Discussion :

ATMOSPHERIC NEUTRINO FLUX CALCULATION IMPROVEMENTS

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MOTIVATION

When considering
Larger Exposures (Mass Time)
for Atmospheric Neutrino Data

Important Effects become in principle
Statistically Detectable
IF
the Systematic Errors are controled
at an adequate level.

SK–1 :

$M_{\text{fiducial}} = 22.5$ Kton
$T_{\text{live}} \simeq 4.08$ years

Exposure $\simeq 91.8$ Kton yr

Hyper–K (MegatonDetector) :

$M_{\text{fiducial}} = 500$ Kton
$T_{\text{live}} \simeq 10$ years

Exposure $\simeq 5000$ Kton yr $\simeq 50$ SK1

QUESTIONS:

- **Where are we ?**
  What are the Systematic Uncertainties of the existing calculations.
  How can we describe these uncertainties.

- **How much better can we get ?**
  How much can we Improve the Existing Pedictions
  What do we Need to obtain these Improvements

- **How much better should we get ?**
  To achieve the physics goals that we are discussing what level of systematic errors are necessary ?

FIRST QUESTION

- Where are we ?

  What are the Systematic Uncertainties of the existing calculations.

  How can we describe and quantify with the necessary accuracy these uncertainties.

SK
Ed Kearns
Neutrino 2004

	error	best fit
Neutrino Flux		
Overall absolute normalization	free	14.0%
FC Multi-GeV sample	5.0%	-5.4%
PC + stopping upward muon	5.0%	-2.5%
Energy spectrum $E^{-2.7+\delta}$	0.05	0.61
K/π ratio	20.0%	-6.4%
μ/e ratio (< 5GeV)	3.0%	-2.5%
μ/e ratio (> 5GeV)	3.0%	1.4%
zenith shape (various)	(0.3%-2.6%)	
Neutrino Interaction		
QE cross section	10.0%	5.0%
Axial mass parameter (1.1 GeV)	10.0%	-1.0%
Meson production (various)	(10%-30% + alt. models considered)	
NC/CC ratio	20.0%	0.6%
Event Selection		
PC data reduction efficiency	3.2%	0.7%
FC/PC events selection (OD hits)	1.5%	0.6%
FC data reduction	0.2%	0.0%
Non-neutrino BG (various)	(<1%)	
Event Reconstruction		
Particle ID (μ/e) 1-ring	(<1%)	
Particle ID (μ/e) multi-ring	(3.4%-4.7%)	
Energy scale	2.0%	0.5%
Ring counting (various)	(1.3%-7.2%)	
Ring counting (multi-GeV e-like)	15.9%	8.1%

Present Description of Systematic Errors
"Pull" method

- Flux Uncertainties:
  - Total normalization:
  - "Tilt" error
  - ν_μ/ν_e ratio
  - Zenith angle dependence

- Cross Section Uncertainties:
  - $\sigma^{\sigma_{QE}}_{\rm norm}$
  - $\sigma^{\sigma_{1\pi}}_{\rm norm}$,
  - $\sigma^{\sigma_{DIS}}_{\rm norm}$
  - $\sigma^{QE,1\pi,DIS}_{i,\nu_\mu}/\sigma^{QE,1\pi,DIS}_{i,\nu_e}$

C.Gonzalez-Garcia

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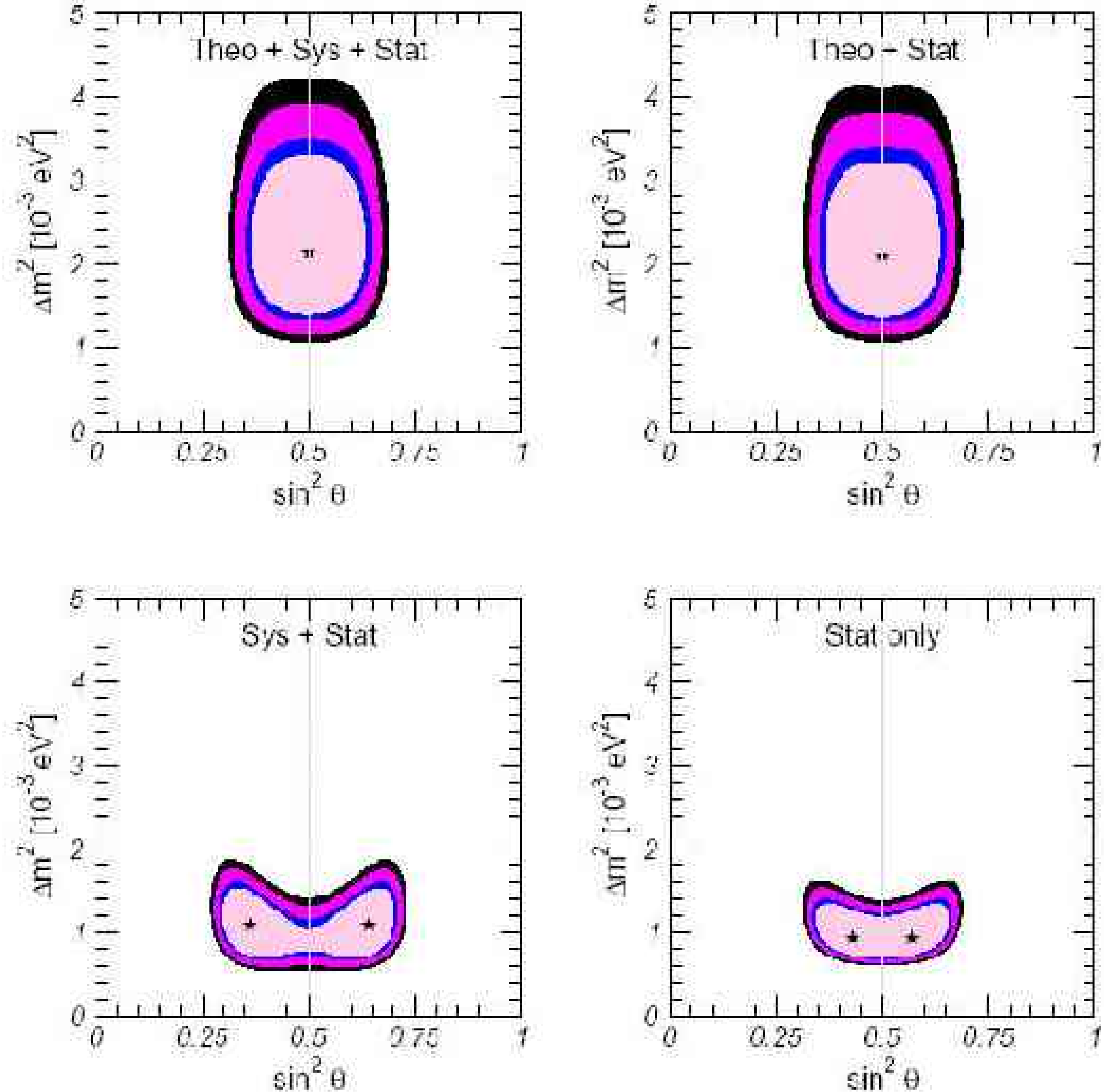


C.Gonzalez-Garcia

- Question/"plea" to flux/cross-section experts:

(1) Is this the most general characterization of uncertainties?

NO

(2) Is it possible to obtain the uncertainties as follows?

– Characterize flux (cross-section) *independent input parameters* $X_i^{\rm flux,cs}$ and their uncertainties $\Delta X_i^{\rm flux,cs}$

– Modify input parameter $X_i \to X_i + \Delta X_i$

– Give $\frac{d\Phi(E_\nu)}{d\Delta X_i^{\rm flux}}$ or $\frac{d\sigma(E_\nu)}{d\Delta X_i^{\rm cs}}$

Very Interesting Line of work

C.Gonzalez-Garcia

- Flux Uncertainties:

(1) Total normalization: $\sigma_{\rm norm} = 20\%$

(2) "Tilt" error

$$\Phi_\delta(E) = \Phi_0(E)\left(\frac{E}{E_0}\right)^\delta$$

$\sigma_\delta = 5\%\ E_0 = 2\,\mathrm{GeV}$

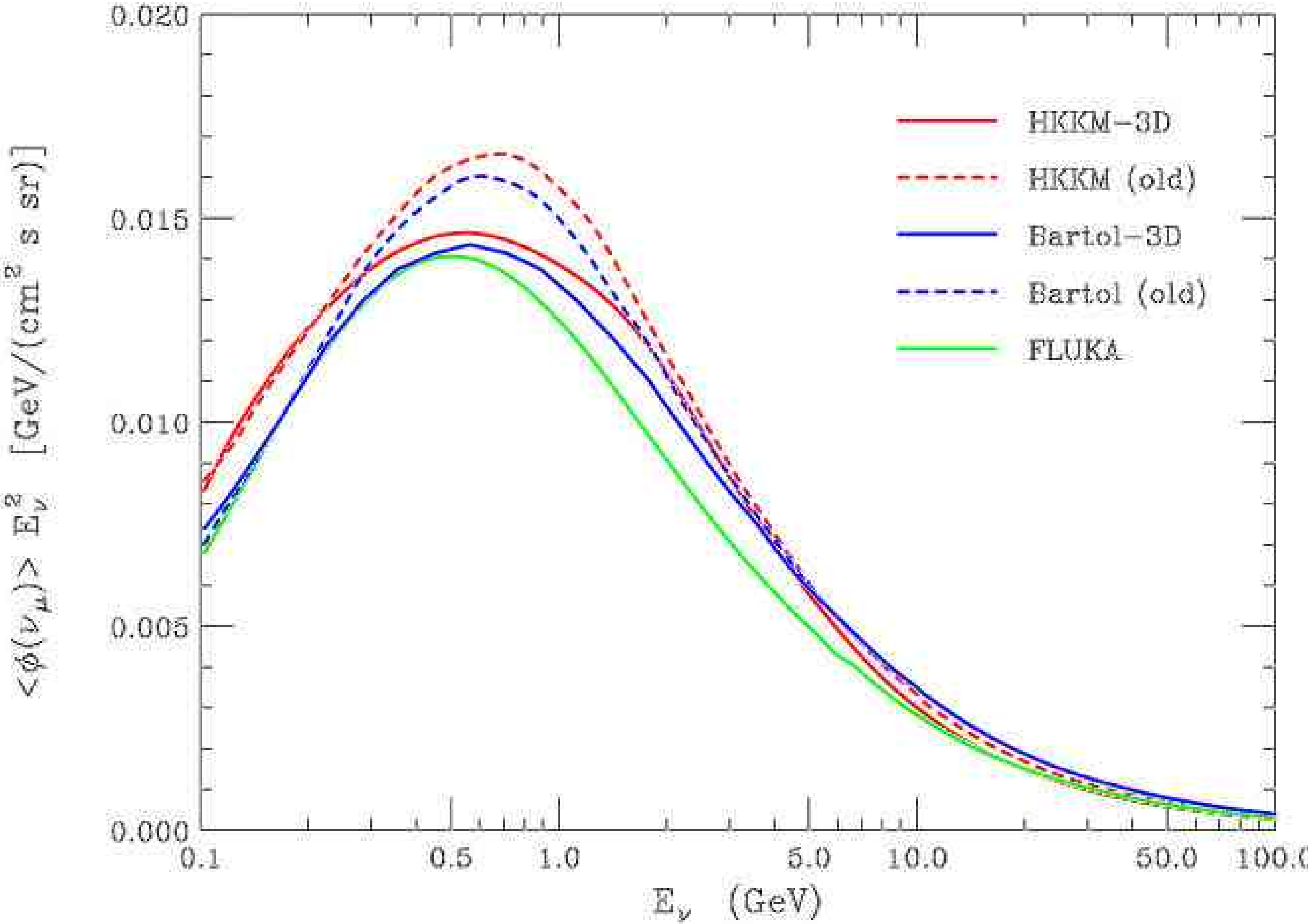
(3) ν_μ/ν_e ratio: $\sigma_{\mu/e} = 5\%$

E independent for contained events

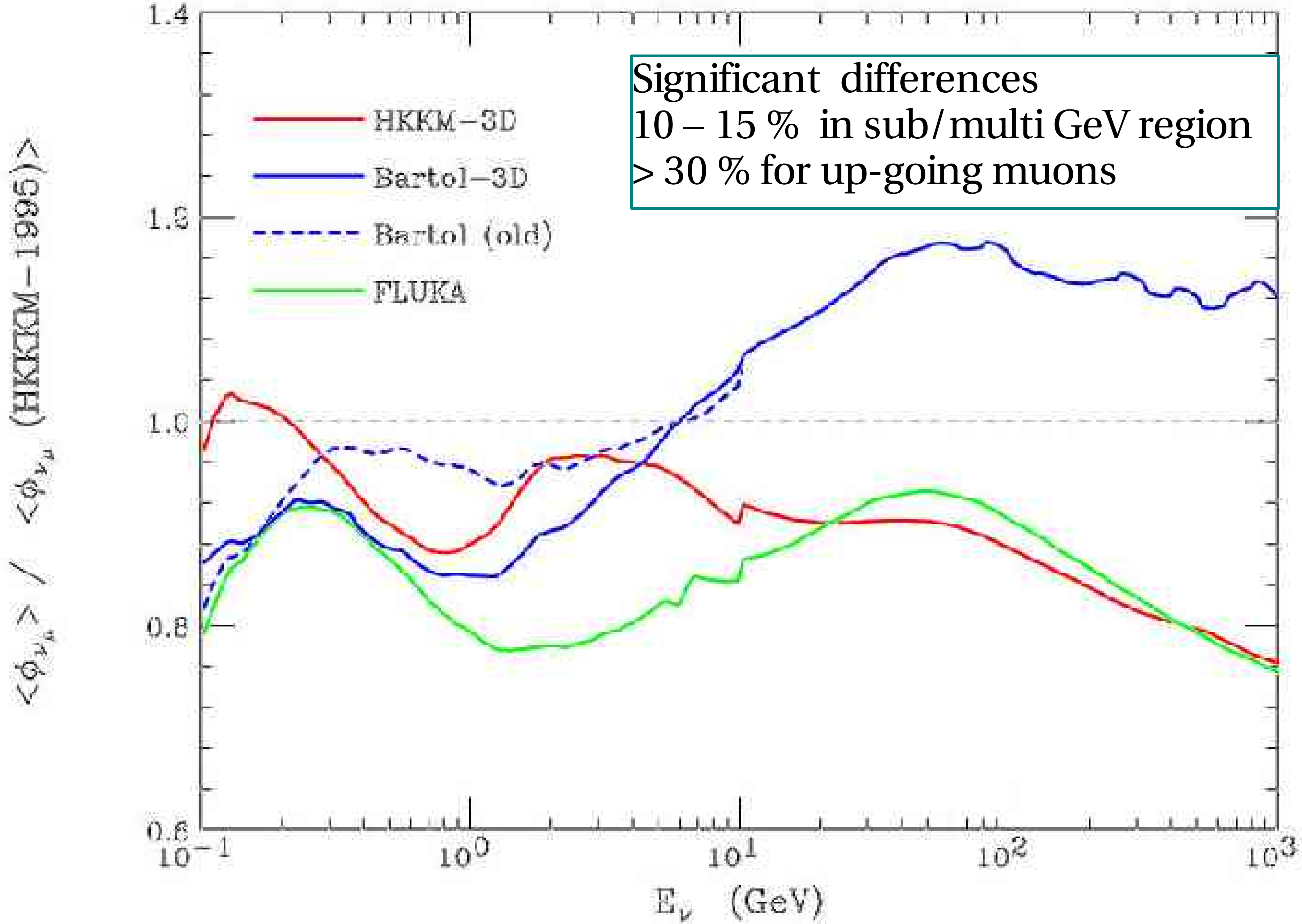
(4) Zenith angle dependence:

$\sigma_{\rm zen,i} = 5\%\langle\cos\theta\rangle_i$

Angle Averaged Fluxes



Comparison: Model / HKKM-1995



$$\phi_{\nu_\alpha}(E_\nu, \Omega)$$

4 functions of two variables

$$\frac{d\phi_{\nu_\alpha}(E_\nu, \Omega)}{dX_j}$$

Different Derivative
at each point

$$\phi_p(E) = K\ E^{-\alpha}\ \text{(Only High Energy)}$$

$$r_K = K/\pi \text{ ratio}$$

Approximate Feynman scaling region

$$K/\pi \to X + |dX|$$

Harder Spectrum More Isotropic Flux

Observable : Convolution of the fluxes in a certain region of Neutrino Energy and Direction

$$[\text{Observable}] = \sum_\alpha \int dE_\nu \int d\Omega \; \phi_{\nu_\alpha}(E_\nu, \Omega) \; \text{Response}(E_\nu, \Omega, \alpha)$$

$$R_V = \left(\frac{\text{Vertical}}{\text{Horizontal}}\right)_{\mu\uparrow}$$

$$\frac{dR_V}{dr_K}, \qquad \frac{dR_V}{d\alpha}$$

Observables:
All "Data Bins"

PREDICTION PARAMETERS

Shape of the Primary Spectrum
(asymptotic Slope) + Lower Energy Shape parmaters (2-3)

Hadronic Interaction Montecarlo
Described by a finite numbers of Parameters
(High Energy : String Formation + Fragmentation)
......

Possibly an Interesting Line of Research

SECOND QUESTION

- How much better can we get ?

  How much can we Improve the Existing Predictions

  What do we NDEE to obtain these Improvements

Elements for the prediction of the Atmospheric Neutrino Fluxes:

- Primary Cosmic Ray Flux
- Geomagnetic Effects
- Hadronic Interaction Modeling
- Calculation Method:

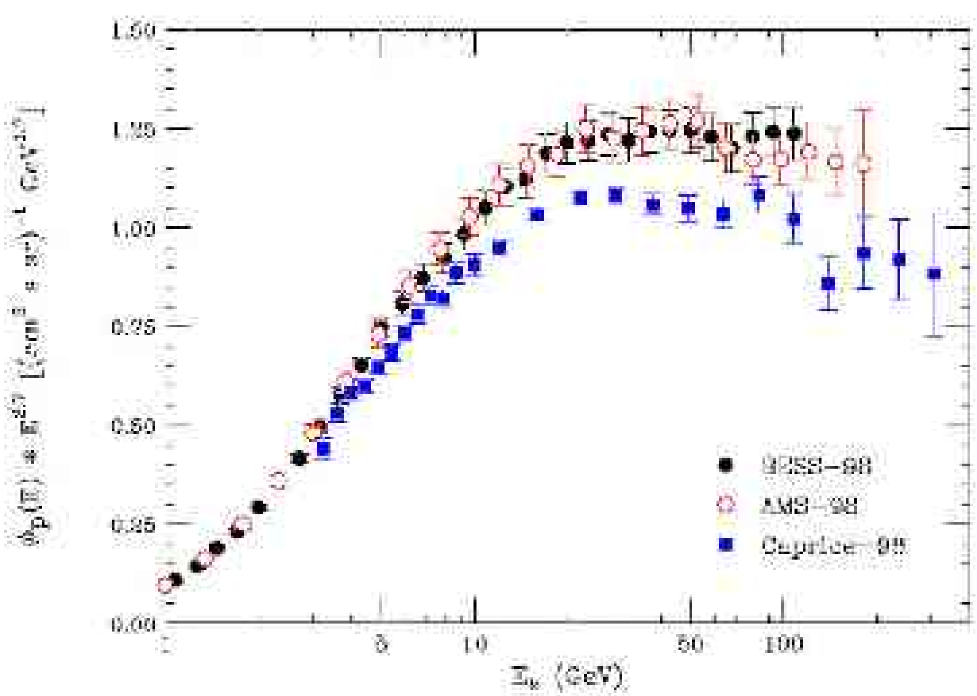
MUON MEASUREMENT CONSTRAINTs

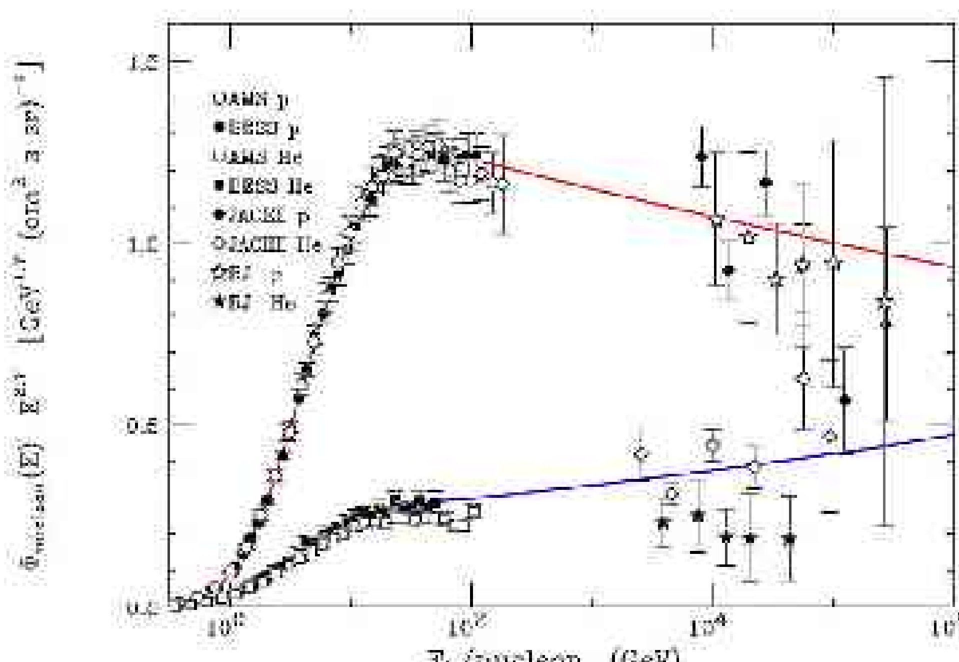
Is the accuracy of the
Atmospheric Neutrino Calculation
ONLY limited by the quality of the INPUT ?

In my personal opinion
the constraints of the MUON measurements
have not been used up to their full potential

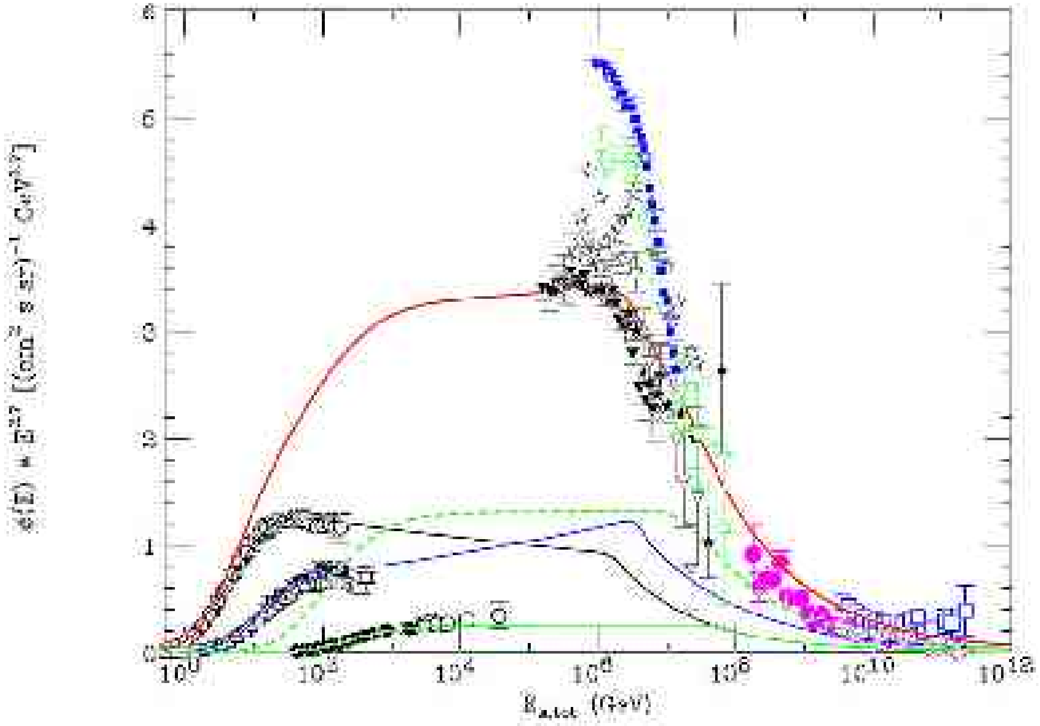
PRIMARY COSMIC RAYS

- Understand better Solar Modulation Effects
- Solve the BESS-AMS/Caprice discrepancy at 10-100 GeV
- Poor measurements in the region
  200 GeV - EAS (> 10^{14} eV)

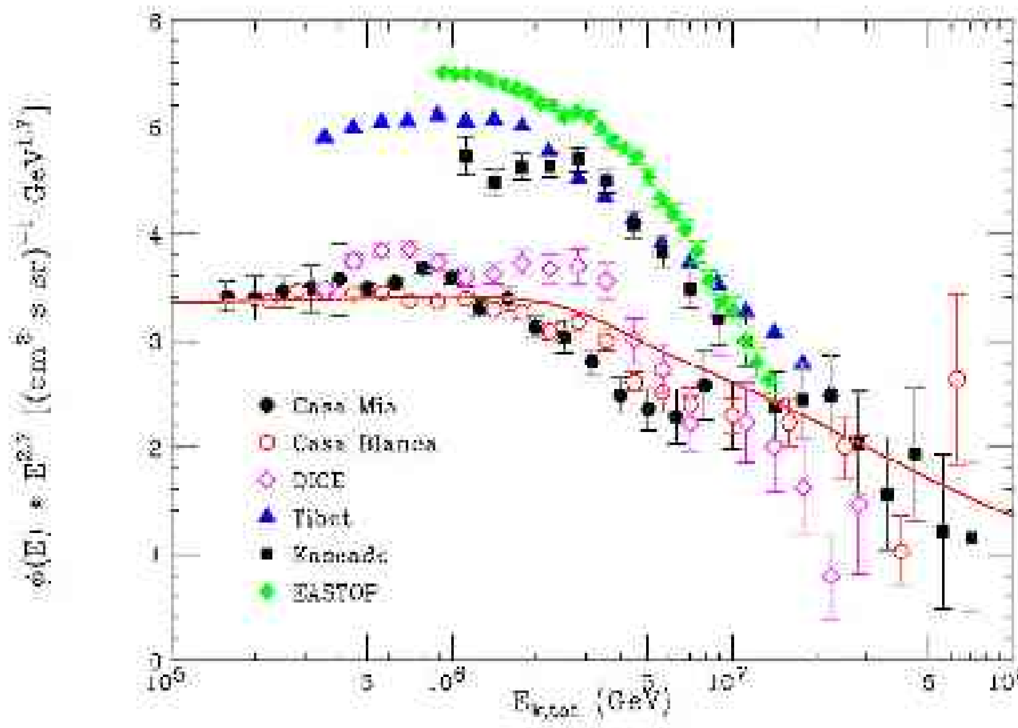




Comparison with
Air Shower Experiments
at the knee $\sim 10^{15}$ - 10^{16} eV



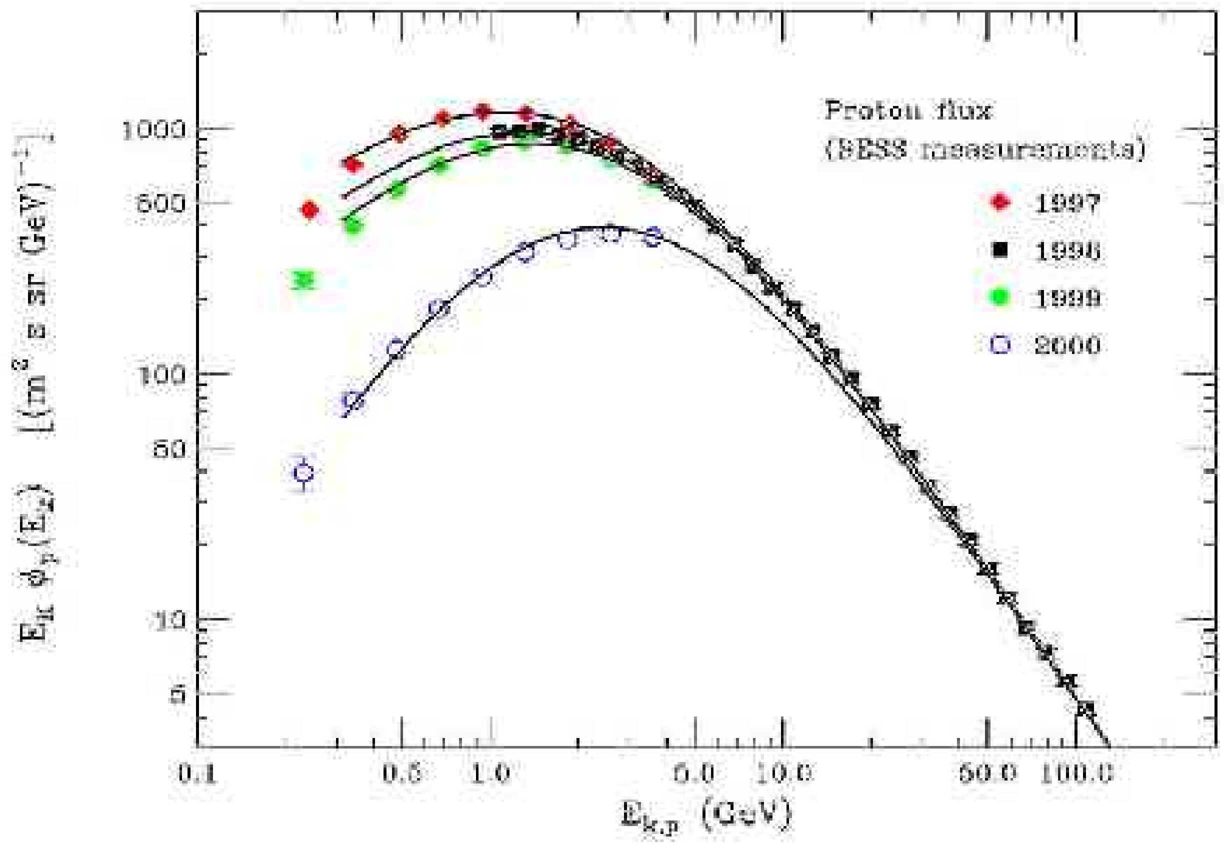
Great importance
for Cosmic Ray
Measurements
in the “knee” region
and beyond



Solar Modulation Effects

Long time Integration Problem
Obtain an observable
(for example:
 Neutron Monitor Data)
to predict the Solar Modulation

BESS protons



THIRD QUESTION

- How much better should we get ?

  To achieve the physics goals that we are discussing what level of systematic errors are necessary ?

Why this Question ?

Very Likely to obtain the required accuracy in the prediction will require dedicated and costly efforts, their (potential) significance should be assessed

A Warning :
We have NOT yet proved
that the interesting Neutrino Physics effects
that we are discussing (for example
the determination of the OCTANT for $theta_{23}$)
are measurable even with Megaton-HyperK

Final Comment

Precision Measurement of the kind we are discussing are extraodinary difficult, and will require very dedicated efforts and the collaboration of many physicists

Cosmic Ray Measurements
Hadronic Interactions
Nuclear Effects
MonteCarlo algorithms

.... (DETECTOR !)

Learn Something Fundamental and deep about Nature