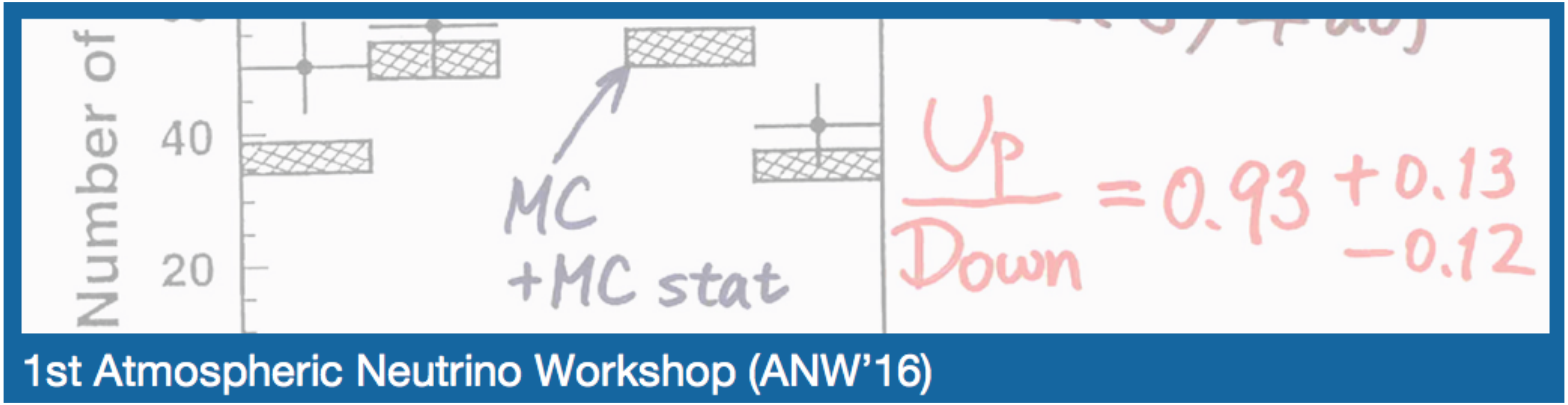
A report from the 1st Atmospheric Neutrino Workshop ANW'16 Munich, Feb. 7-9, 2016



Alessandra Tonazzo

Atmospherics/NDK WG meeting, January 15th, 2016

ANW’16

http://indico.universe-cluster.de/indico/conferenceDisplay.py?ovw=True&confId=3533

36 participants: experiment + theory, neutrino physics + nuclear physics
Nice atmosphere, lively discussion

ANW'16 Programme

Sunday 07 February 2016

Atmospheric neutrinos fluxes: physics, models and calculations

- 14:15 HKKM atmospheric neutrino fluxes HONDA, M.
- 15:00 Bartol atmospheric neutrino fluxes BARR, G.

Atmospheric Neutrinos Flux, uncertainties in sensitivity studies

- 16:30 CORSIKA conventional atmospheric neutrinos FEDYNITCH, A.
- 17:15 Impact of uncertainties in sensitivity studies of future experiments HUBER, P.

Monday 08 February 2016

Neutrino interactions in the energy region 1- 100 GeV

- 09:00 Atmospheric neutrino measurement and neutrino interaction physics HAYATO, Y.
- 09:45 Neutrino interaction physics overview KATORI, T.
- 11:00 Neutrino Interactions with Nucleons and Nuclei MOSEL, U.
- 11:45 QE, nucleon correlations BENHAR, Omar

Atmospheric Neutrinos Prompt Component

- 16:15 Prompt atmospheric leptons FEDYNITC, A.
- 16:45 Theoretical uncertainties on prompt neutrino fluxes GARZELLI, M.V.
- 17:10 Extreme calculation of the prompt neutrino flux WILLE, L.
- 17:35 The prompt atmospheric neutrino flux in the light of LHCb TALBERT, J.

ANW'16 Programme

Monday 08 February 2016

Atmospheric Neutrino Experimental Results and Prospectives:

- 13:30 Hyper-Kamiokande (and atmospheric neutrino studies with it) KAJITA, T.
- 14:15 Atmospheric Neutrino Flux at Super-Kamiokande OKUMURA, K.
- 15:00 Atmospheric Neutrino Studies in IceCube/DeepCore YANEZ, J.P.

Tuesday 09 February 2016

Atmospheric Neutrinos Future Experiments

- 09:00 Sensitivity studies to atmospheric neutrinos with ORCA - BRUNNER, J.
- 09:30 Sensitivity studies to atmospheric neutrinos with PINGU - BOESER, S.
- 10:00 Atmospheric neutrino studies in DUNE - TONAZZO, A.

Summary & Conclusion: open discussion (11:00-12:30)

- Conveners: Lipari, Paolo

I will not give a "summary"… look at the slides
I will not report on talks note relevant for DUNE (e.g., very high E)
I will not show SK results: see talk by K.Okumura at WG meeting on Dec.21st

HKKM fluxes

HKKM Calculation of Atmospheric Neutrino Flux.
M. Honda @ ANW'16

1. Full 3D calculation with inclusive interaction code.
   => Very fast (a few 100 times of original code)
   => Easy to modify the secondary spectra.

2. Muon calibration of the inclusive interaction code.

3. Use relatively large virtual detector
   with virtual detector correction.

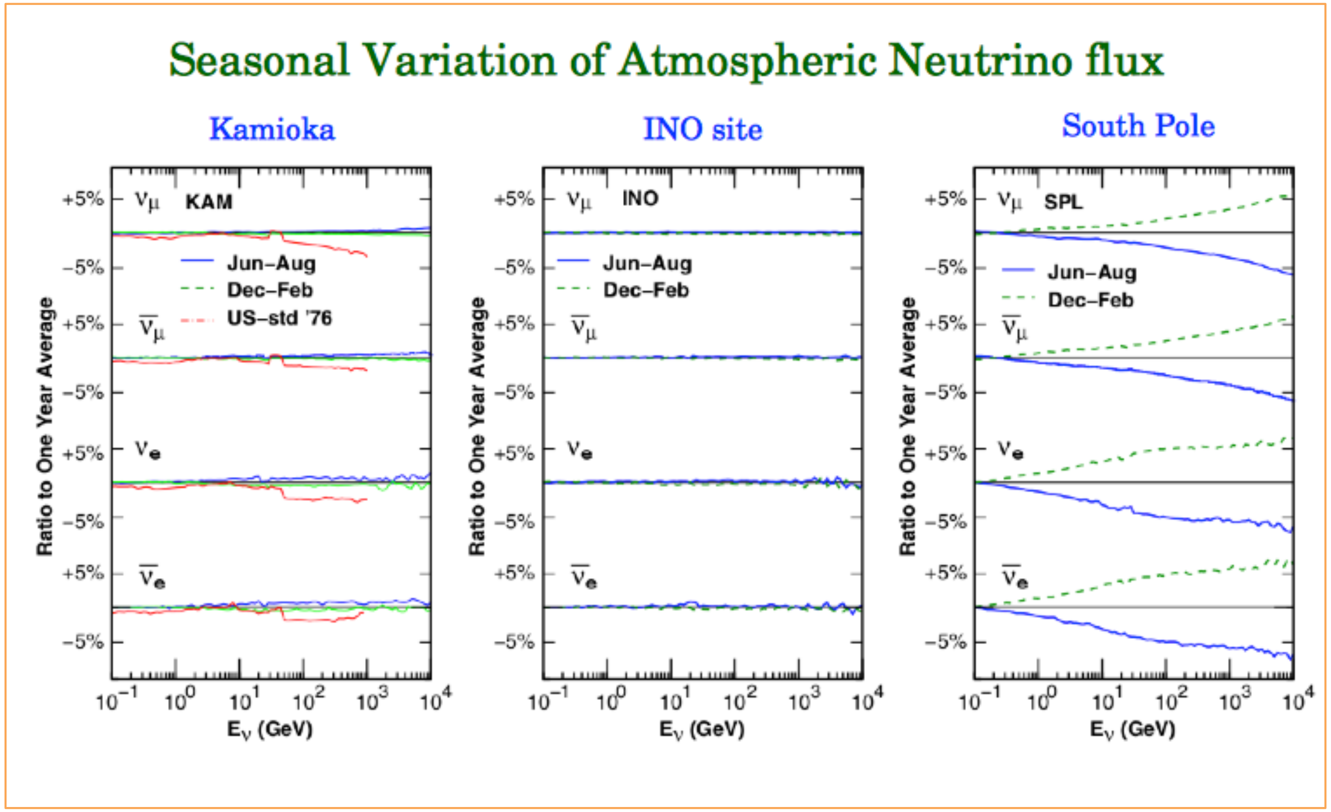
4. Realistic geomagnetic field and air profile.
   IGRF and NRLMSISE-00.

5. New Cosmic Ray Spectra Model (preliminary).

HKKM fluxes

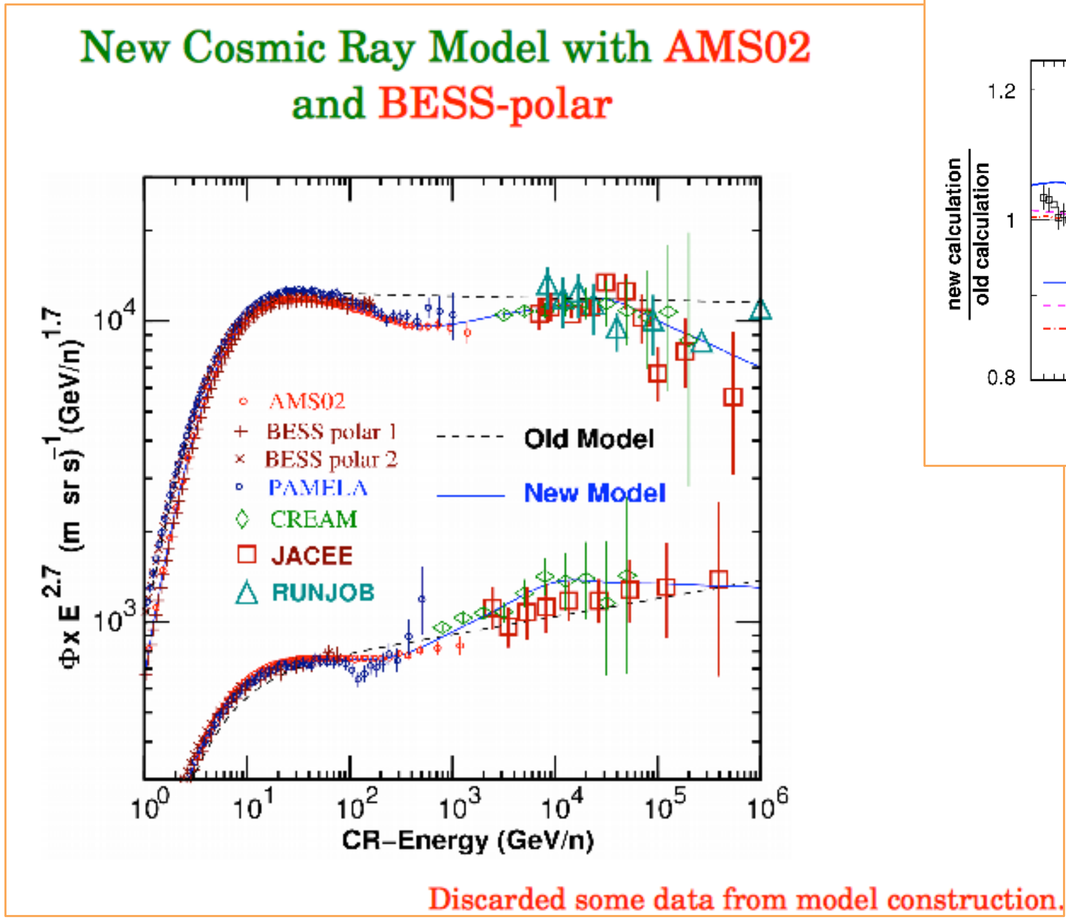
2. Muon calibration => modification of DPMJET-III => better agreement with accelerator data (NA49, HARP)

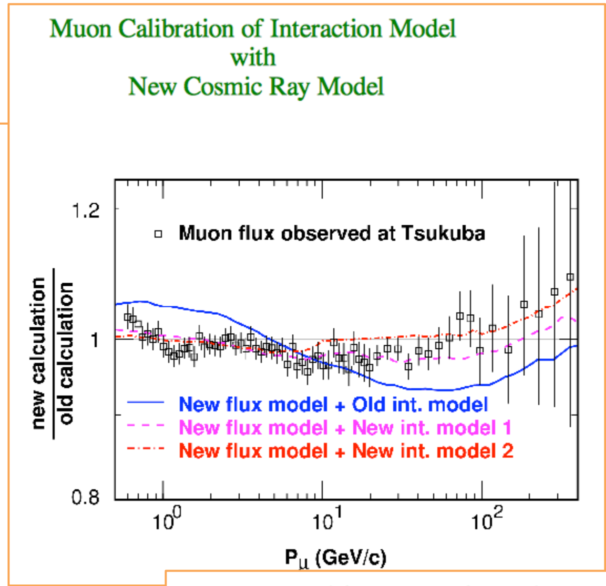
4. NRLMSISE-00 Atmosphere Model => large seasonal variation at South Pole (also on ratios)

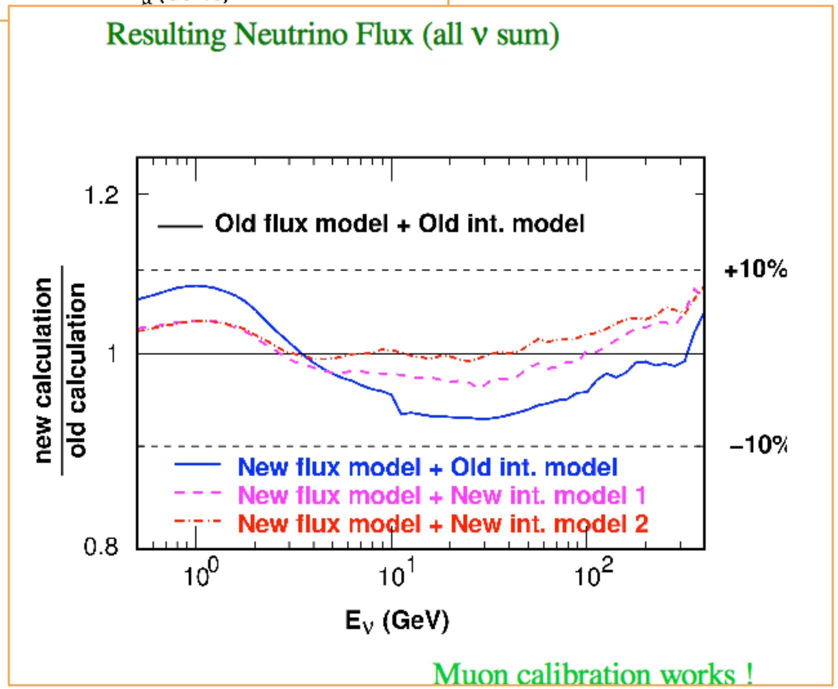


HKKM fluxes

5. New Primary spectra: impact of AMS-02 and BESS-Polar

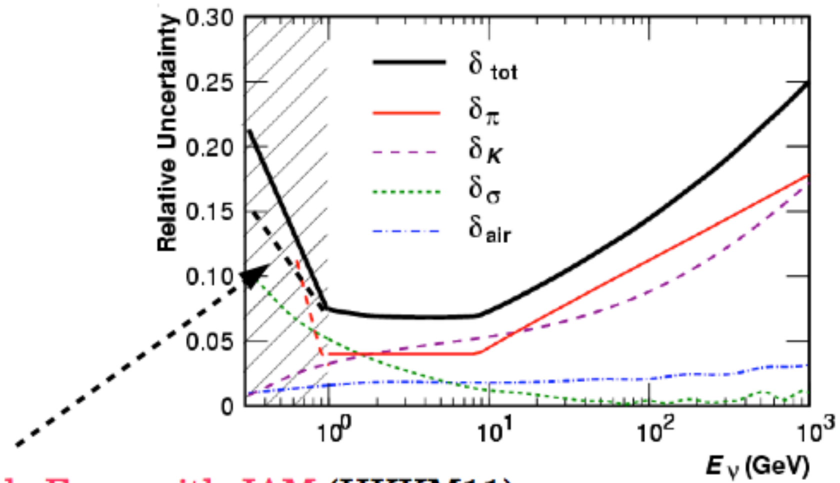






HKKM fluxes

Estimated Error in Atmospheric ν-flux Calculation (HKKMS07)



Possible Error with JAM (HKKM11)

δ_π μ -observation error + Residual of reconstruction

δ_K Kaon production uncertainty

δ_σ Mean free path (interaction crossection) uncertainty

δ_{air} Atmosphere density profule uncertainty

SK is now observing predicted features of neutrino fluxes: Solar Modulation, Azimuth variation, Energy Spectra (talk by K.Okumura, also at DUNE Atmos.WG on Dec.21st)

Calculation for Homestake (no mountain) available: see talk by John LoSecco later

Bartol fluxes

Overview

Section 1: Bartol atmospheric neutrino fluxes

- Introduction
- Components of calculation technique
  - Propagation through atmosphere…
  - Back tracing primaries to get cutoffs
- Results

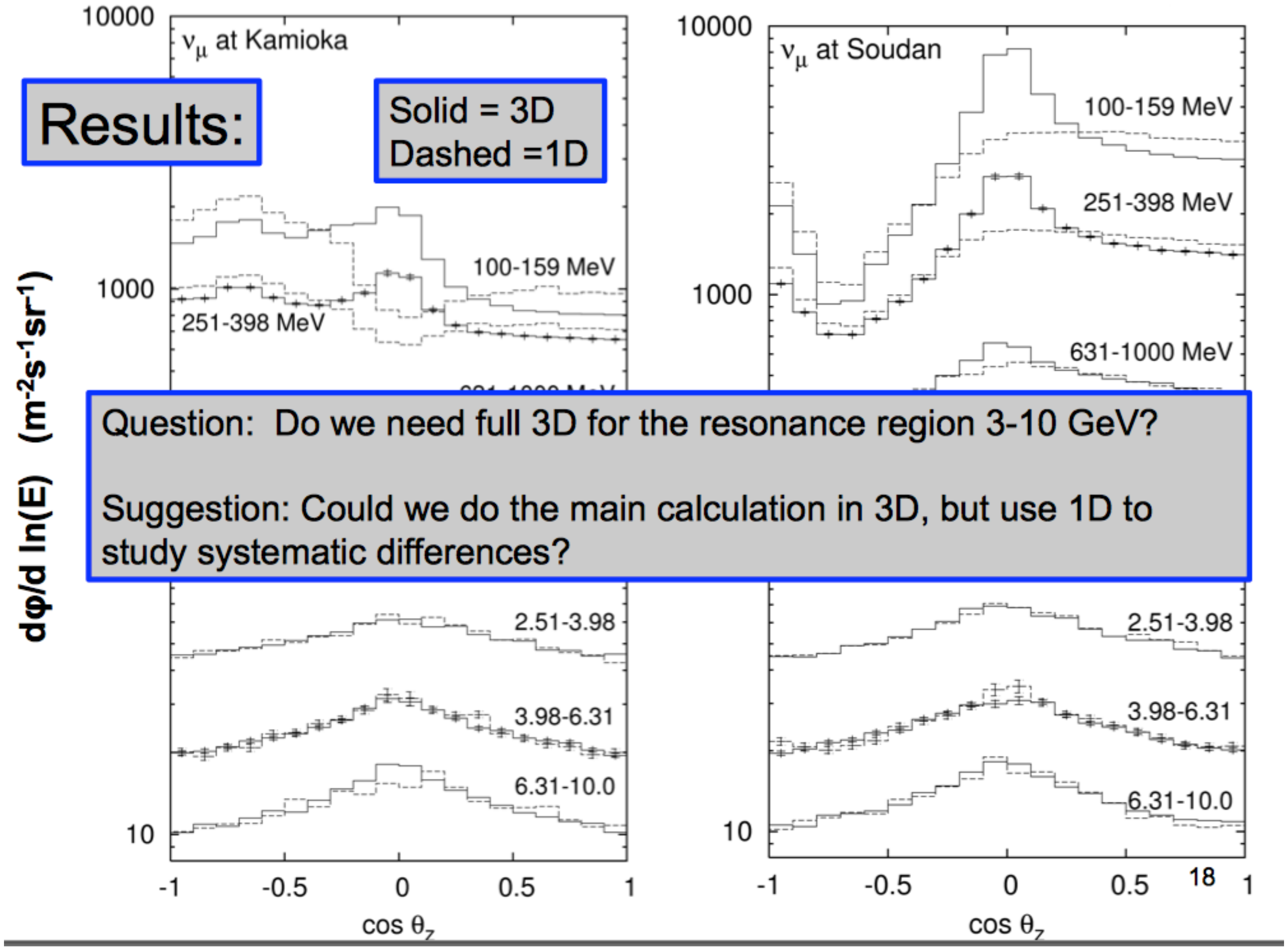
Section 2: Inputs and their uncertainties

- Methodology
- Hadron production
- Primary fluxes
- Uncertainty estimation results

Section 3: Outlook

Bartol fluxes

Used for LBNE atmospheric neutrino studies



Bartol fluxes

Uncertainties

We have two separate methods of propagating uncertainties in inputs to uncertainties in outputs

1. Variation in z-factors (spectrum weighted moments) and spectral indices
   - well follows the key inputs into calculation
   - can be traced with analytic calculation
   - emphasizes extrapolation uncertainties well
2. Changes in hadron production and flux in 'zones'. More empirical, related to regions where experiments are good and where they are not.

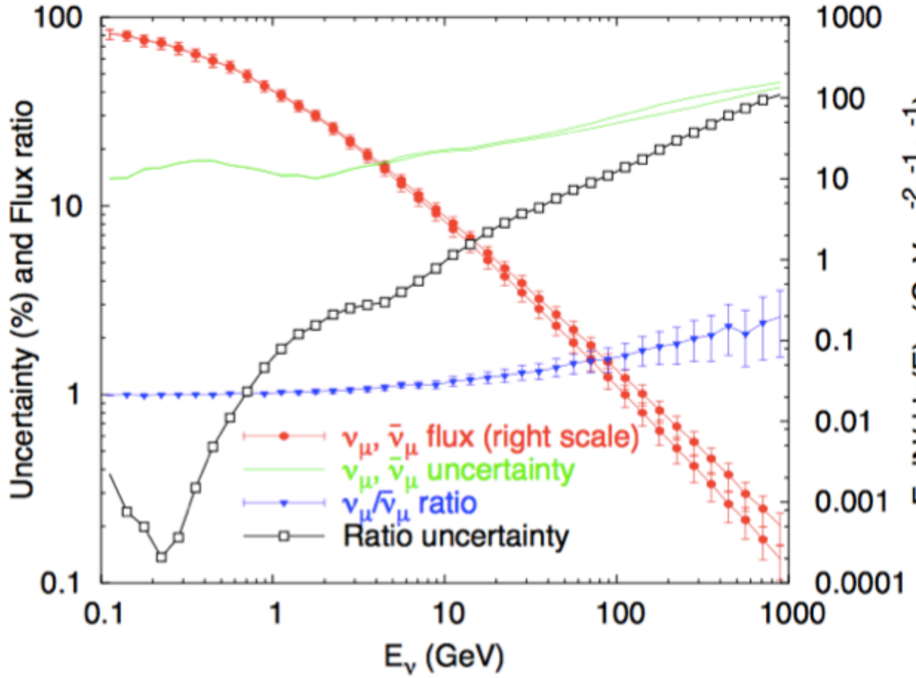
Have avoided comparing different MC for uncertainty estimation attempt

Extensive new data: especially NA61/SHINE and primary fluxes

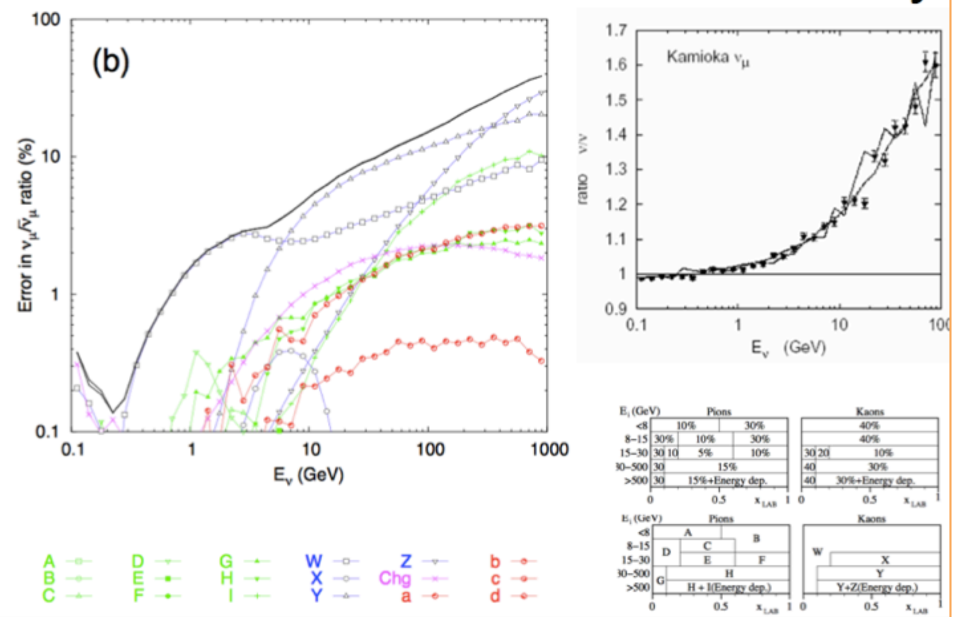
- We have not got it wrong, but must tune with this modern data

Bartol fluxes

Summary plot, illustration of ratio cancellation effects



nu-mu/nu-mubar ratio & uncertainty



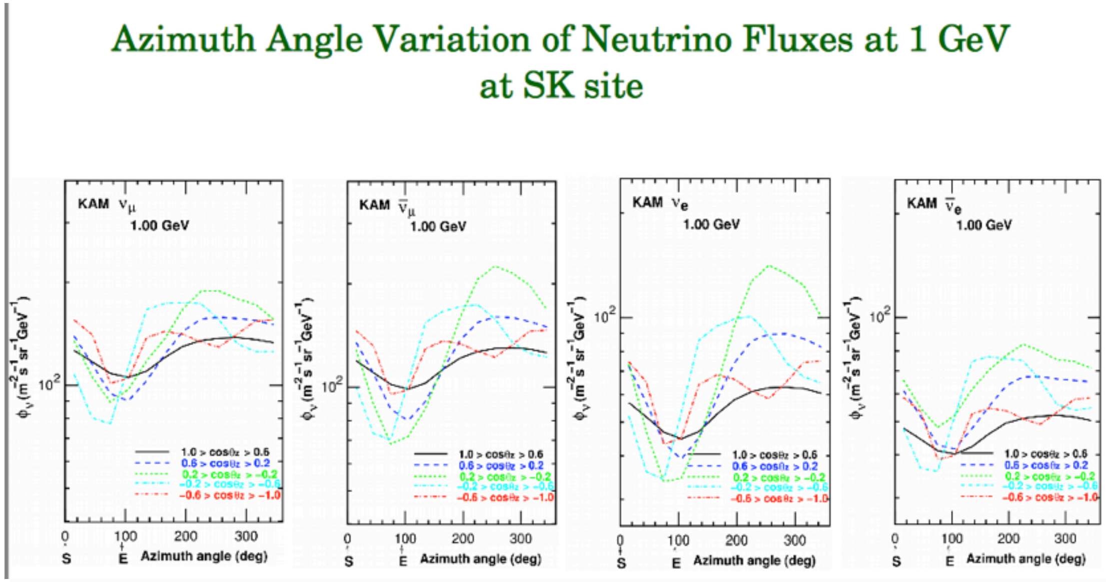
also: nu-e/nu-ebar ratio, direction ratios, flavour ratio

Compared with 2006 uncertainty calculation. Zones W, Y and Chg are the most important

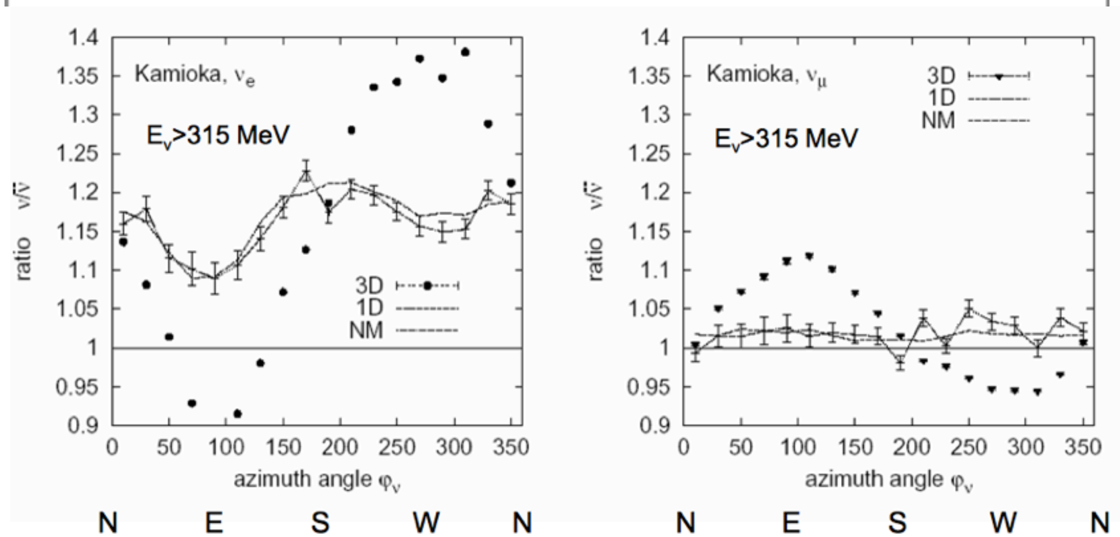
- Perhaps divide W up – suggestions?

Fluxes : Azimuth angle distribution

HKKM



Bartol et al.



Hugh's suggestion: nice early measurement at DUNE

Neutrino interaction physics (Y.Hayato)

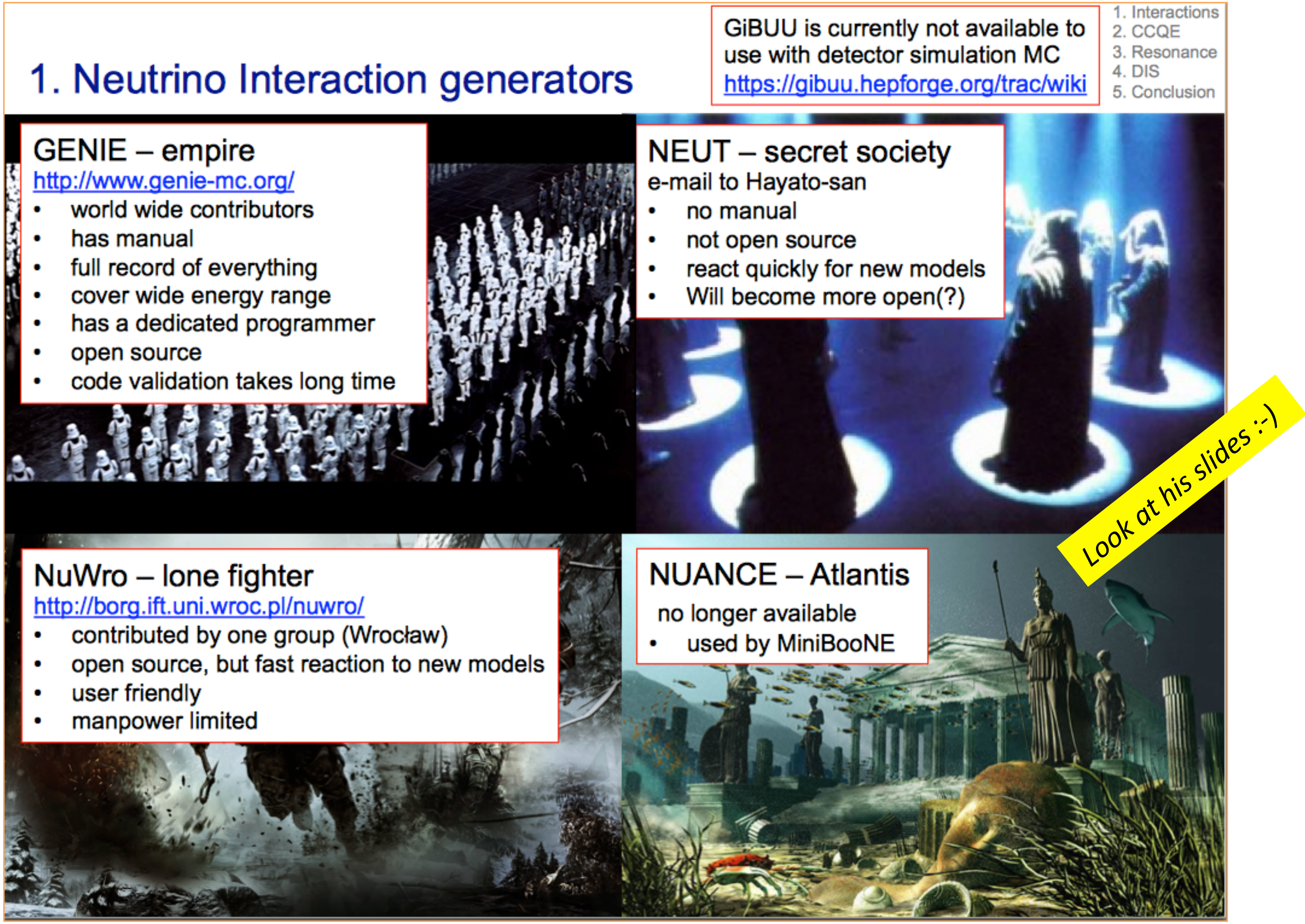
Very complete introduction and presentation of available data…

Summary ~ what has to be understood

- Neutrino – nucleus interactions
  - Major sources of the systematic errors
    - Axial coupling
    - Treatment of `bound' nucleon
    - Hadron multiplicities
    - Re-interaction of hadrons in nucleus
      - pion interactions
      - re-scattering of nucleon etc..
    - Nuclear parton distribution function

- Actual systematic uncertainties in the neutrino experiments
  - Neutrino – nucleus interactions
  - Hadron interactions in nucleus
    - pion interactions in the detector
    - nucleon interactions
      - high energy nucleon ~ particle production

Neutrino interactions (T.Katori)



Neutrino interactions (T.Katori)

5. Model-independent analysis of neutrino interactions

Experimentalists want to provide data to theorists, but flux-unfolding (model-dependent process) lose details of measurements…

Now, all modern beam neutrino experiments publish flux-integrated differential cross-section

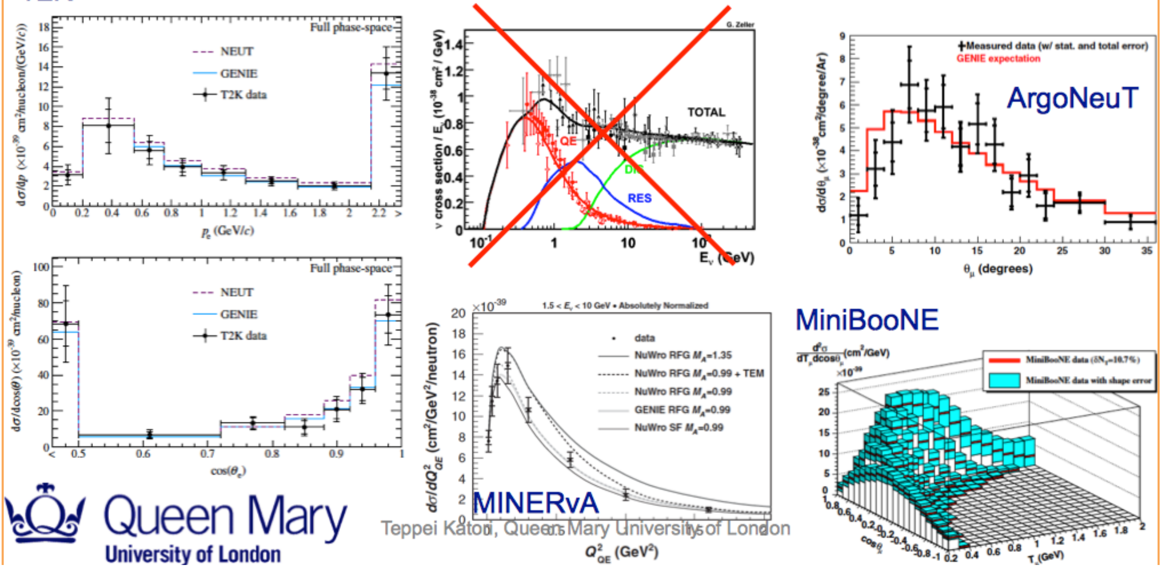
(Can anybody propose a better name for this quantity? Flussintegrierterdifferentiellerwirkungsquerschnitt®?)

→ Detector efficiency corrected event rate
→ Theorists can reproduce the data by convoluting their cross section model with neutrino flux tables from experimentalists
→ Minimum model dependent, useful for nuclear theorists

These data play major roles to study/improve neutrino interaction models by theorists

Various type of flux-integrated differential cross-section data are available from all modern neutrino experiments.
→ Now PDG has a summary of neutrino cross-section data! (since 2012)

T2K



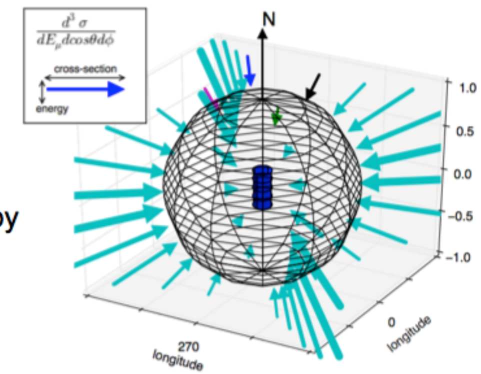
Neutrino interactions (T.Katori)

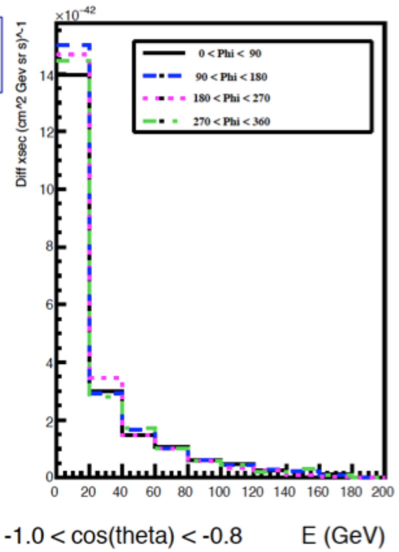
5. Atmospheric neutrino flux-integrated cross-section?

Are we exploit all details of atmospheric neutrino data?
Are any big discoveries hidden in data?

Is it possible for random theorists to take a look Super-K/IceCube/ANTARES data?
random theorists = theorists who don't own detector simulation of Super-K/IceCube/ANTARES, not friend of Super-K/IceCube/ANTARES collaborators

IceCube low E fake data atmospheric neutrino flux-integrated triple differential cross-section





Neutrino interaction community was successful by this approach last ~8 years

Queen Mary
University of London

A lot of analyses are confined within collaborations. It may be interesting to open up the situation, somehow. Neutrino interaction community succeeded this by producing flux-integrated differential cross-section, least model-independent data, which allows more theorists to participate to tackle the problems.

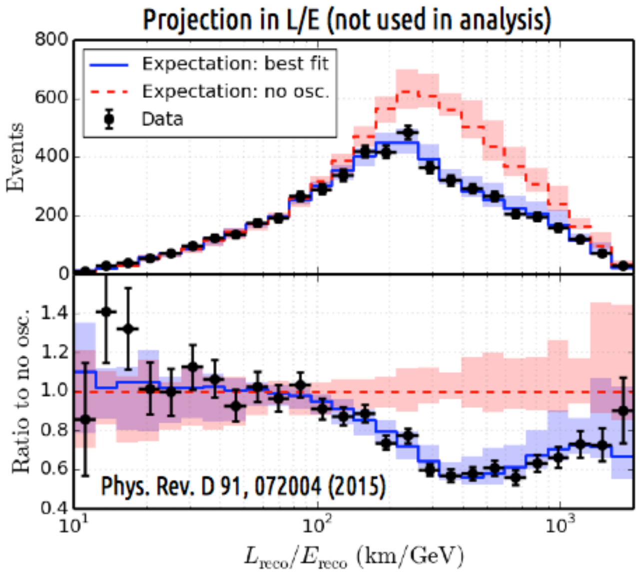
Atmospheric ν's: current results

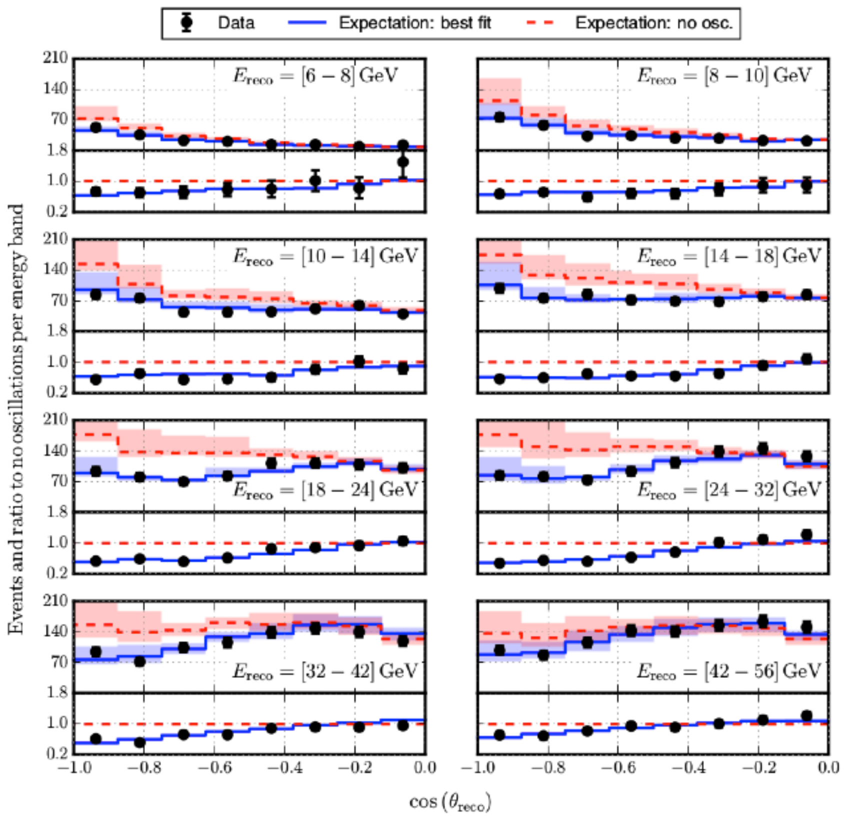
***SK**: K.Okumura, see talk at WG meeting on Dec.21st*

IceCube/DeepCore : Phys. Rev. D 91, 072004 (2015) Data available at https://icecube.wisc.edu/science/data

DeepCore results

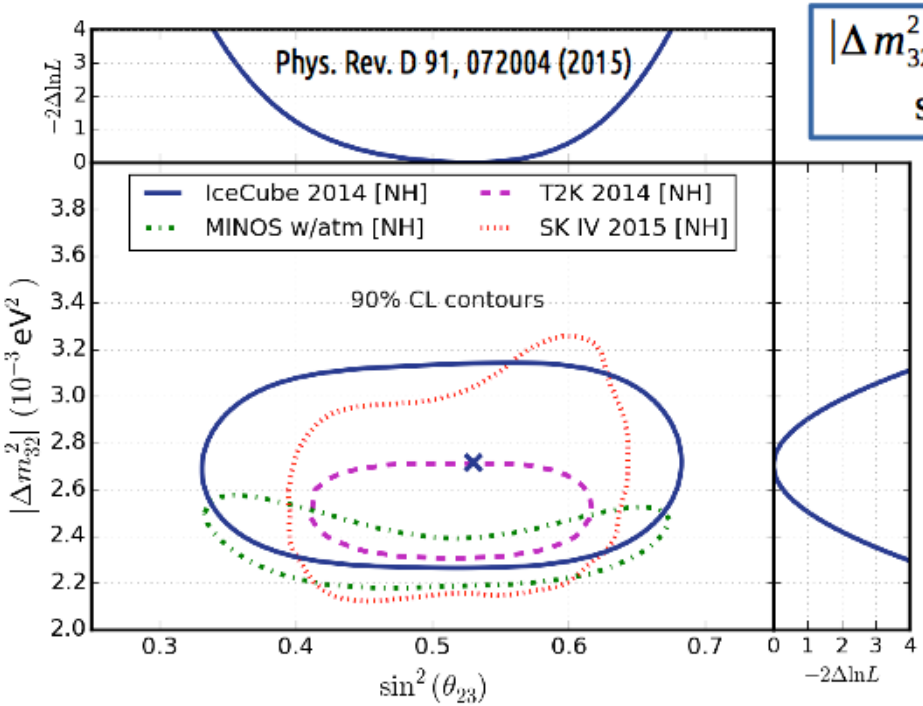
- Using muon tracks only
- Best fit to the data from a 2D analysis (E, θ)
- Up-going events
- Using E < 56 GeV
- 5174 events in 3 years
- In 2D fit histogram
  - χ^2 = 54.9 / 56 d.o.f.





Atmospheric ν's: current results

DeepCore results

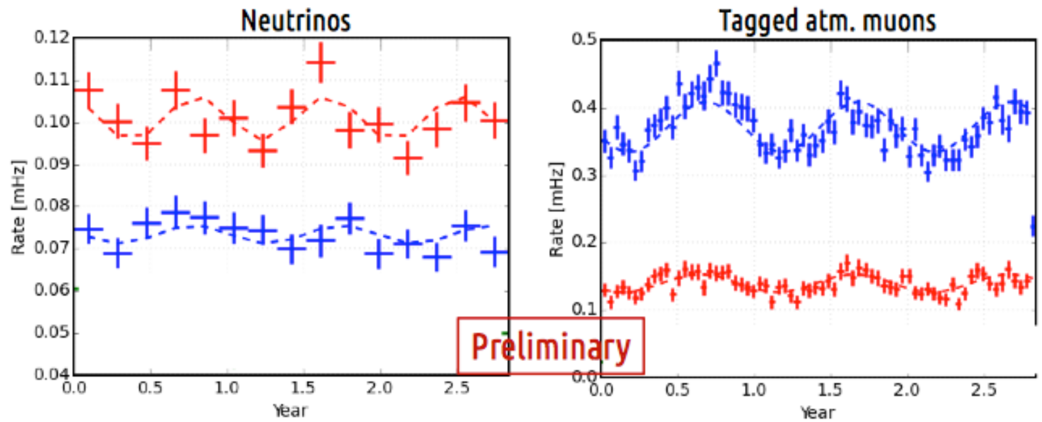


$$|\Delta m^2_{32}| = 2.72^{+0.19}_{-0.20} \times 10^{-3}\ \mathrm{eV}^2$$
$$\sin^2(\theta_{23}) = 0.53^{+0.09}_{-0.12}$$

- First time a very large volume neutrino detector fits in this figure
- Measuring large L/E range
- Affected by different syst. than accelerator results
- Stat. only errors

$$\sigma(|\Delta m^2_{32}|) = ^{+0.14}_{-0.15} \times 10^{-3}\ \mathrm{eV}^2$$
$$\sigma(\sin^2\theta_{23}) = ^{+0.06}_{-0.08}$$

Seasonal variation :



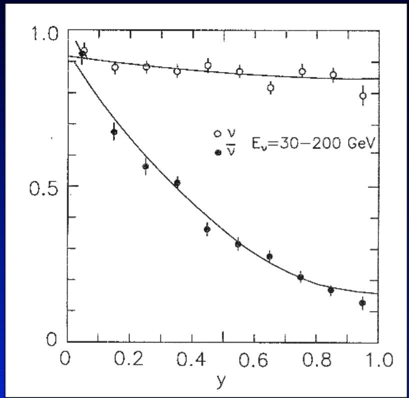
P.Huber: uncertainties in sensitivity studies

Outline

- What are your trying to measure? **(MH)**
- What does it take to do so?
- Lessons from long-baseline experiments (LBL)
  - rate-bases systematics
  - energy reconstruction issues
- What does this mean for atmospheric neutrinos
- Summary & Outlook

P.Huber: uncertainties in sensitivity studies

Resolution – continued



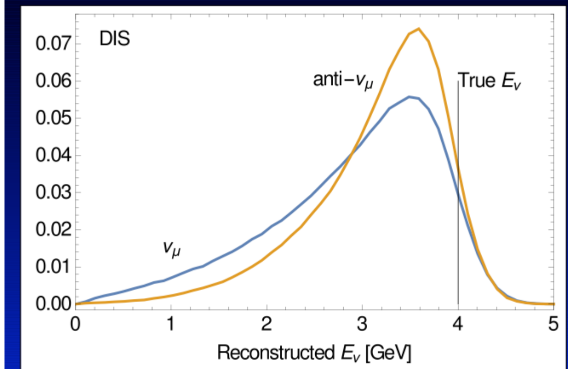
The map from $E_\mu, \theta_\mu, \phi_\mu, E_H$ to $E_\nu, \theta_\nu, \phi_\nu$ depends on neutrino vs antineutrino

The total cross section ratio is not well known at 10 GeV.

CDHS, 1979

Any bias in energy reconstruction between $\bar{\nu}$ and ν will have potentially large impact.

DIS resolution – an example



adapted from Ankowski *et al.*, 2015

Includes some pseudo-realistic detector effects for liquid argon, in particular charged lepton resolution, detection efficiency.

Calorimetry

In some detectors, there will be calorimetry

- Calorimetric resolution significantly worse than leptonic resolution, but how much?
- Neutral particles will give rise to missing energy, can we compute that?
- Missing energy dependent on detector size, near/far comparison?

Fraction of hadronic energy very different for neutrinos and antineutrinos

The relative robustness of DUNE with respect to rate-based systematics derives from the precise reconstruction of the energy dependence of the oscillation pattern!

P. Huber – p. 21

Outlook

A realistic assessment of the energy resolution beyond simple Gaußian smearing is a priority

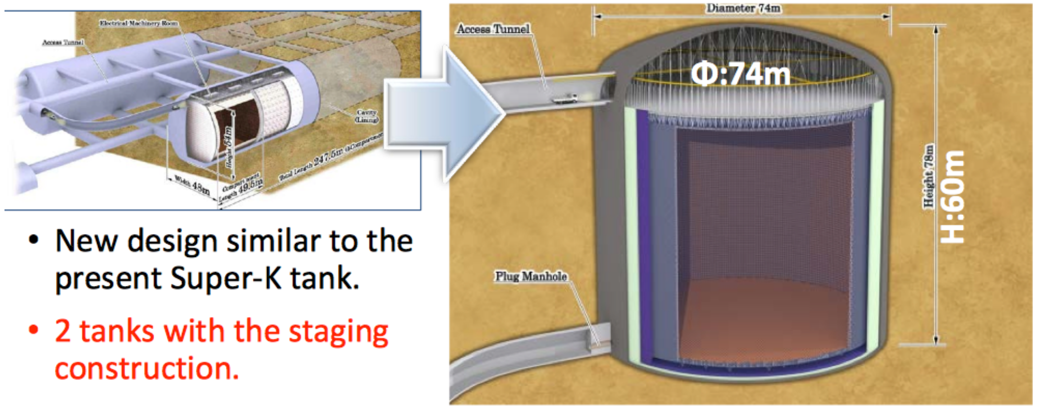
In LBL we learned a lot from simulating data with one generator and fit it with a model derived from another generator

Much of the analysis tools and framework developed for LBL should be applicable (and can be made available) to atmospheric neutrinos

Any chance of doing real measurements to test the underlying neutrino interaction physics?

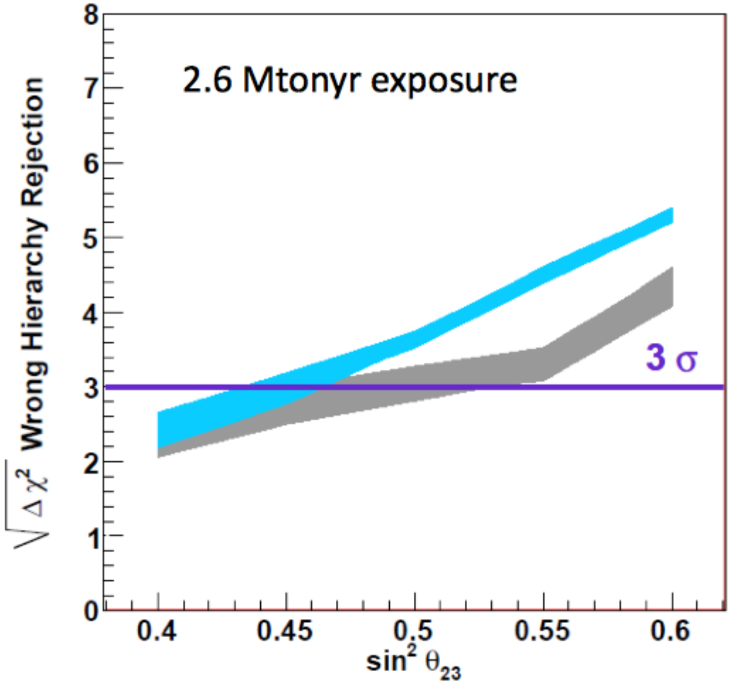
Future experiments : HyperK

New Hyper-K design



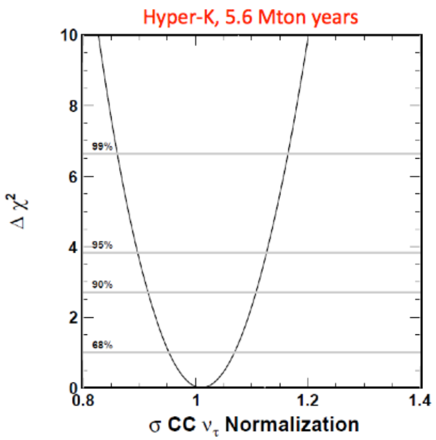
- New design similar to the present Super-K tank.
- 2 tanks with the staging construction.
- Cylindrical tank with Φ 74 meters and H 60 meters.
- The total and fiducial volumes (for one tank) are 0.26 and 0.19 Mtons, resp.
- Photo-cathode coverage is 40%. 40,000 ID PMTs and 6700 OD PMTs per tank.
- Planned time line: Project approval 2018, experiment 2026 (1^{st} tank).

Sensitivity to MH



Tau neutrino appearance

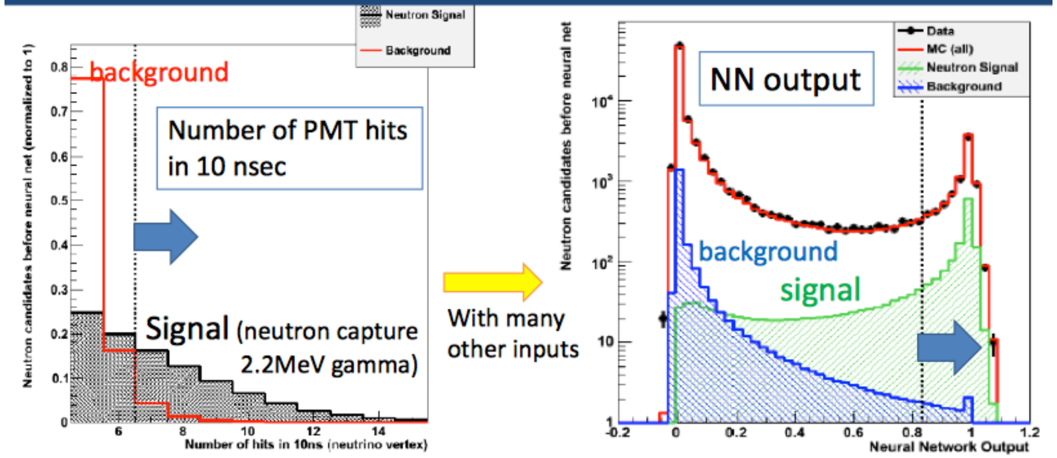
- the normalization of the CC ν_τ cross section (relative to CC ν_μ cross section) can be constrained to about 7% with a 5.6 Mton year exposure of Hyper-K.
- This measurement will help understand the CC ν_τ cross section near the threshold, which is known rather poorly.



Future experiments : HyperK

Appendix: Other non-accelerator physics with Hyper-K (proton decay)

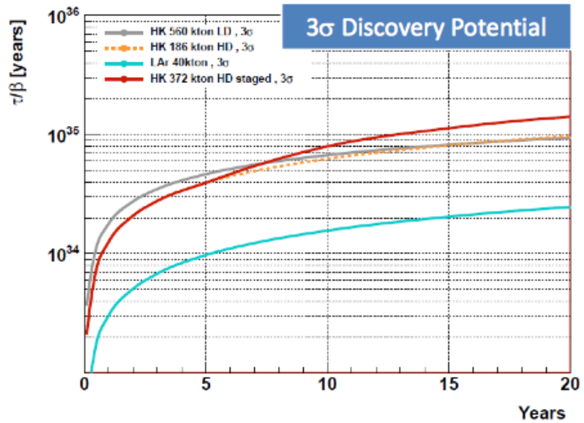
2.2 MeV gamma ray detection (Super-K)



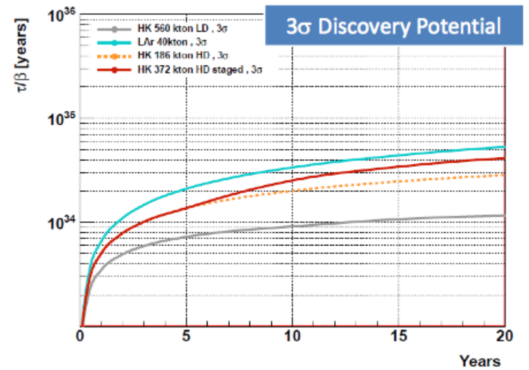
- ✓ In super-K, the detection efficiency for 2.2 MeV gamma rays is 20.5% and the background rate per event is 0.018. (T. Irvine thesis, 2014)
- ✓ In Hyper-K, due to ~2 times higher photon detection efficiency, the ε (2.2 MeV gamma rays) is estimated to be 70% (prelim).
  ➔ Preliminary study for proton decays. (To be implemented to the atmospheric neutrinos studies as well.) 21

- ✓ Overall, the number of neutrons detected agree (surprisingly) well with the MC simulation. (T. Irvine thesis, 2014)

P→ $e^+ \pi^0$: sensitivity



P→ ν K^+ : sensitivity

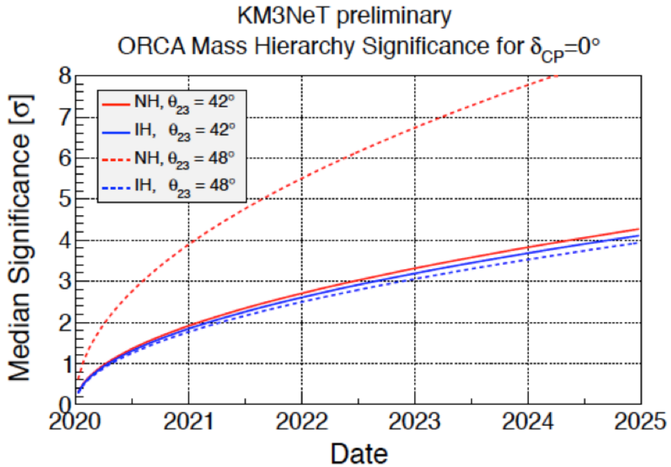


Future experiments : ORCA, PINGU

Neutrino Mass Hierarchy

ORCA

- Time dependence of sensitivity



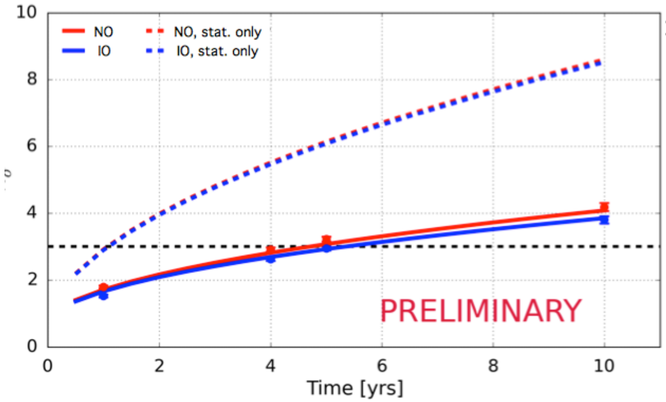
Deployment of 1st line, Dec. 2015

KM3Net 2.0 LoI: ArVix:1601.07459

PINGU

NMH sensitivity

Assignment of systematics non-obvious



syst. group	σ in 3yrs (NMH)*	σ in 3yrs (IMH)*
stat. only	4.84	4.82
flux only	4.55	4.56
det. only	4.06	3.99
θ_{23} only	3.52	3.26
osc. only	2.96	2.53
all	2.90	2.51

* numbers slightly outdated
→ for illustration purposes only

ν_τ appearance

- appearance @6σ in 10 months
- <10% precision in 1 year

Future experiments : DUNE

Many thanks to Hugh and Andy for all the material, information and support !

- People's first reaction: "DUNE is so small, what can it do with atmospheric neutrinos?". I insisted on the excellent resolution…
- Lots of questions and discussion during the talk, positive feeling and reactions
- I mentioned the measurements of p-Ar and π-Ar cross-sections by ProtoDUNE [WA105 TDR], important to tune neutrino interaction models

BUT…

- DUNE is not mentioned at all in P.Lipari's summary talk !!!!

Anyways, we must participate to the next ANW edition