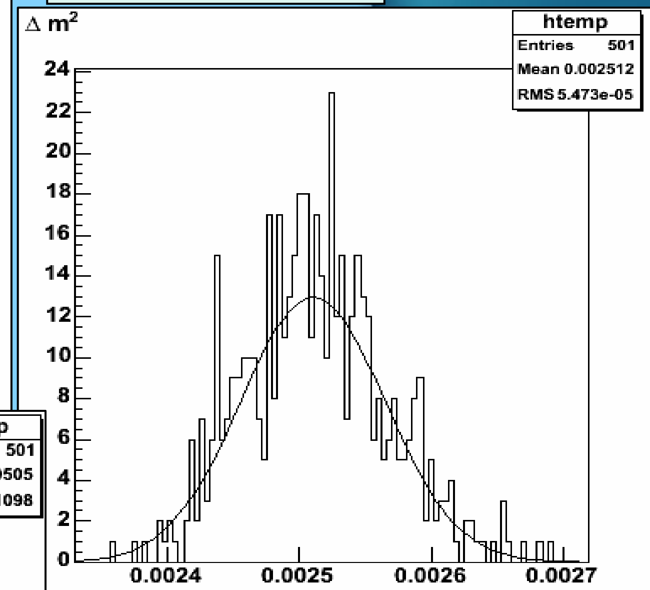
Y. Ashie *et al.,* Phys.Rev.Lett.93, 101801 (2004)
G. Fogli, *et al.*, Phys. Rev D66, 053010 (2002)
Para and Szleper (hep-ex/0110001)

Example global oscillation fit

$\Delta m^2=0.0025$
$\sin^2 2\theta_{23}=0.95$
$\theta_{13}=0°$



Fit $\sin^2 2\theta_{23}$



Fit Δm^2

Uncertainty:
$\sim$2% on Δm^2_{23}
$\sim$1.2% on $\sin^2 2\theta_{23}$

Preliminary example: no inclusion of 280m detector.

Conclusions

- **Global fit of oscillation parameters including systematics, near detectors, and backgrounds is a work in progress.**
- **Current goals are**
  - **Perform sensitivity analysis for oscillation parameters using different detector configurations.**
  - **Determine effect of systematic uncertainties on T2K sensitivity.**
- **Method is not limited to Water Cerenkov detectors or to T2K-I experiment**