Atmospheric neutrino flux measurement by Super-Kamiokande
Kimihito OKUMURA and Euan RICHARD (ICRR, Univ. of Tokyo) for Super-Kamiokande collaboration
Institute for Cosmic Ray Research (ICRR), Univ. of Tokyo
okumura@icrr.u-tokyo.ac.jp, richard@icrr.u-tokyo.ac.jp

Abstract
Directional-integrated fluxes of atmospheric electron and muon neutrinos are measured in the energy range from sub-GeV to several TeV using Super-Kamiokande detector. Super-Kamiokande is the largest detector in the world which has sensitivity in this energy range, and excellent capabilities to distinguish $\nu_e$ and $\nu_\mu$ by particle identification of out-going leptons. The energy spectrum is reconstructed using unfolding technique with the estimation of the systematic uncertainties, and compared with the existing flux calculation models.

Motivation
- Quantify neutrino flux with current understanding uncertainties and compare existing flux model.
- Give constraint on flux uncertainties due to kaon production.
- Scientific requirements in astroparticle physics (ex. HE astronomical $\nu$).

Event sample
- Three sample (fully-contained, partially-contained, upward-going muons) are utilized.
- FC and UPMU are separated into electron-like and muon-like by particle identification algorithm.
- FC and UPMU are categorized by $\nu_e$ sample, but $\nu_\mu$ flux by UPMU are separately calculated due to different acceptance of solid angle.
- Eliminate neutral current enriched sub-sample to enhance flux sensitivity.

<table>
<thead>
<tr>
<th>$\nu_e$ flux</th>
<th>$\nu_\mu$ flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully-contained (FC) electron-like</td>
<td>Fully-contained (FC) muon-like</td>
</tr>
<tr>
<td>Partially-contained (PC)</td>
<td>Upward-going muon (UPMU)</td>
</tr>
<tr>
<td>0.15 – 100 GeV</td>
<td>0.25 GeV – 1 TeV</td>
</tr>
<tr>
<td>1 GeV – 1 TeV</td>
<td>4 $\pi$</td>
</tr>
<tr>
<td>4 $\pi$</td>
<td></td>
</tr>
</tbody>
</table>

Flux reconstruction
Bayes unfolding:
We adopt near-side Bayes unfolding [5] (implemented in RooUnfold) to convert from observable to neutrino energy spectrum.

Response function:
and provide for each Super-K period (SK-I-4) respectively.

Bias check:
Reproducibility of energy spectrum is checked by bias study using Monte-Carlo samples.

Conclusions and discussions
- Atmospheric neutrino flux is measured from sub-GeV to 10 TeV for $\nu_e$ and $\nu_\mu$, respectively, by Super-Kamiokande. Bayes unfolding method is utilized and energy spectrum reproducibility is checked by bias check. Statistical and systematic uncertainties are estimated by toy calculation, and about 20% uncertainties are derived. Calculated fluxes agree with existing flux models within systematic uncertainties.
- As shown in Figure 2, measurement of wider energy range with km$^3$ size detector would lead better understanding of atmospheric neutrino spectrum, and also could constraint uncertainty due to kaon production by combined analysis.

Reference