JHF Sensitivity and the 2km Intermediate Detector

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Work in collaboration with Dave Casper

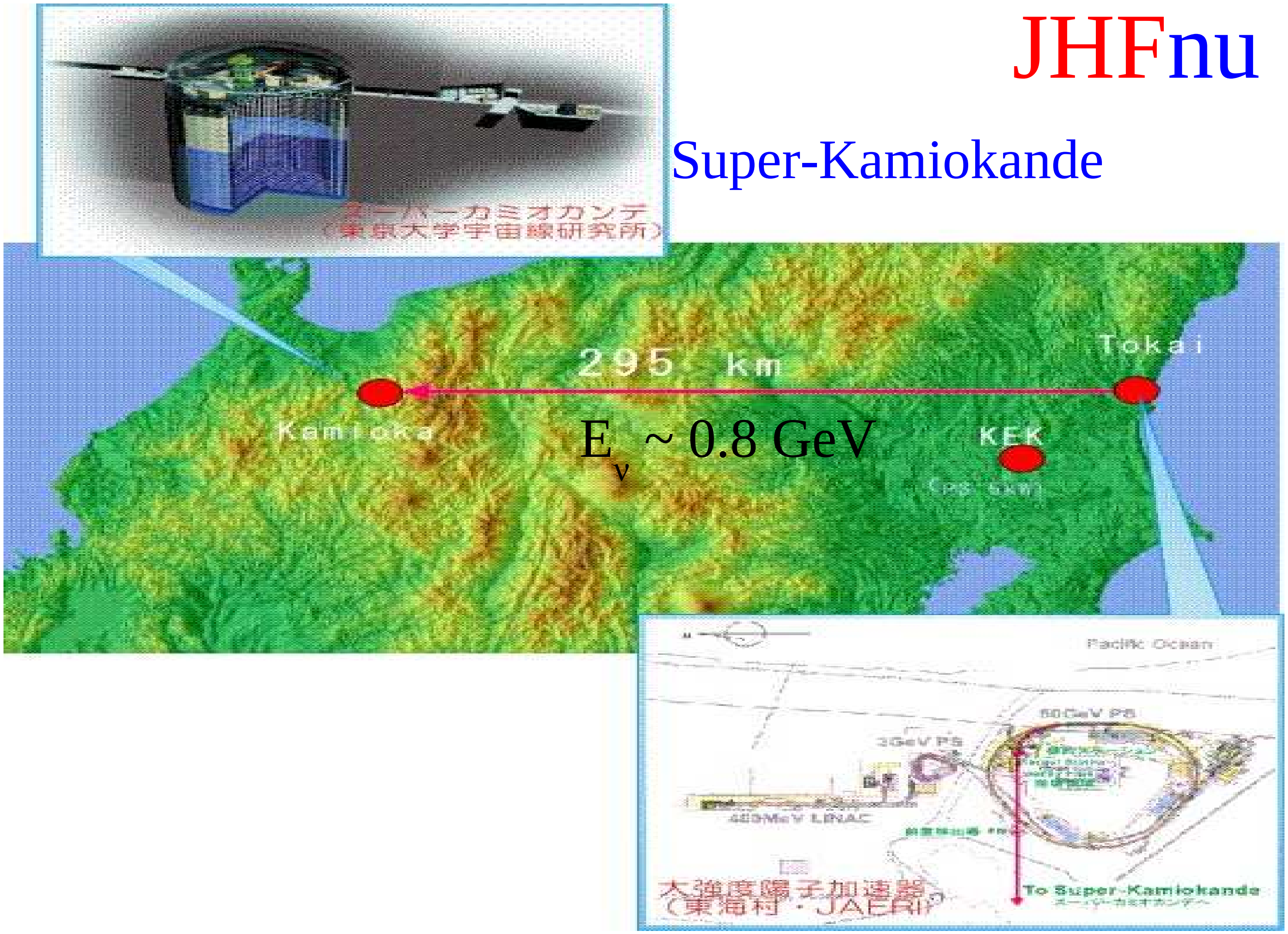
JHF Sensitivity and the 2km Intermediate Detector

- Introduction
- Systematic Uncertainties
  - Controlling Systematics
- The 2km Intermediate Detector
- Analysis
  - Near-to-far Correlation Matrix
  - Preliminary results
- Conclusions

Introduction

JHFnu

Super-Kamiokande



$E_\nu \sim 0.8$ GeV

$$\pi^{+} \rightarrow \mu^{+} \nu_{\mu}$$

High intensity proton beam (0.75 MW) from JHF PS

Introduction

GOALS

Precision measurements

$$\Theta_{23} \rightarrow \delta(\sin^2 2\Theta_{23}) \sim 0.01$$

$$\Delta m^2_{23} \rightarrow \delta(\Delta m^2_{23}) \sim 10^{-4} eV^2$$

Disappearance

Discovery

$$\Theta_{13} \rightarrow \sin^2 2\Theta_{13} \sim 0.006$$

Appearance

Search

Sterile component

→ See little demo of why it is sensitive to those parameters

Systematic Uncertainties

- Beam
  - Details in beam modelization
  - Distribution of pions in the decay volume
  - Horn current and displacements
- Detector
  - Interaction models (cross-section): QE and π^0
  - Particle ID (e/μ)
  - Pattern Recognition (e/π^0)
  - Energy scale
  - Fiducial Volume

Controlling Systematics: Off-axis Beam

Precision of the oscillation parameters mainly limited by high-energetic neutrinos with inelastic reactions.

↓

Use off-axis beam

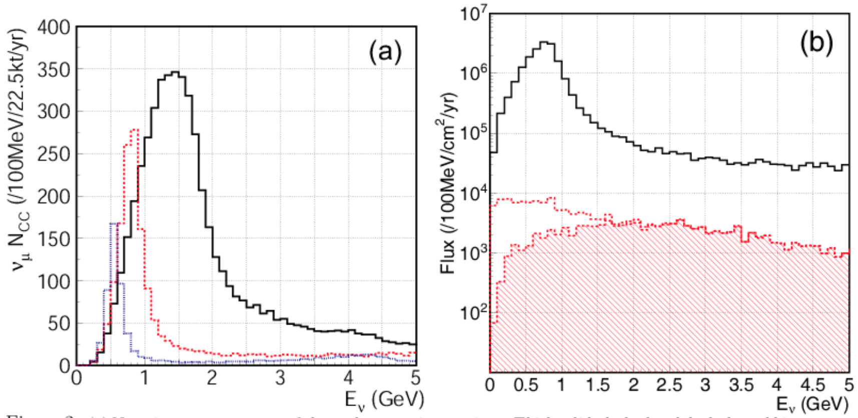
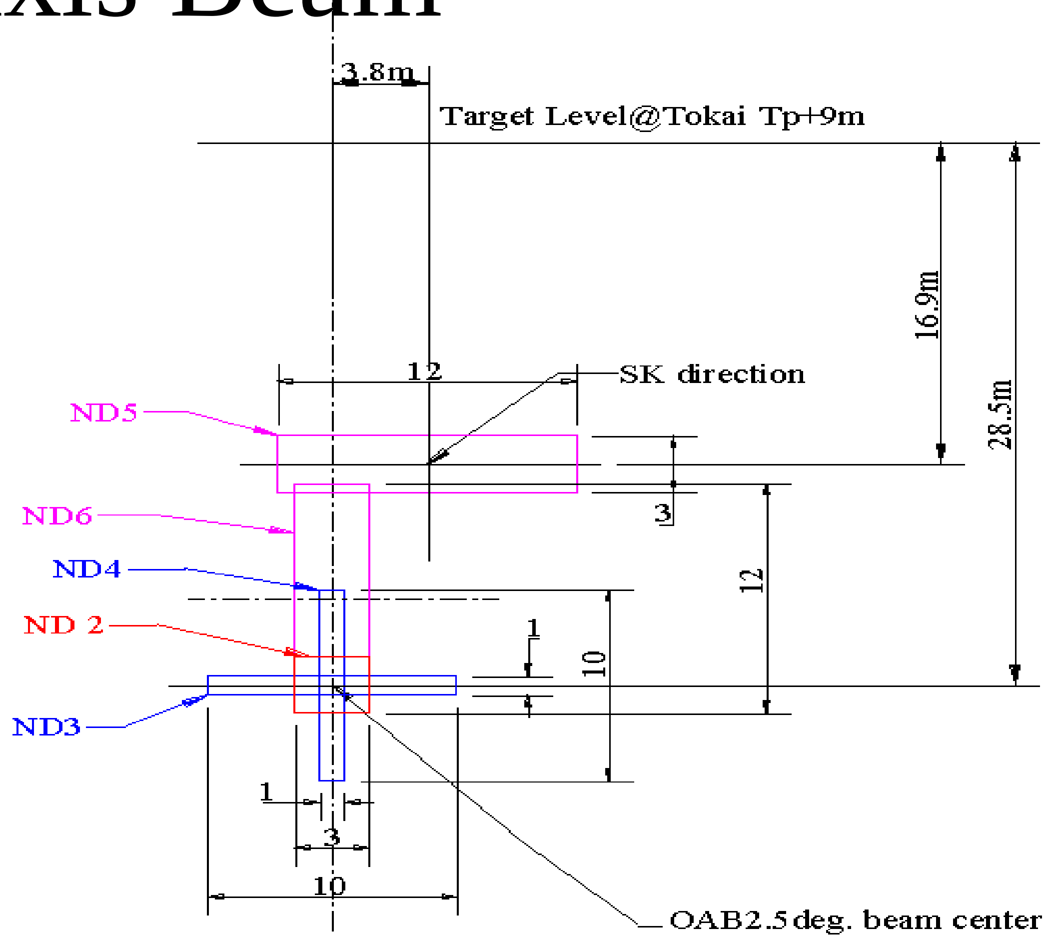


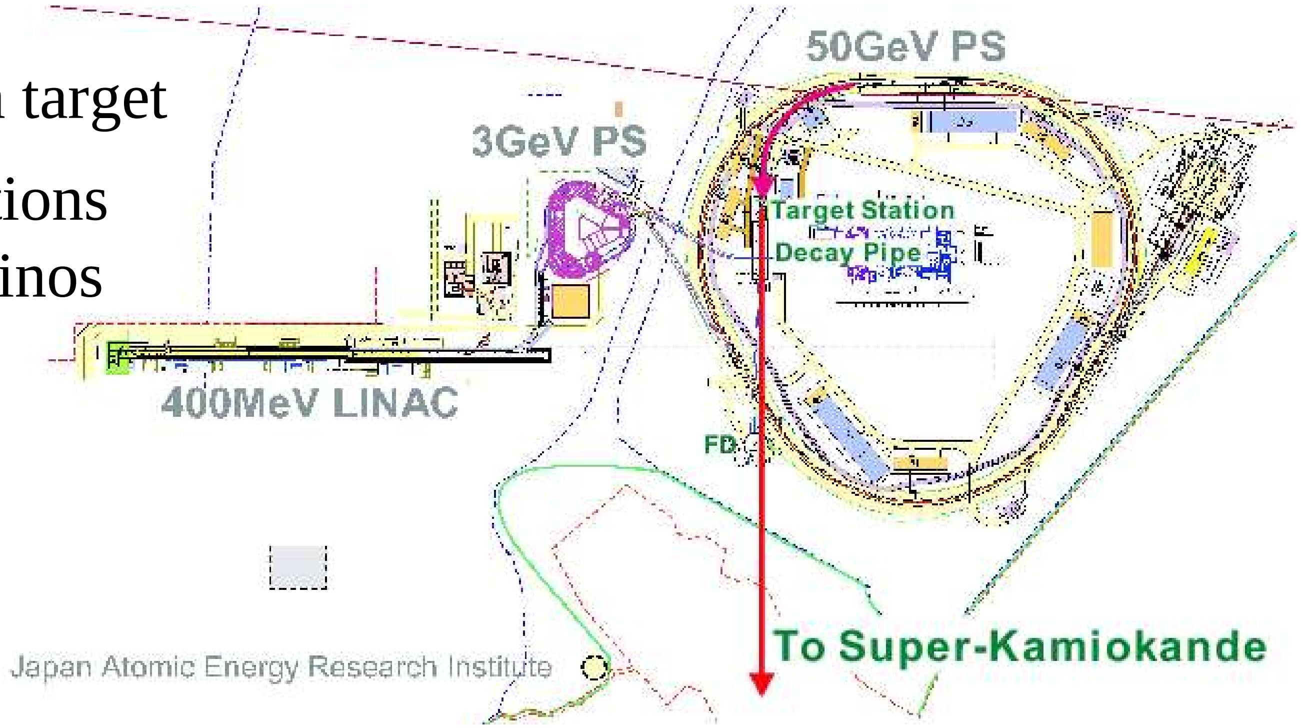
Figure 2: (a) Neutrino energy spectra of charged current interactions. Thick solid, dashed and dash-dotted histograms are OA1°, OA2° and OA3°, respectively. (b) Comparison of ν_e and ν_μ spectra OA2°. Solid (black) histogram is ν_μ and dashed (red) one is ν_e. Hatched area is contribution from K decay. The low energy ν_e component is due to μ decay.



Controlling Systematics: Near Detector

Location: 280m from target

Role: provide predictions of the expected neutrinos at the far detector



Fully-active fine-grained scintillator tracker

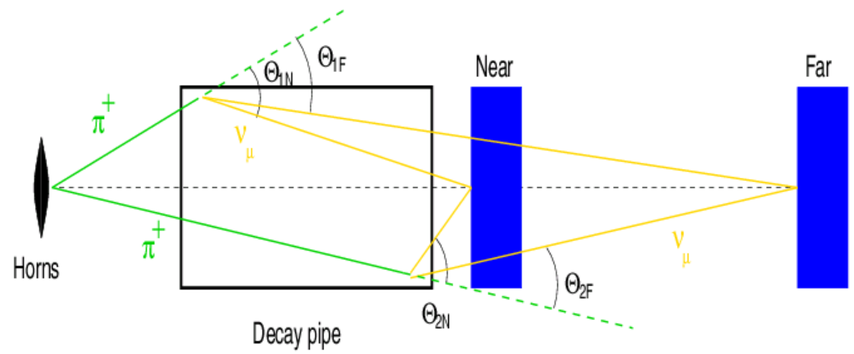
- Identifies CCQE, inelastic events and NC
- Sees neutrino spectrum

Controlling Systematics with Near Detector: Caveats

Ideally: All systematics cancel out using the measured spectra in the near detector.

In reality: not quite, the near detectors are different from the far detector in material, size (radiation length), and responses.

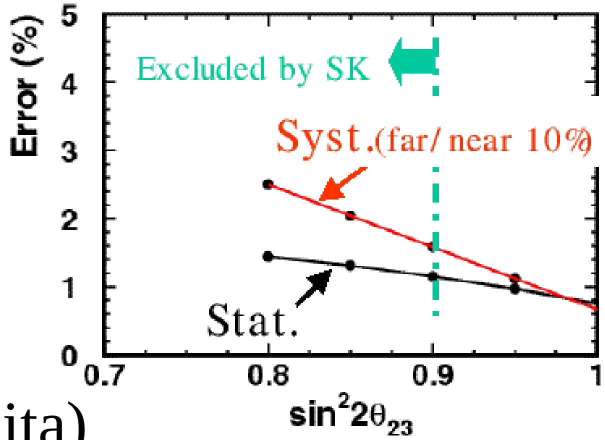
And the closer location to the decay pipe introduces a large and complicated far-to-near spectrum ratio
(neutrino source is point like for the far detector, but the length of the decay pipe is not negligible for the near detector)



Controlling Systematics with Near Detector: Caveats

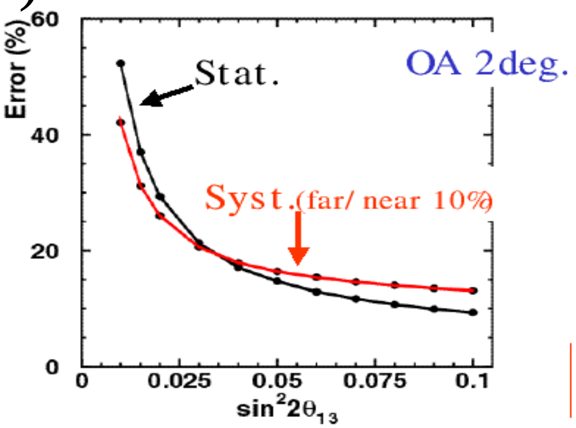
A ~ 10% far/near systematic uncertainty is problematic:

For $\sin^2 2\Theta_{23} < 1$, there is some concern that the effect is bigger than statistical uncertainties.

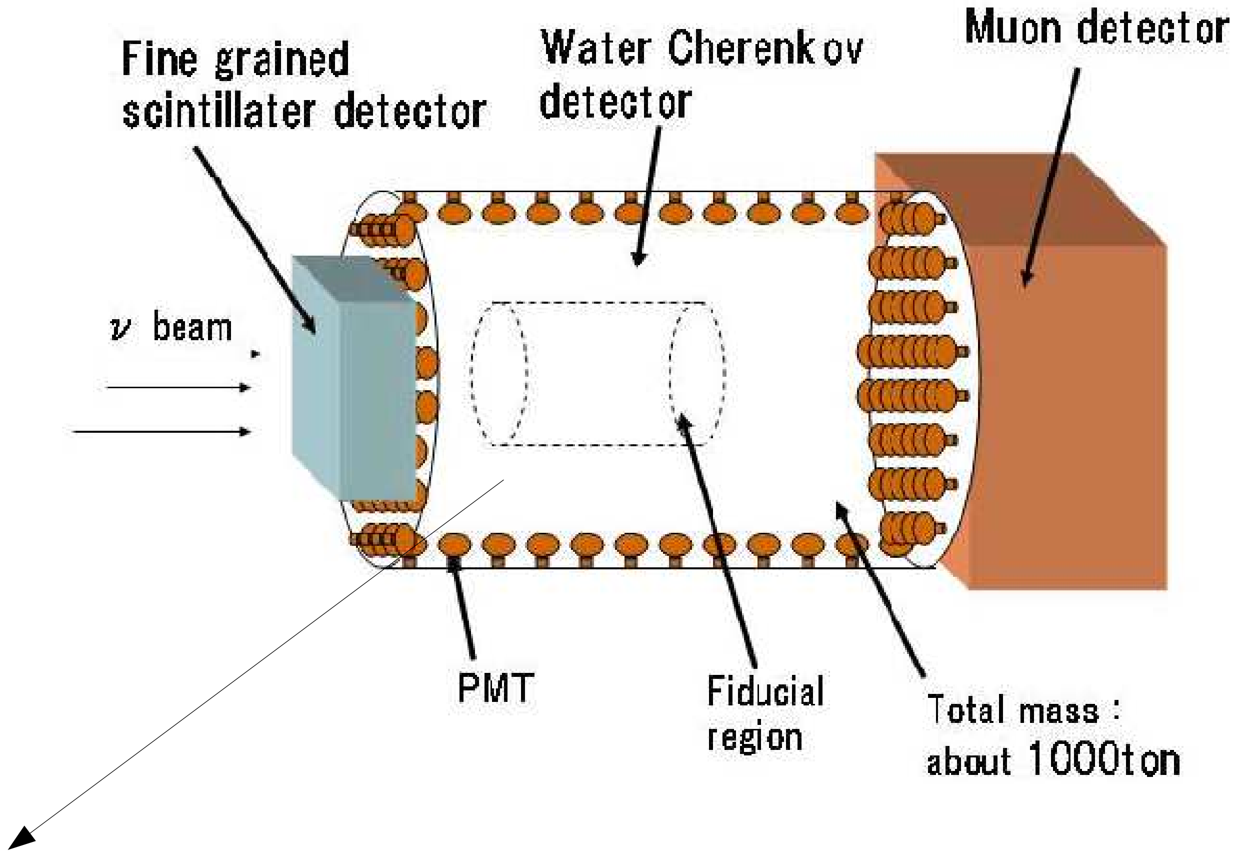


(T. Kajita)

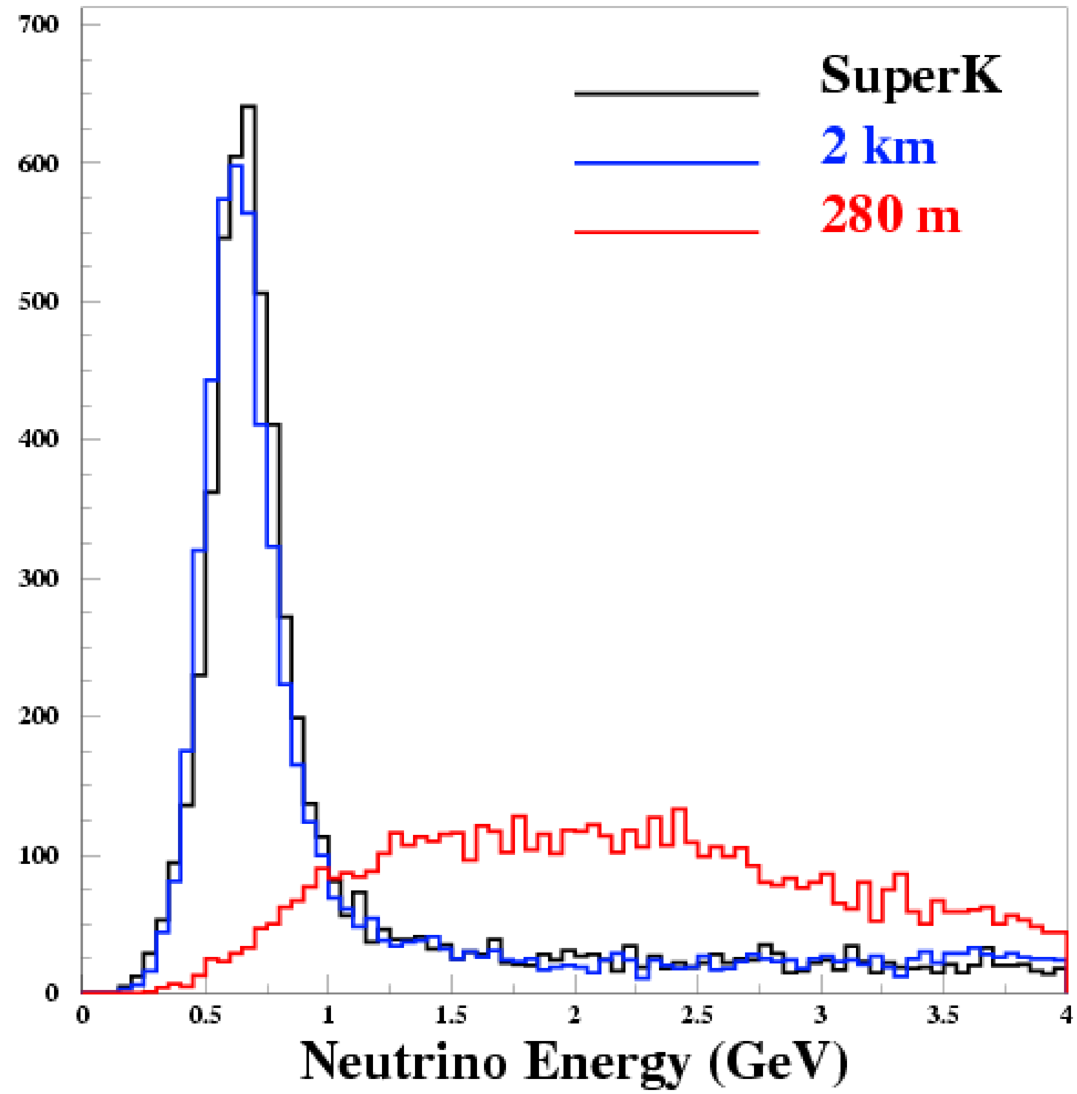
Also, for a Θ_{13} not at the limit of sensitivity the uncertainty in its measure increases significantly due to the systematics.



2km Intermediate Detector



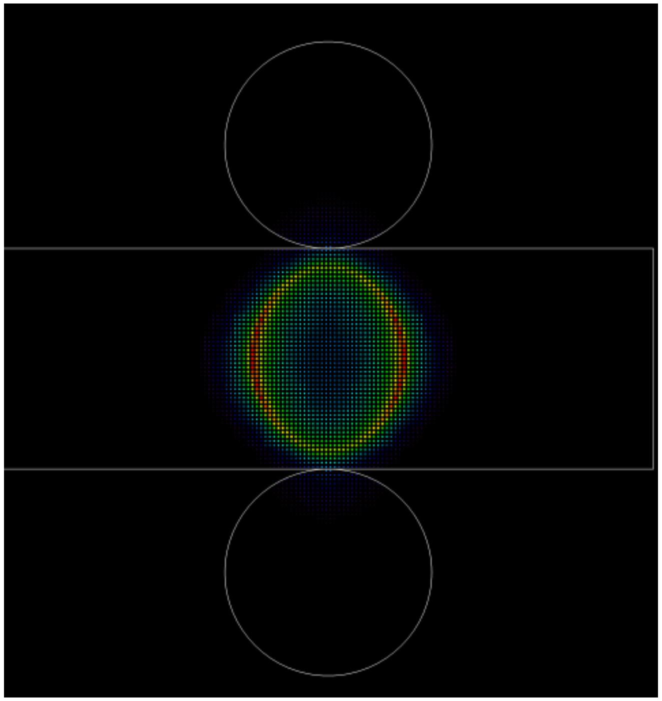
Same material, same cross-section



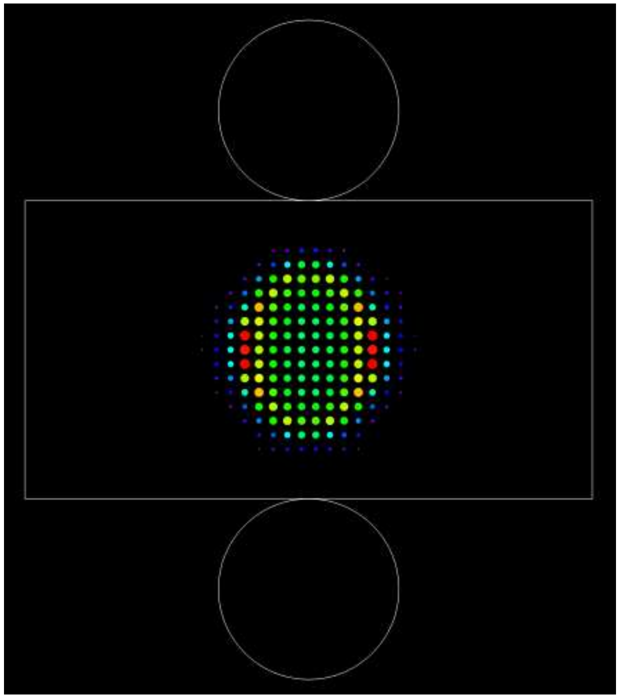
2km CC event spectrum similar to that at SK

2km Intermediate Detector

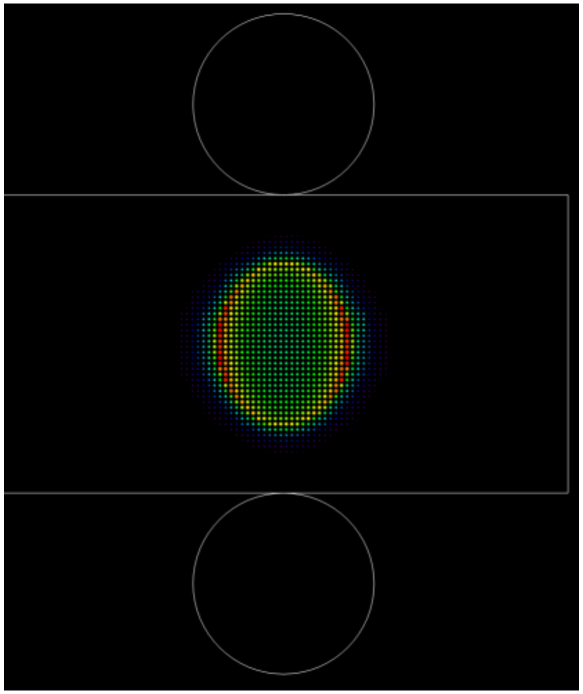
Electron simulation



Super-Kamiokande



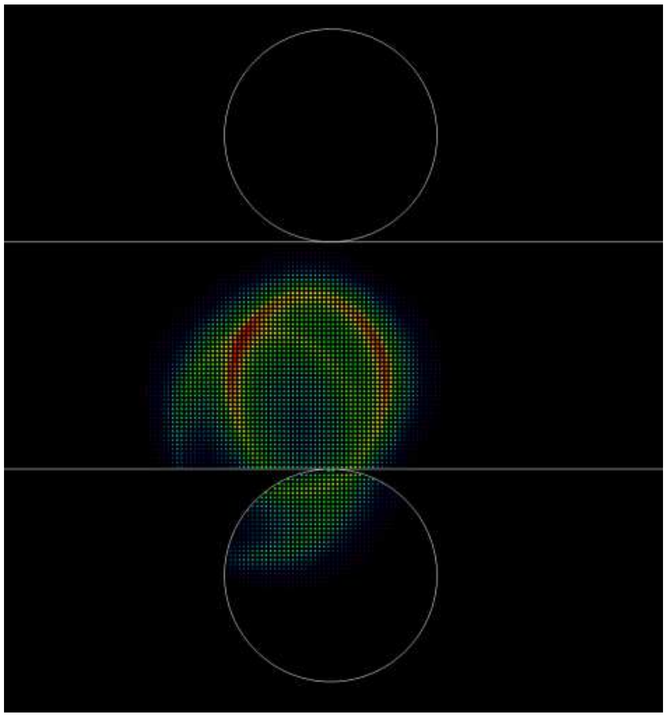
Intermediate detector
20 inches



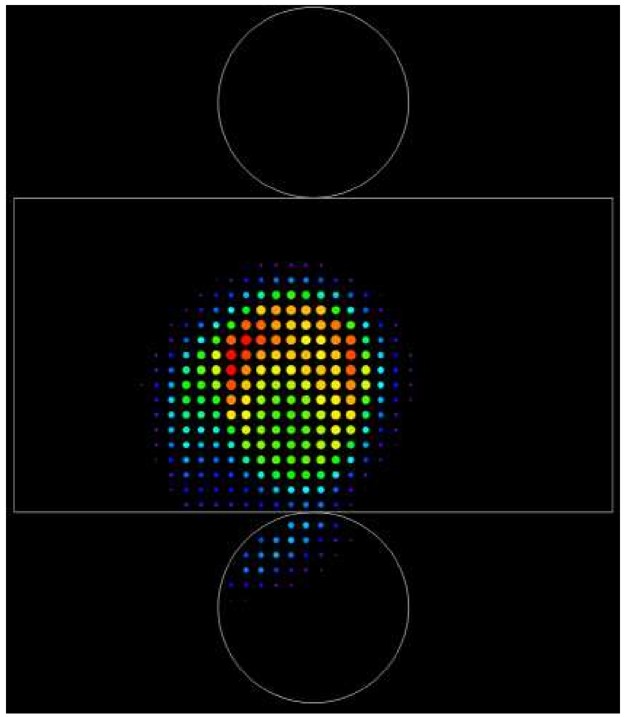
Intermediate Detector
8 inches

2km Intermediate Detector

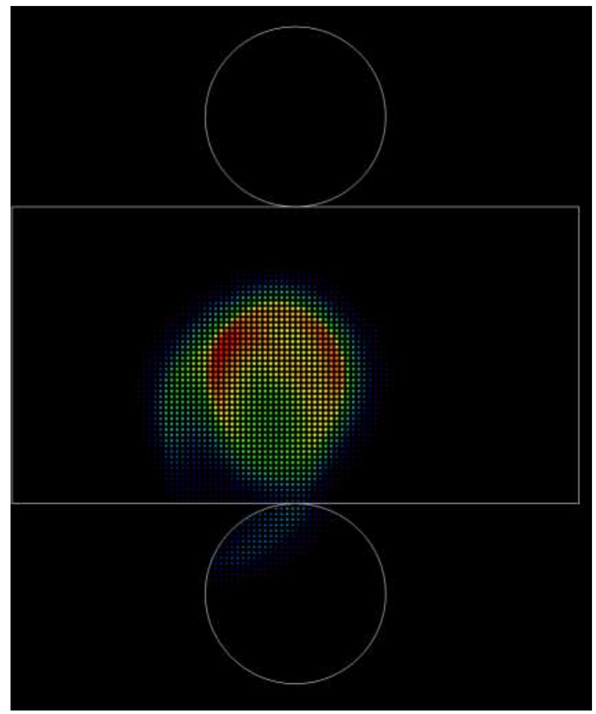
π^0 simulation



Super-Kamiokande



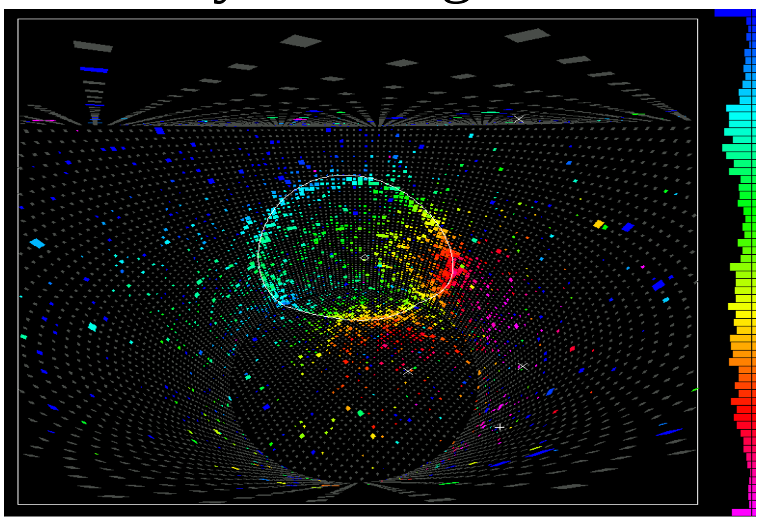
Intermediate detector
20 inches



Intermediate Detector
8 inches

Analysis

Sub-GeV fully-contained events with only one ring



JHF beam — JHF inverted beam

+ SK reconstruction

Reconstructed ν interactions (non oscillated)

Reconstructed ν interactions (totally oscillated)

+ oscillation parameters $(\vec{\alpha})$

+ systematics $(\vec{\epsilon})$

$$\frac{dN_\nu}{dE}(\vec{\alpha},\vec{\epsilon})$$

Real flux → $\frac{dN^r_\nu}{dE}$

$$\chi^2(\vec{\alpha}) = \sum \frac{(N^r_i - N_i(\vec{\alpha},\vec{\epsilon}))^2}{\sigma^2_{N_i}} + \sum \frac{\epsilon^2}{\sigma^2_\epsilon}$$

Systematics

Near-to-far Correlation Matrix

A. Para, M. Szleper (hep-ex/0110001)

$$\frac{dN^{\nu}_{near}}{dE_{near}} = \iiiint \underbrace{F_{\pi/K}(r_i,\theta,p)P_{\pi/K}(r_i,\theta,p,z)}_{\text{Independent on far/near}}\underbrace{W_{\pi/K}(z,r_{dec},\theta,p,z_{near},E_{near})}_{\text{Dependent on far/near}}\,dr_i\,d\theta\,dp\,dz \quad (3)$$

and

$$\frac{dN^{\nu}_{far}}{dE_{far}} = \iiiint F_{\pi/K}(r_i,\theta,p)P_{\pi/K}(r_i,\theta,p,z)W_{\pi/K}(z,r_{dec},\theta,p,z_{far},E_{far})\,dr_i\,d\theta\,dp\,dz \quad (4)$$

$$\frac{dN}{dE_f} = \frac{W(z,r_{dec},p,z_f,E_f)}{W(z,r_{dec},p,z_n,E_n)}$$

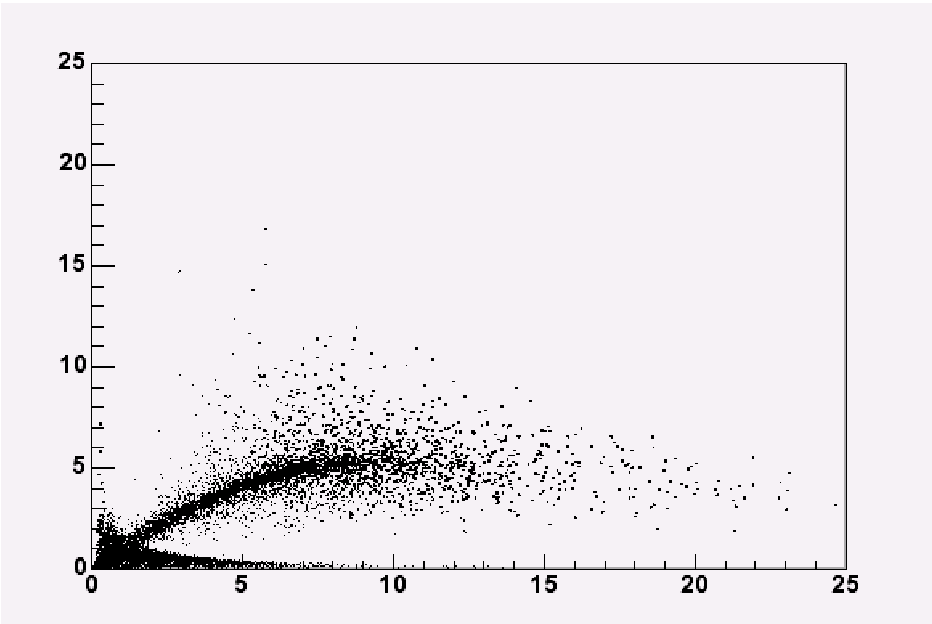
Far flux from the flux at near detector

$$(F_1,F_2,\cdots,F_n) = \begin{bmatrix} M_{11} & M_{12} & \ldots & M_{1n} \\ M_{21} & M_{22} & \ldots & M_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ M_{n1} & M_{n2} & \ldots & M_{nn} \end{bmatrix} \begin{bmatrix} N_1 \\ N_2 \\ \ldots \\ N_n \end{bmatrix}$$

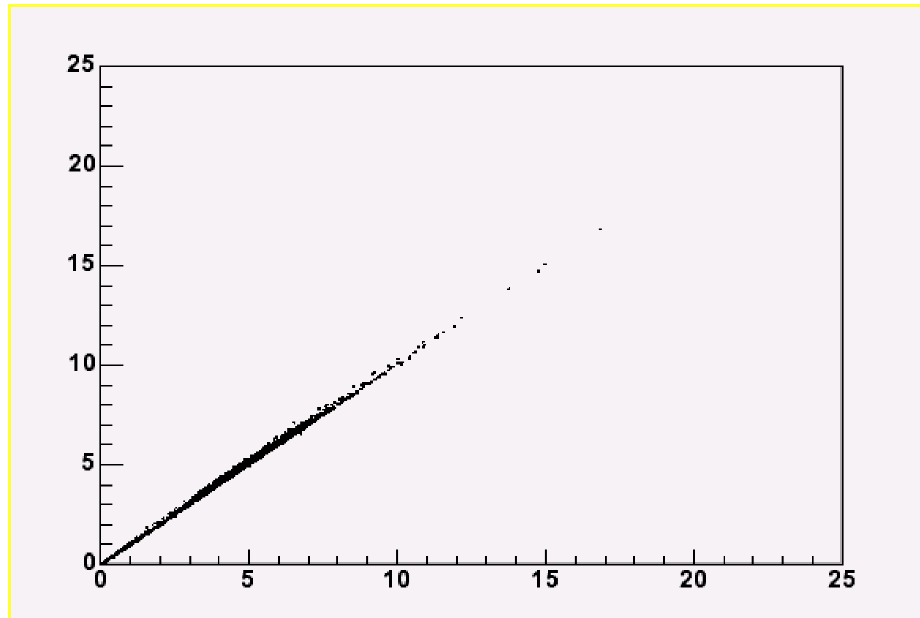
- Improvement over the "double ratio" method
- Used by K2K, MINOS

Near-to-far Correlation Matrix

Correlation matrix elements



Near detector to SK



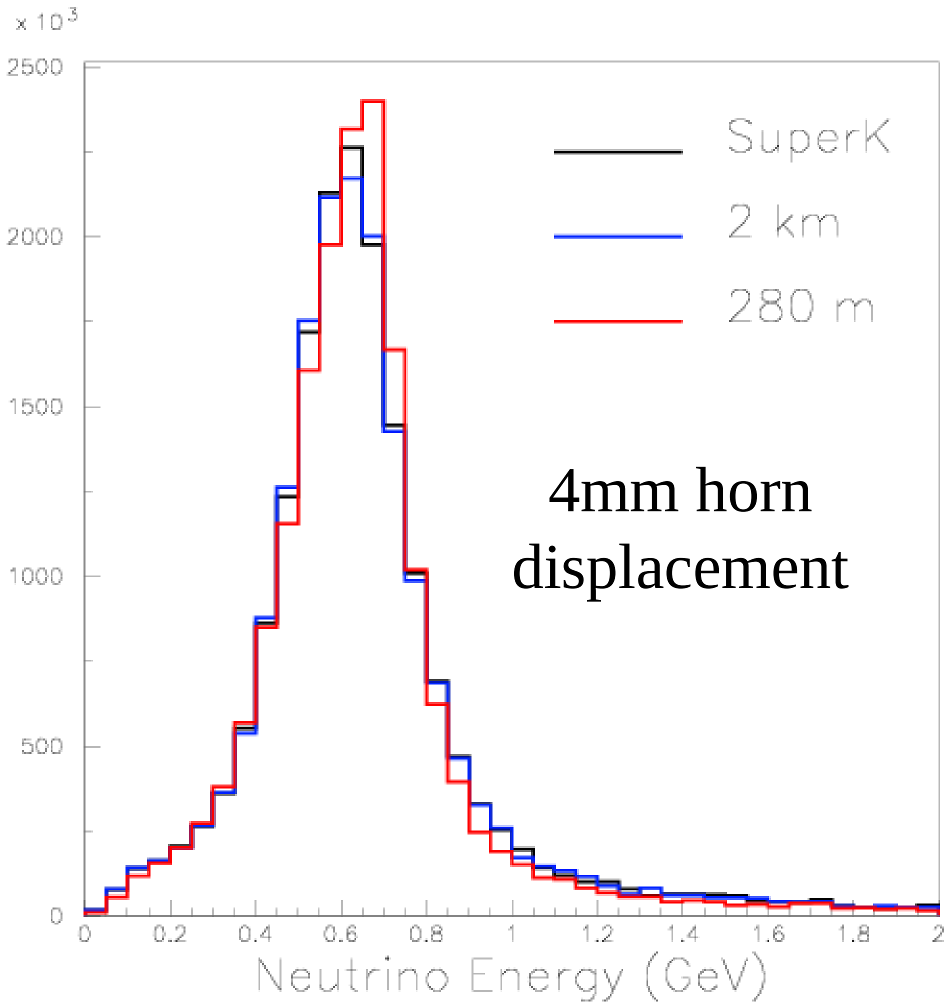
2km detector to SK

$$\chi^2(\vec{\alpha}) = \frac{\sum (N_i^r - N_i(\vec{\alpha}, \vec{\epsilon}))^2}{\sigma_i^2}$$

$$N_i \rightarrow M_{ij}^{near} N_j^{near}$$

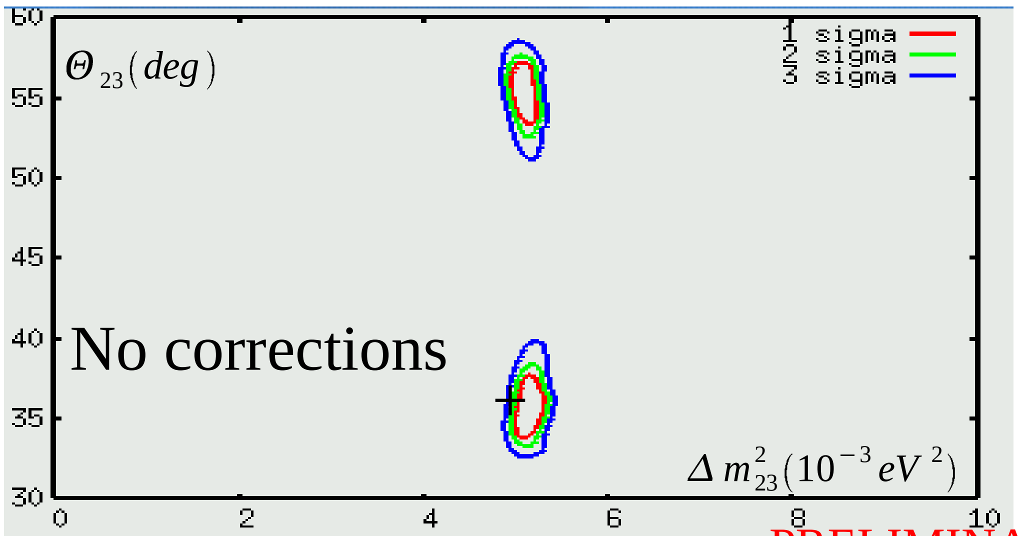
$$N_i \rightarrow M_{ij}^{2km} N_j^{2km}$$

Near-to-far correction

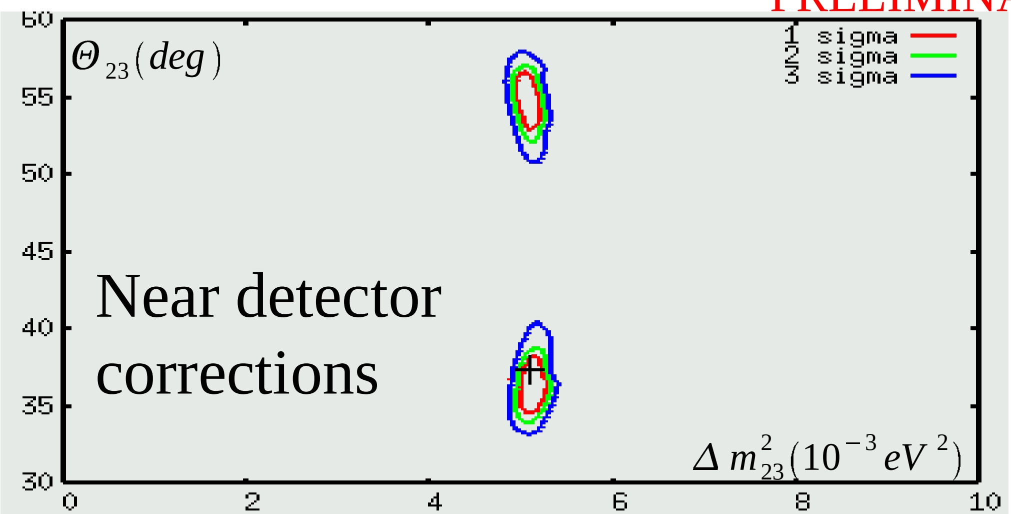


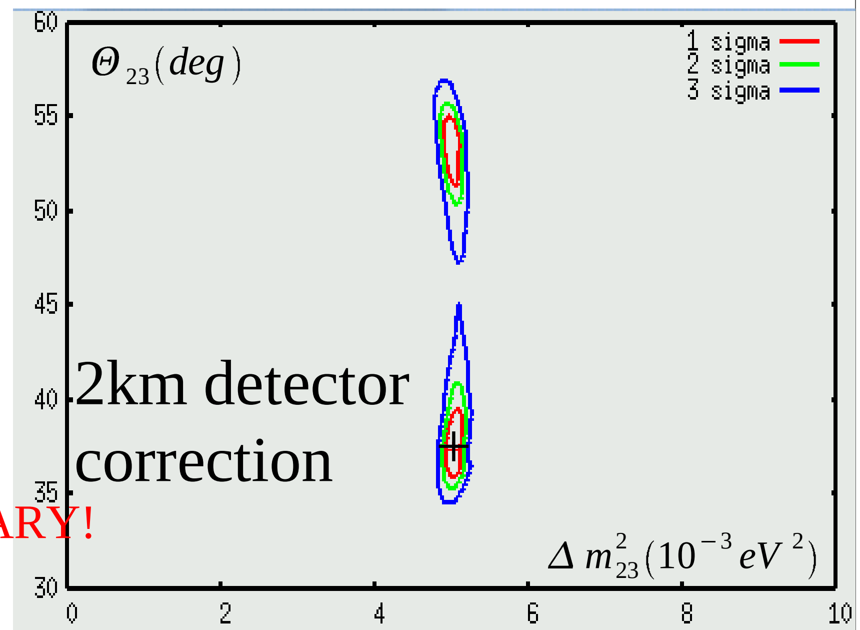
The 2km detector prediction is much closer to the true spectrum

A typical reconstruction



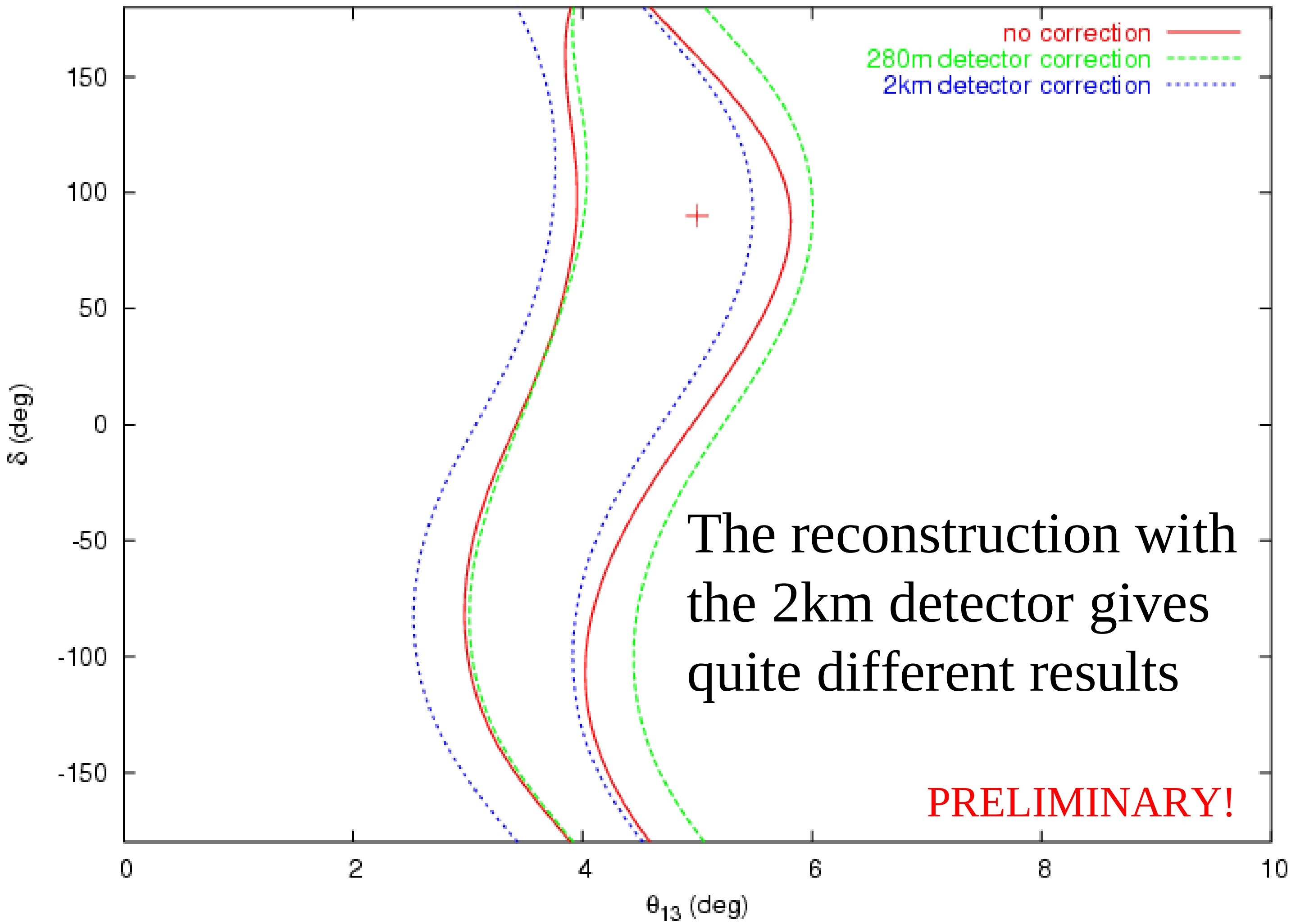
PRELIMINARY!





There is a bias not corrected by the 280m detector

Some other comparisons



The reconstruction with the 2km detector gives quite different results

Systematic Uncertainties

- Beam
  - Details in beam modelization
  - Distribution of pions in the decay volume
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- Detector
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Conclusions

- The beam extrapolation and background measurement are essential to the sensitivity of JHFnu.
- The 2km detector will dramatically simplify the systematic error analysis for both the appearance and disappearance experiments.
- More thorough studies are needed (and in progress).