Upper bound on neutrino mass with T2K

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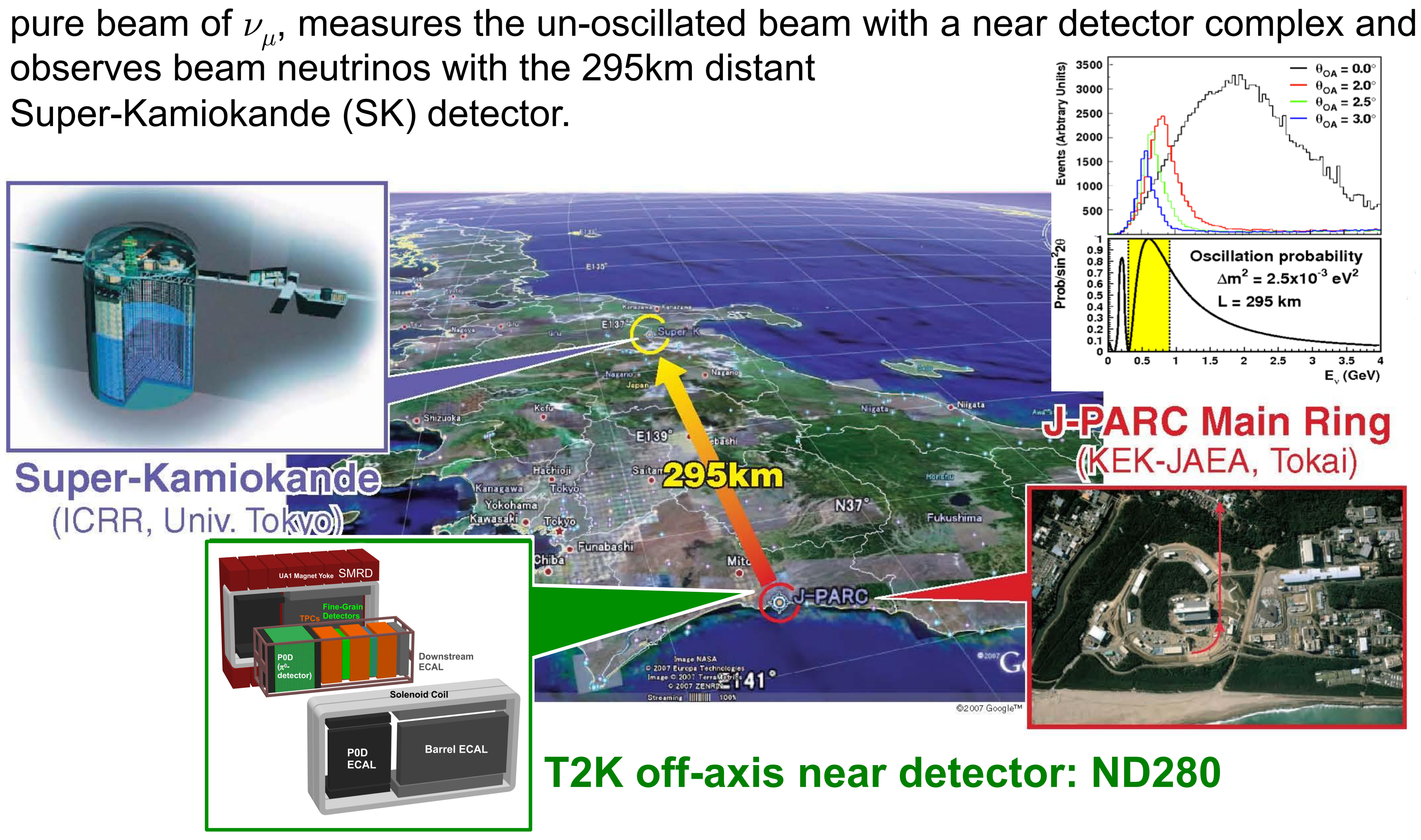
Introduction

The Tokai to Kamioka (T2K) long-baseline neutrino experiment measures different modes of neutrino oscillations, neutrino cross sections and pursues a variety of other physics measurements. It employs the J-PARC proton beam to produce a nearly pure beam of ν_μ, measures the un-oscillated beam with a near detector complex and observes beam neutrinos with the 295km distant Super-Kamiokande (SK) detector.



A timing system which is based on GPS units and Rb clocks is located at the near and far sites. It provides event times and thereby associates events with one of the 8 bunches per beam spill. Based on event times we study the relative neutrino time of flight (TOF) for neutrino candidate events as function of neutrino energy. Assuming special relativity, the 0.6 GeV T2K neutrino beam provides sensitivity to neutrino masses of order of a few MeV/c^2.

Method and Data Selection

- Perform one parameter fit (m_ν^2) in likelihood analysis

Measured times — τ : light travel time — Fit parameter

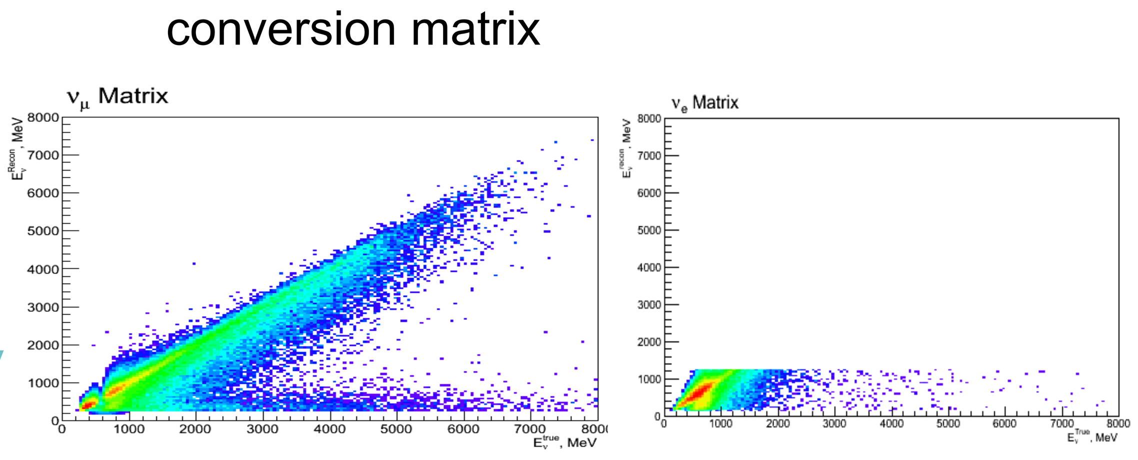
$$L = \sum_i -\ln P_2\left(t_2^i - T_{m_\nu}(E_\nu)\right) \qquad T_{m_\nu}(E_\nu) = \frac{\tau}{\sqrt{1-\left(\frac{m_\nu}{E_\nu}\right)^2}}$$

Far detector PDF based on timing resolution from SMRD, GPS system and far detector

Energy dependence
→CCQE candidate events at SK
→Convert E_{recon} into E_ν by sampling from conversion matrix

$$\overline{\left(t_2^i - T_{m_\nu}(E_\nu)\right)} \approx \overline{\left(t_2^i - \tau\right)} = 0$$

Time residual normalization for E_ν >2 GeV



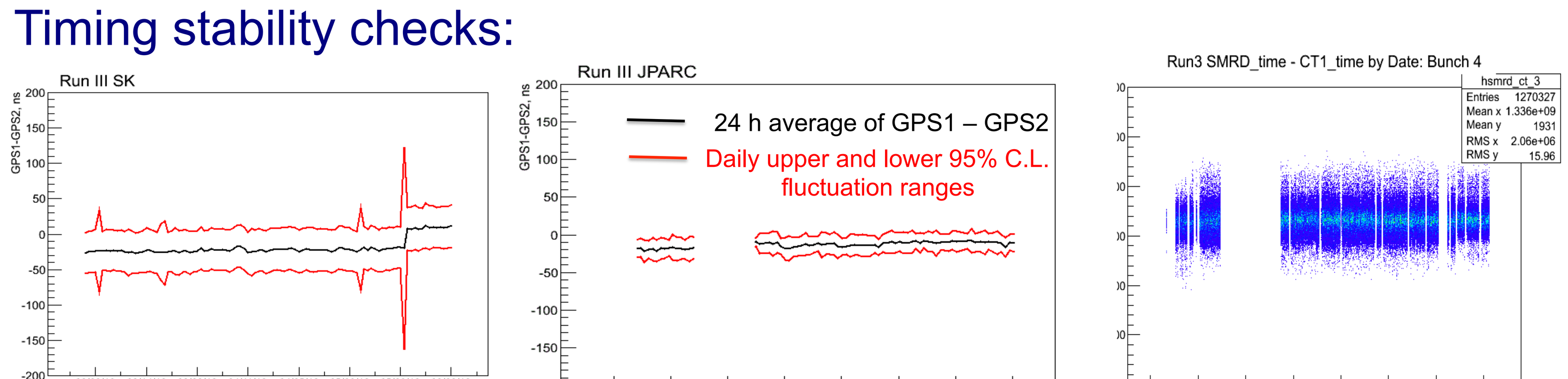
- Use SK sideband data sample to determine resolutions to construct far detector PDF $P_2(t_2)$ and near detector event sample to derive PDF $P_1(t)$

$$P_2^n(t_2) = \int \frac{1}{\sigma_{SK+GPS}\sqrt{2\pi}} e^{-\frac{(t_2-t)^2}{2\sigma^2_{SK+GPS}}} P_1^n(t)\,dt \qquad (n = 6,8 \text{ bunches})$$

$P_1(t)$: Gaussian with σ derived from SMRD data

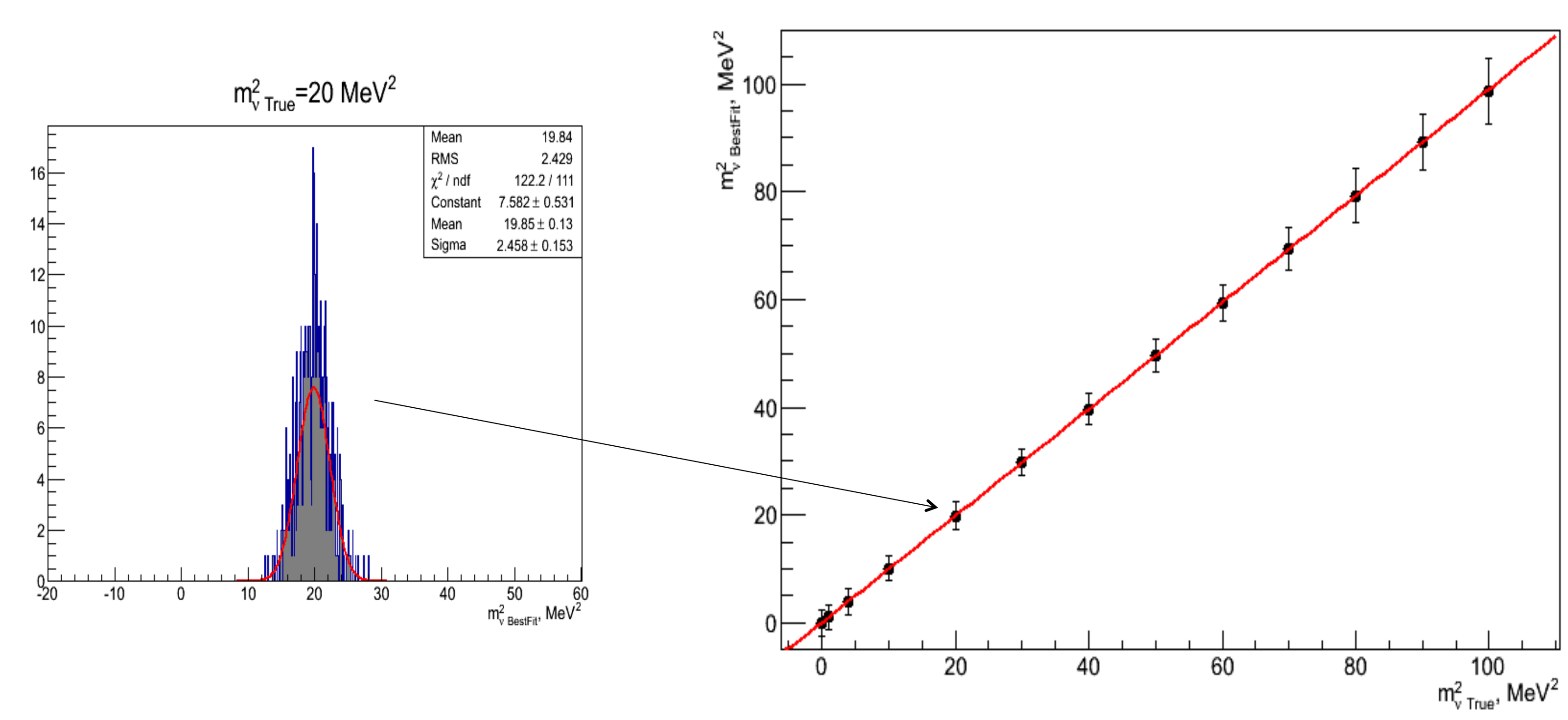
Run period number	RMS of SK $FC_{sideband}$ event timing residuals [ns]	SMRD hit timing resolution $\sigma_{smrd+bunch}$ [ns]
I	19.4 ± 4.3	12.1 ± 0.1
II	21.4 ± 5.2	13.7 ± 1.2
III	22.9 ± 5.9	14.5 ± 0.3
IV	26.0 ± 3.6	13.8 ± 0.8

- Timing stability checks:



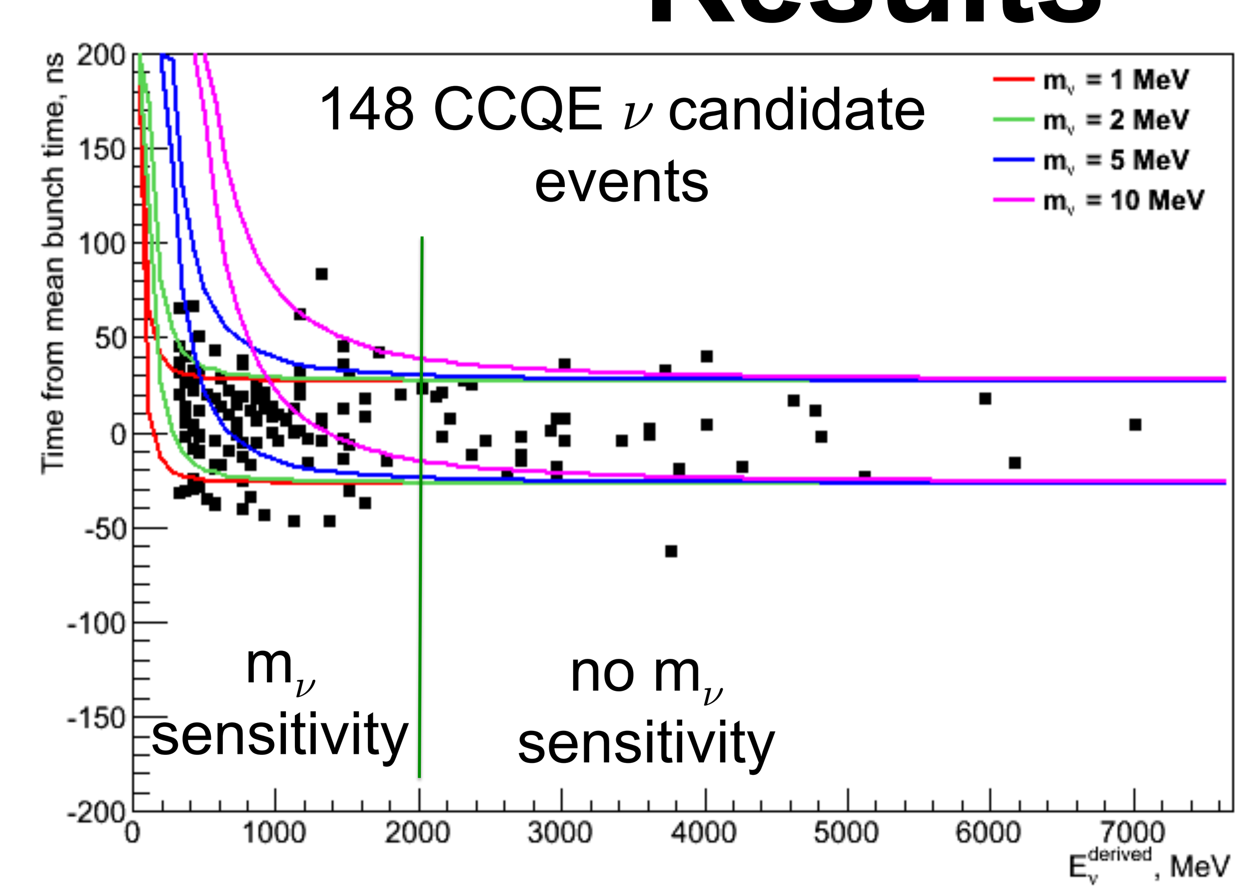
Analysis Performance

Generate ensembles of *toy data sets* based on different values of $m^2_{\nu\text{-true}}$ and run analysis to extract a best-fit value for m_ν^2.

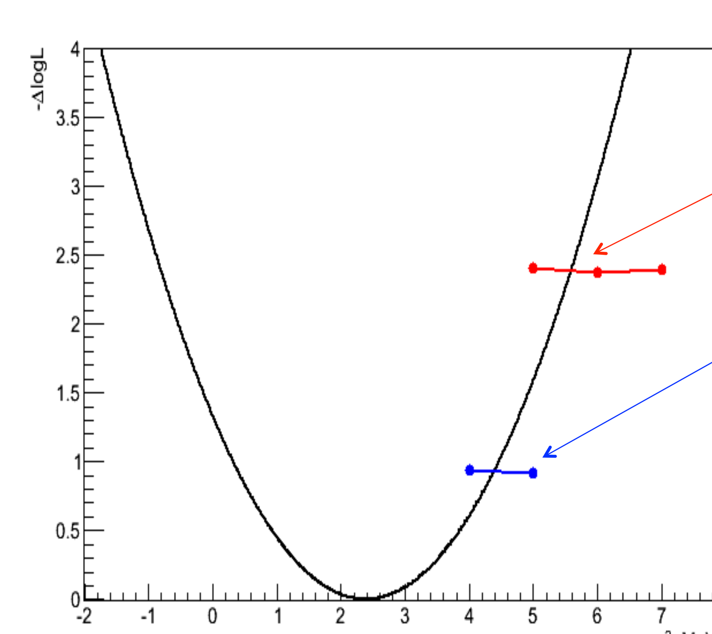


→ Successfully extract best fit value m^2_ν for wide range of $m^2_{\nu\text{-true}}$ values.

Results



± (combined time resolution and systematic uncertainties)



FC 90% C.L. critical values with total and without systematics

Effects of systematic uncertainties

Systematic	90% CL absolute [MeV^2/c^4]	% change
Time normalization	5.09	+15.9
Lepton momentum + angular bias	4.4	+0.2
SK + GPS time resolution uncertainty	4.75	+8.2
SMRD time resolution uncertainty	4.41	+0.5
Total	**5.58**	**+27.1**

without systematics :
m_ν^2 < 4.4 MeV^2/c^4 (90% C.L.)

with systematics :
m_ν^2 < 5.6 MeV^2/c^4 (90% C.L.)

Conclusion

We set a 90% C.L. upper limit on the neutrino mass square of m_ν^2 < 5.6 MeV^2/c^4. This value may be compared to the MINOS result of a 99% C.L. upper limit on neutrino mass based on a neutrino TOF analysis of m_ν < 50 MeV/c^2 [1]. The PDG lists a limit of 0.19 MeV/c^2 for ν_μ based measurements [2] in pion decay.

Bibliography

1. P. Adamson et al., Phys. Rev. D **76**, 072005 (2007)
2. J. Beringer et al. (PDG), Phys. Rev. D **86**, 010001 (2012)