MANTS - Sept. 24 2011

Systematic challenges in neutrino analysis

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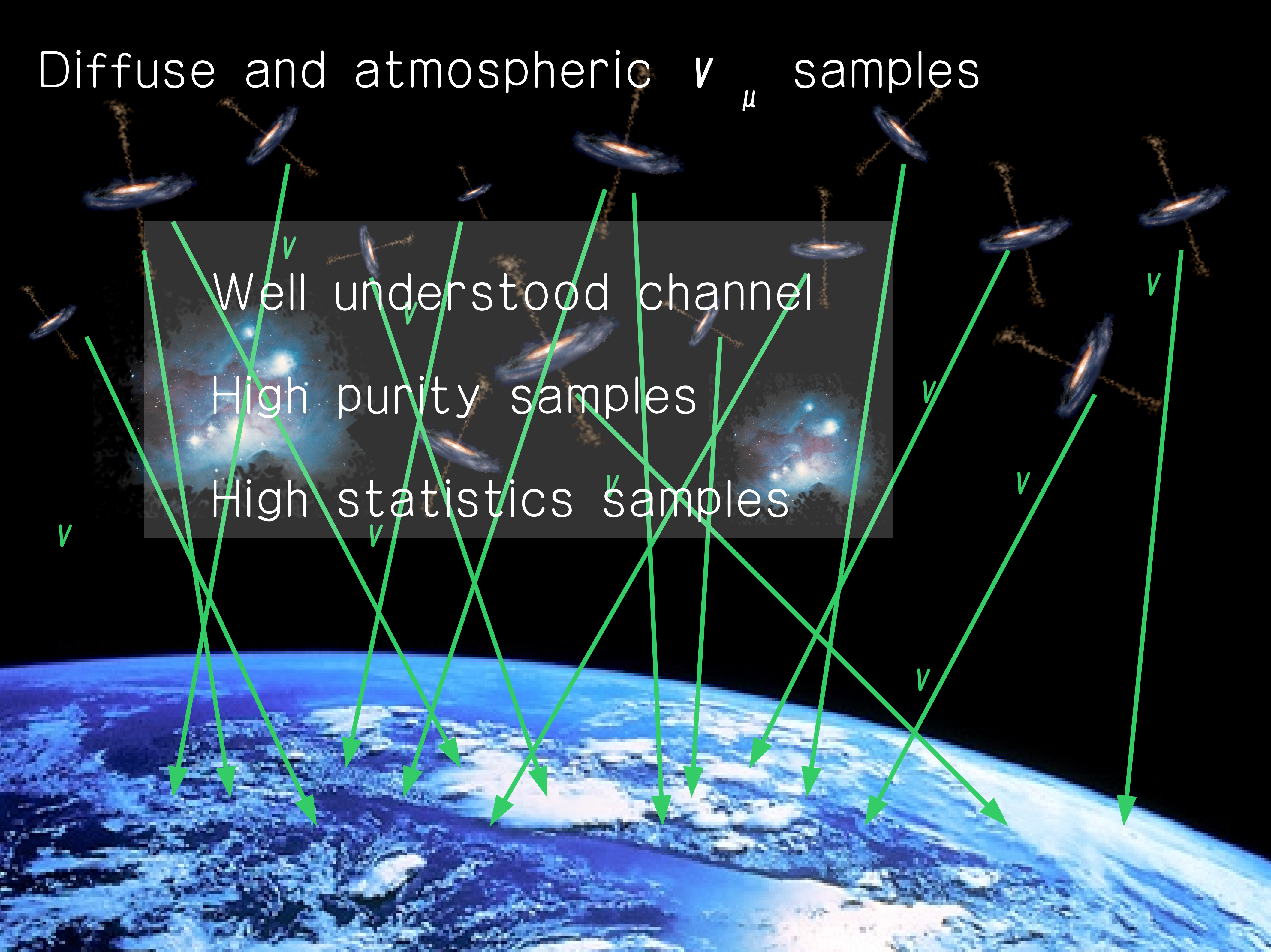
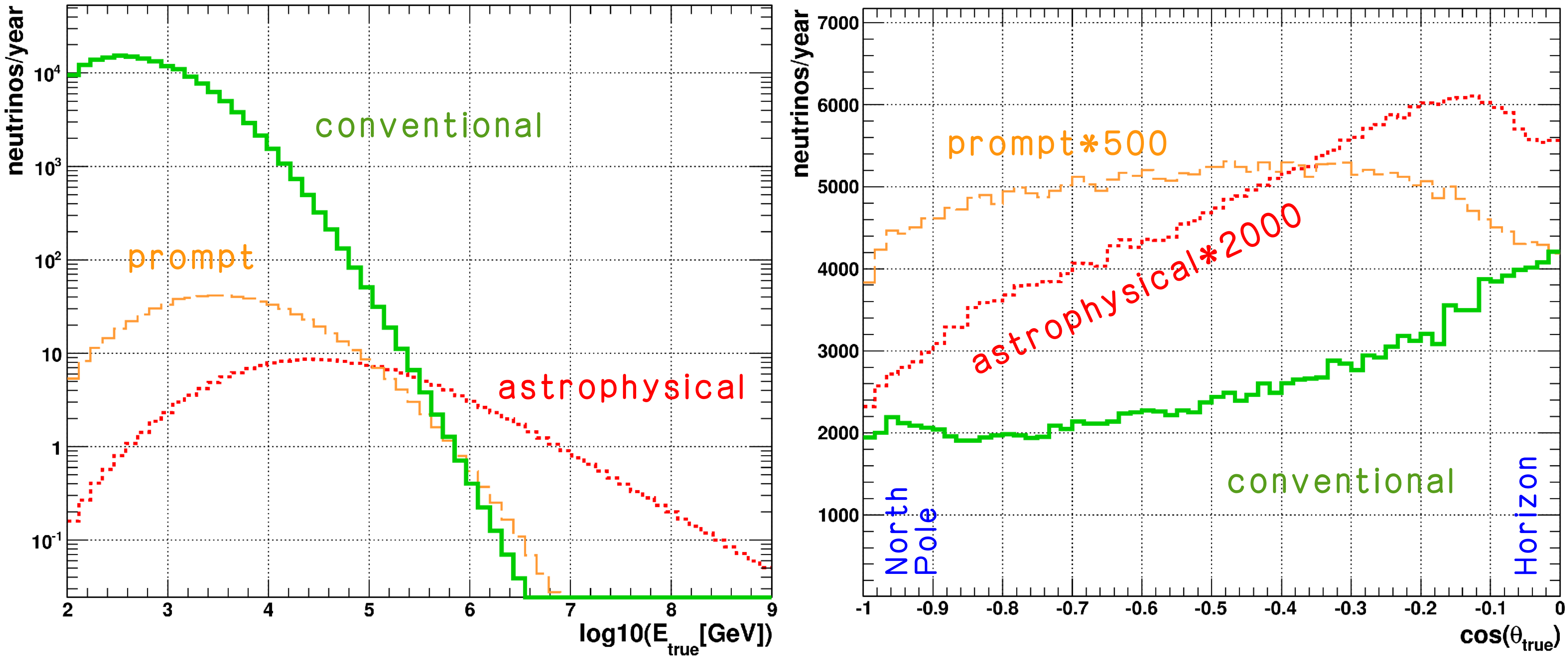

Diffuse and atmospheric ν_μ samples
Well understood channel
High purity samples
High statistics samples

Analysis principle

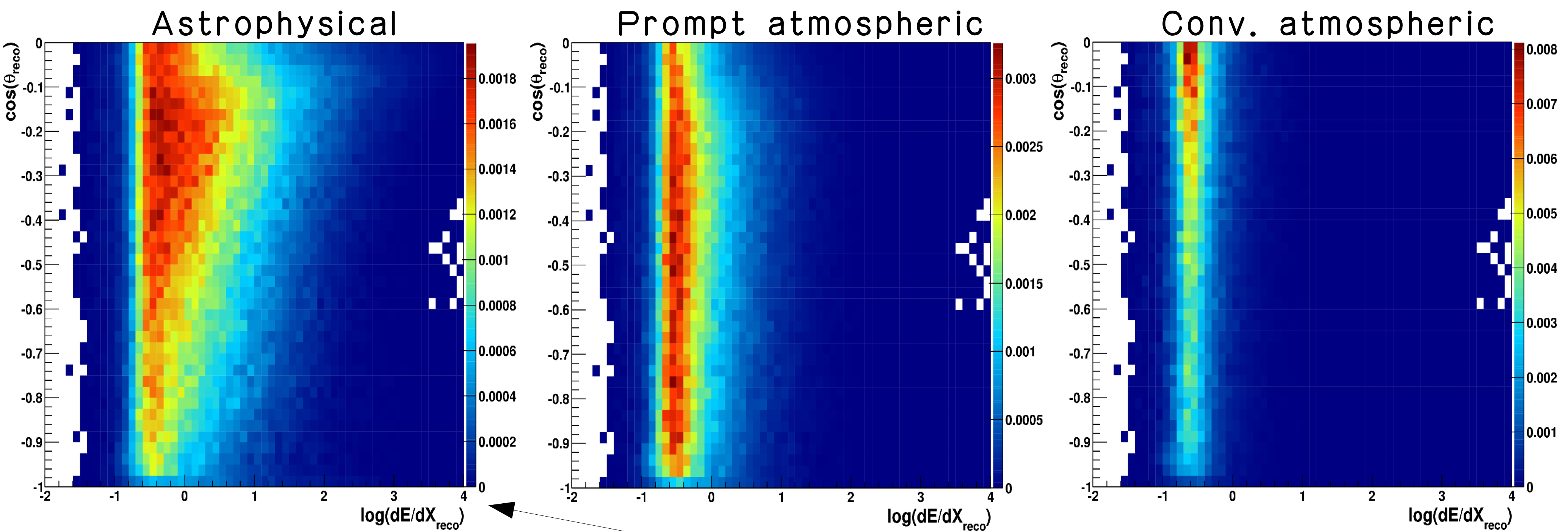
Energy distribution Zenith angle distribution

of simulated neutrinos in the IceCube detector.



Conventional atmospheric neutrinos (Honda 2006)
Prompt atmospheric neutrinos (Engberg et al.)
Astrophysical neutrinos (IC40 limit)

Likelihood analysis



2–dim (energy and zenith) binned Likelihood fit for

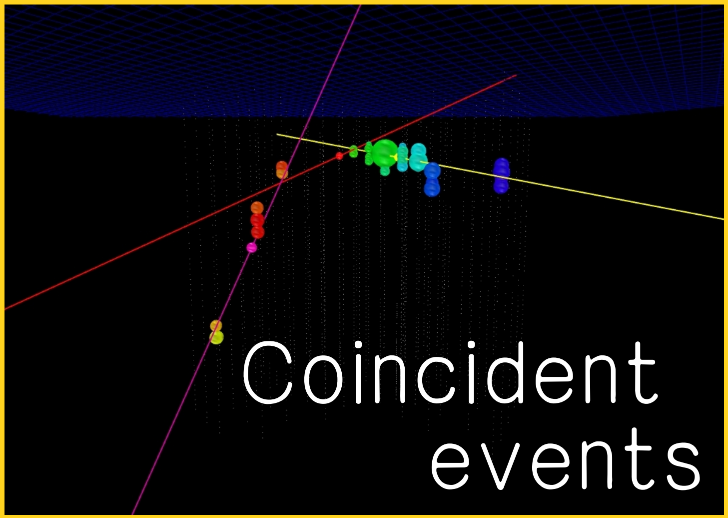
N_a = number of astrophysical neutrinos
N_p = number of prompt atmospheric neutrinos
N_c = number of conventional atmospheric neutrinos.

$$\mu_{ij} = N_a \cdot a_{ij} + N_p \cdot p_{ij} + \cdot N_c \cdot c_{ij}$$

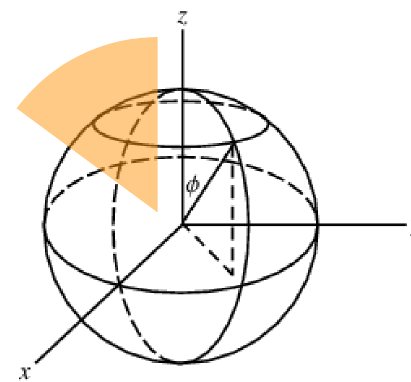
$$\mathcal{L} = \prod_{i,j} \frac{\mu_{ij}^{n_{ij}}}{n_{ij}!} \cdot e^{-\mu_{ij}}$$

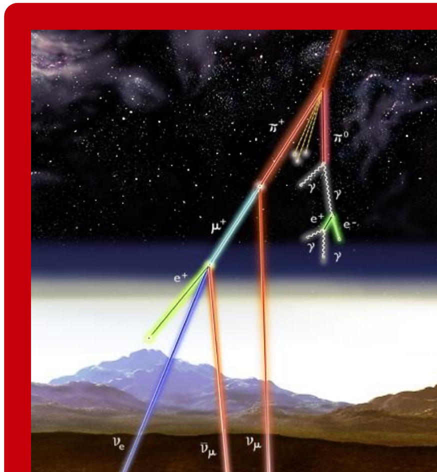
Outline

A small selection of interesting topics:



Zenith angle
distribution



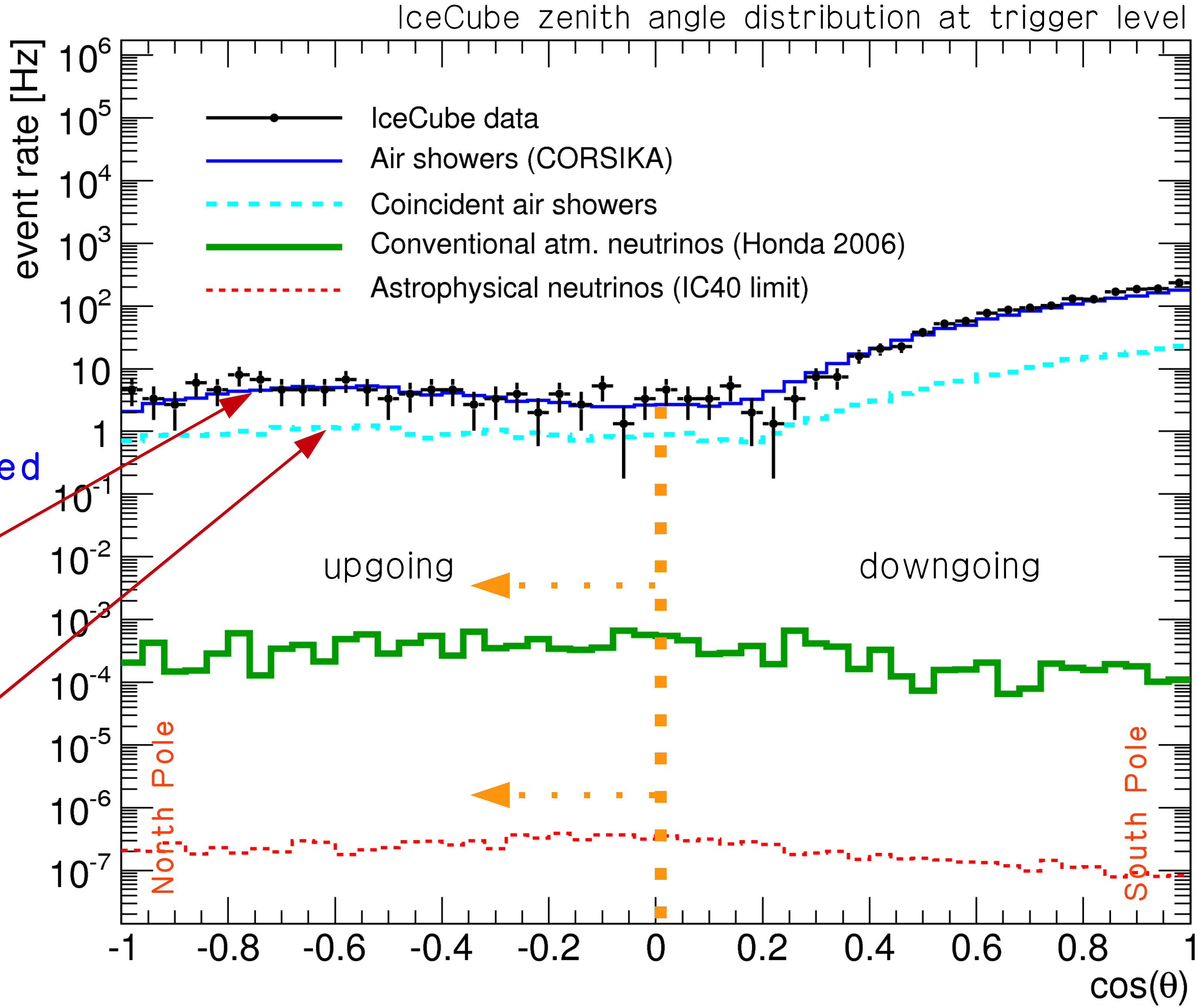


Atmospheric
neutrino
fluxes

Background rejection

For diffuse/ atmospheric analysis:

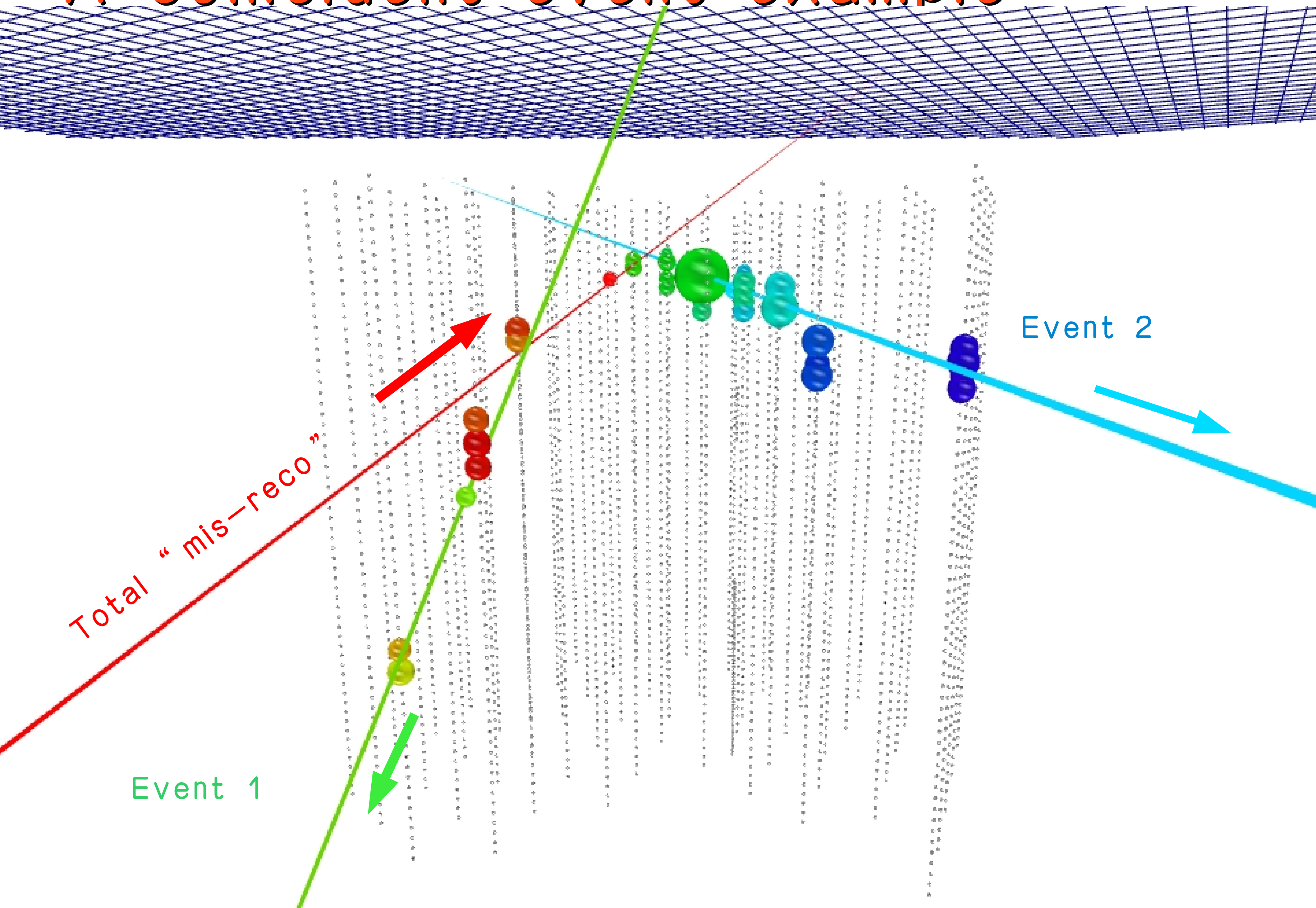
Only northern hemisphere



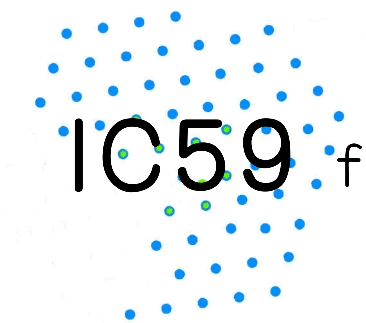
Misreconstructed air showers in the upgoing region.

Coincident air shower background

A coincident event example



Neutrino event selection



IC59 filter level

↓

Topological trigger

Search for
spatial and time clusters
in hit pattern

1 cluster	> 1 cluster
↓	↓
Define series of cuts	Define another series of cuts

Event numbers at neutrino level
— for the burnsample (= 10% of lifetime)

	DATA	Atmospheric neutrinos	CORSIKA (total)	Coincident CORSIKA
total	2662	2444	16	12

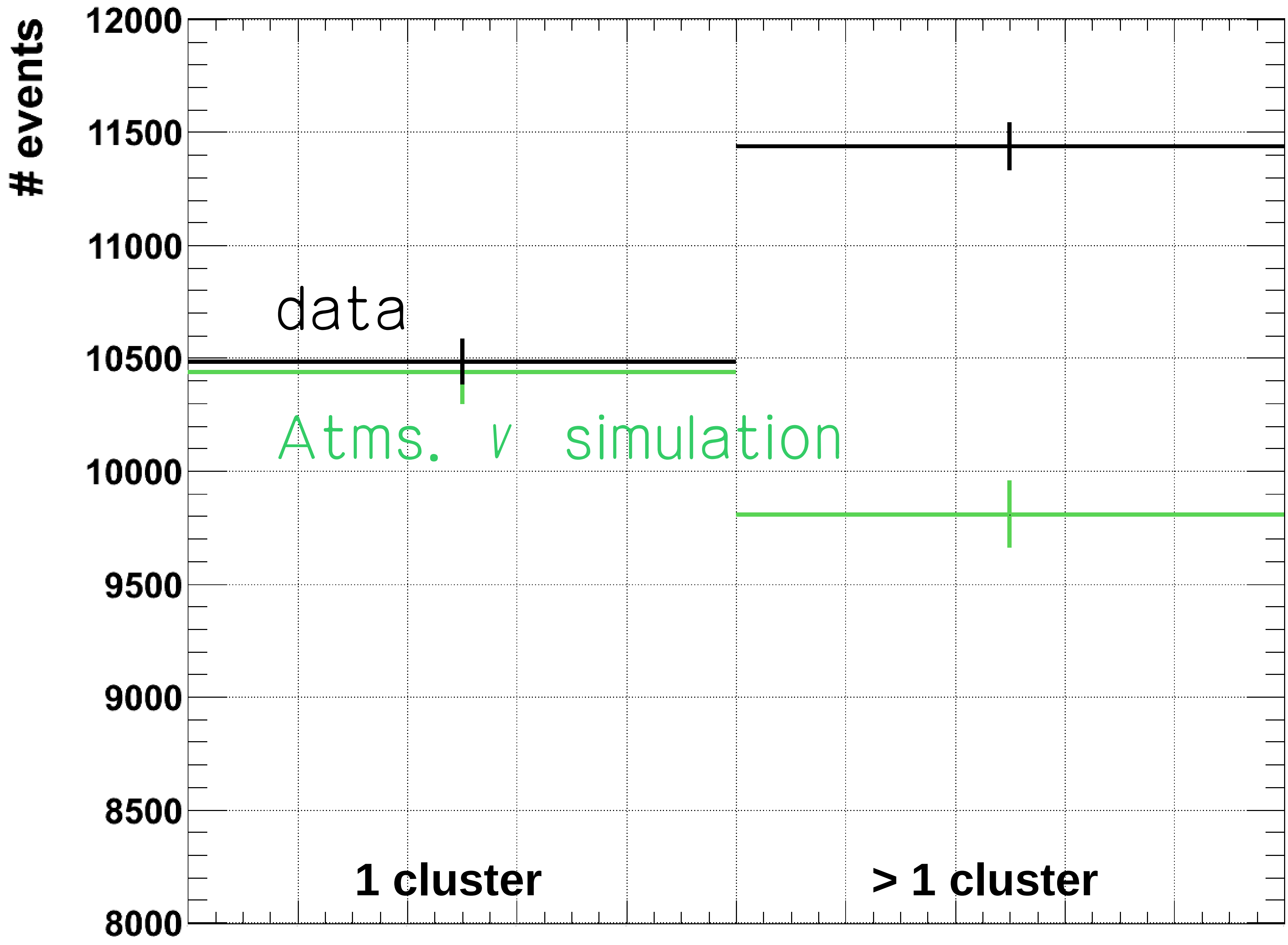
(not final)

Diffuse/atmospheric samples are high purity samples

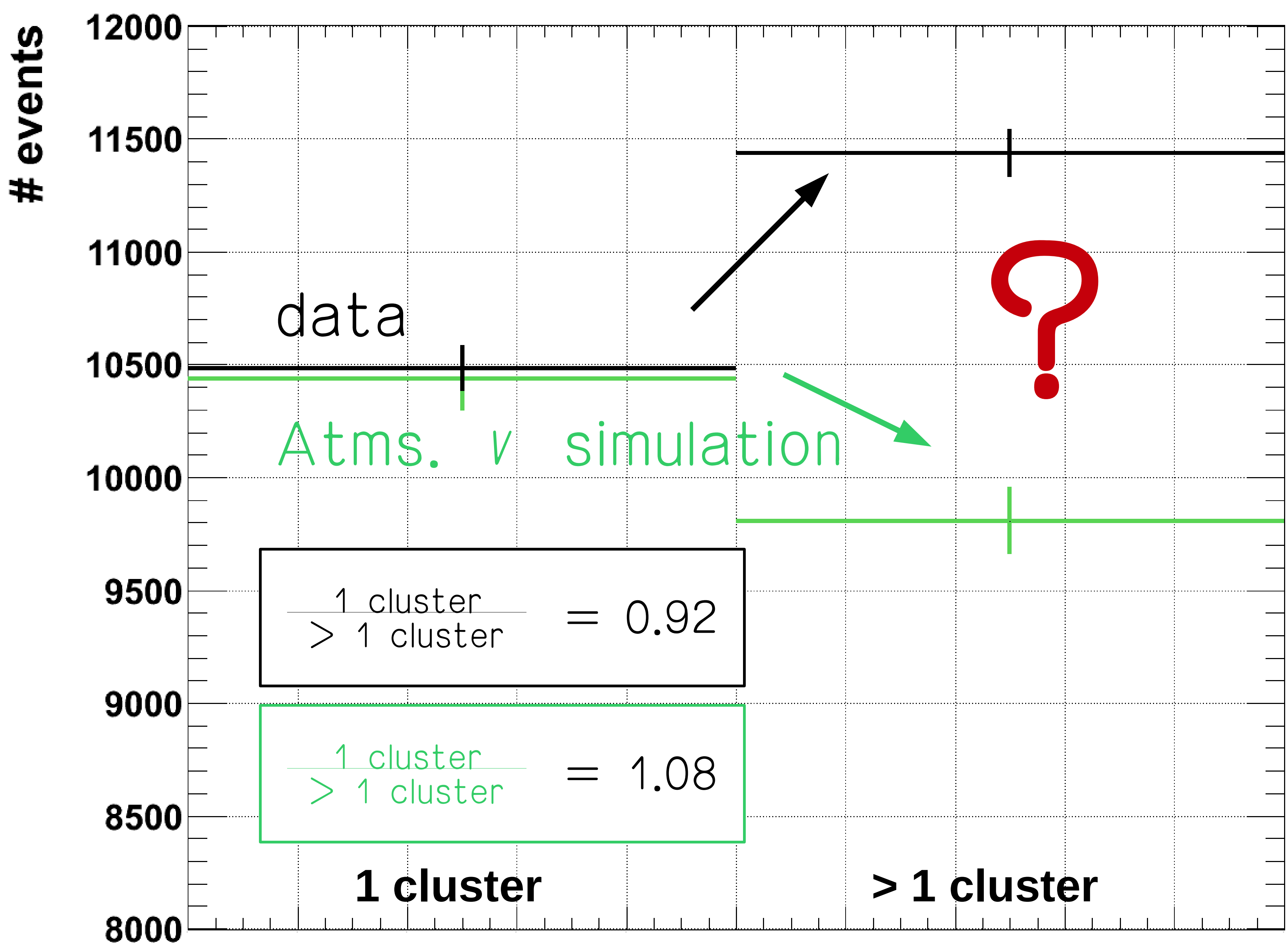
→ muon background contamination < 1%

→ excellent for systematic studies

Hit clusters at neutrino level



Hit clusters at neutrino level

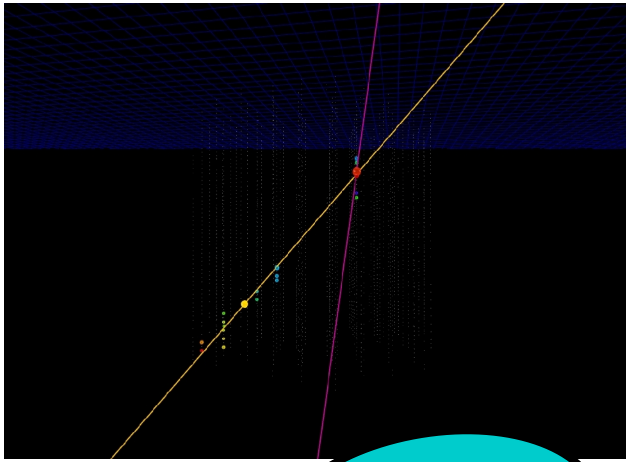


"Clustered event categories"

Look at the > 1 cluster events in the burnsample with the event viewer

Studied 157 events by eye
(out of 2000 burnsample events)

Dust layer



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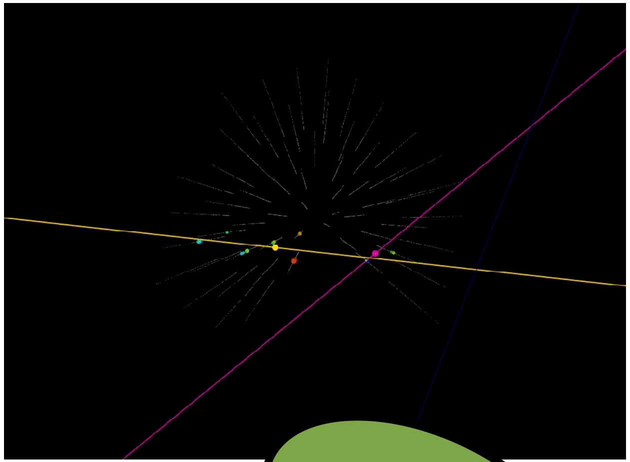
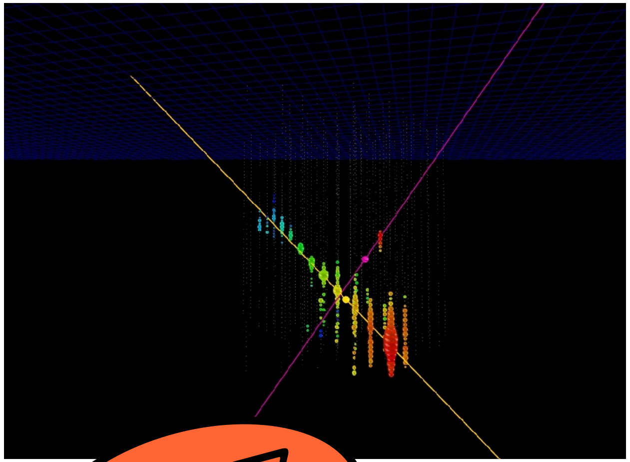
Pac–Man



20

Neutrino + muon

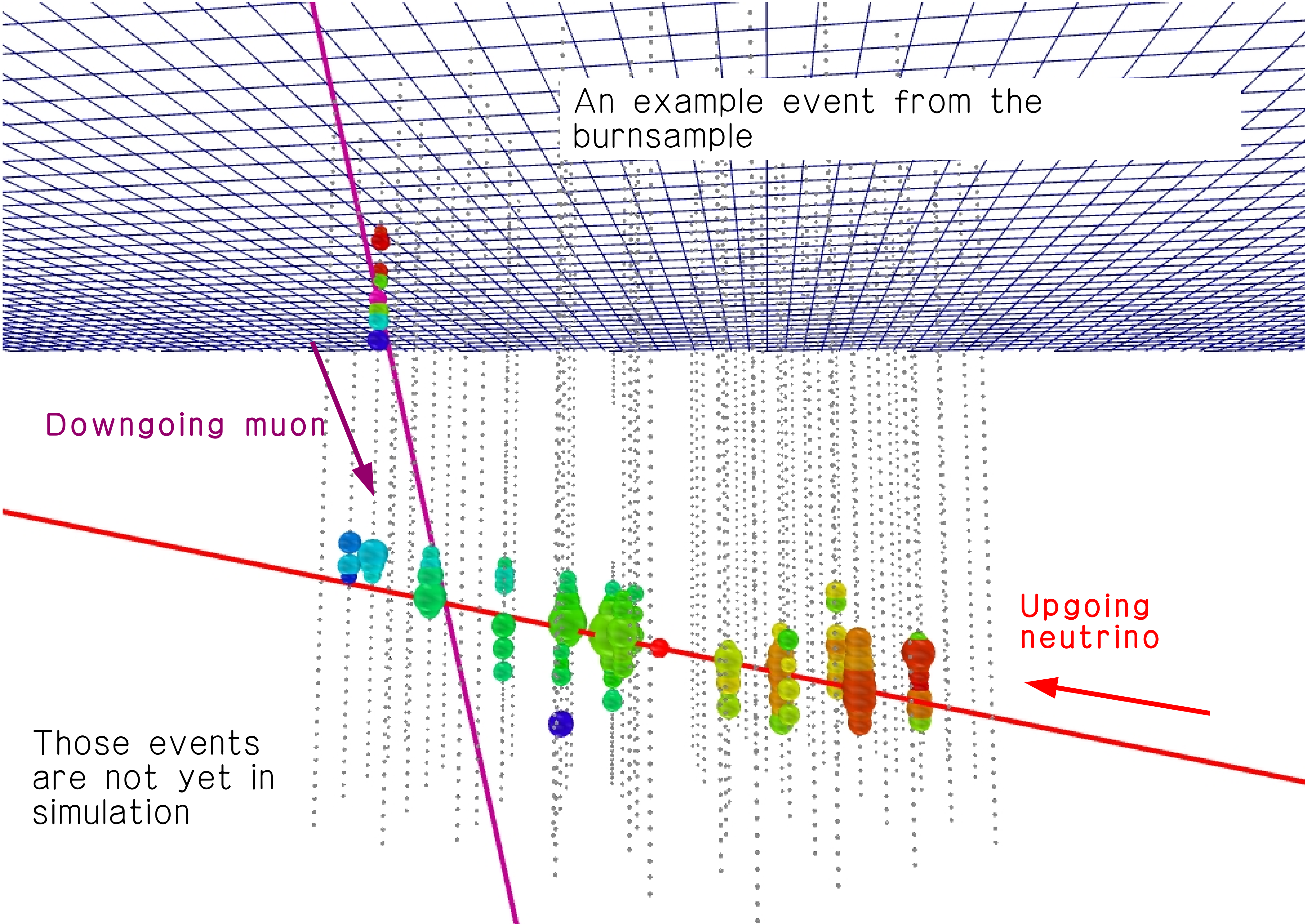


107

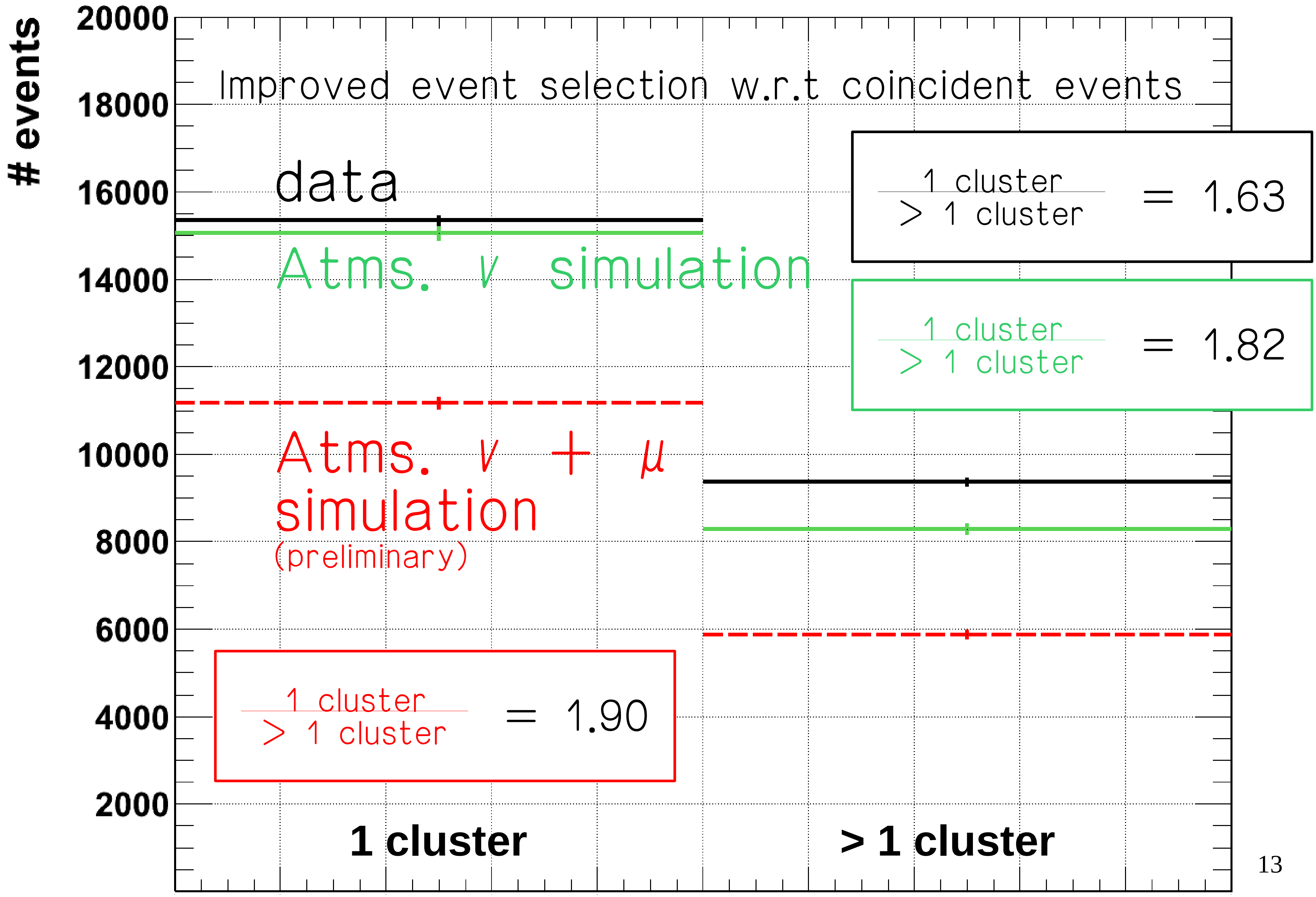
5% of total burnsample

These events are not in our simulation, yet!

ν + air shower coincident events

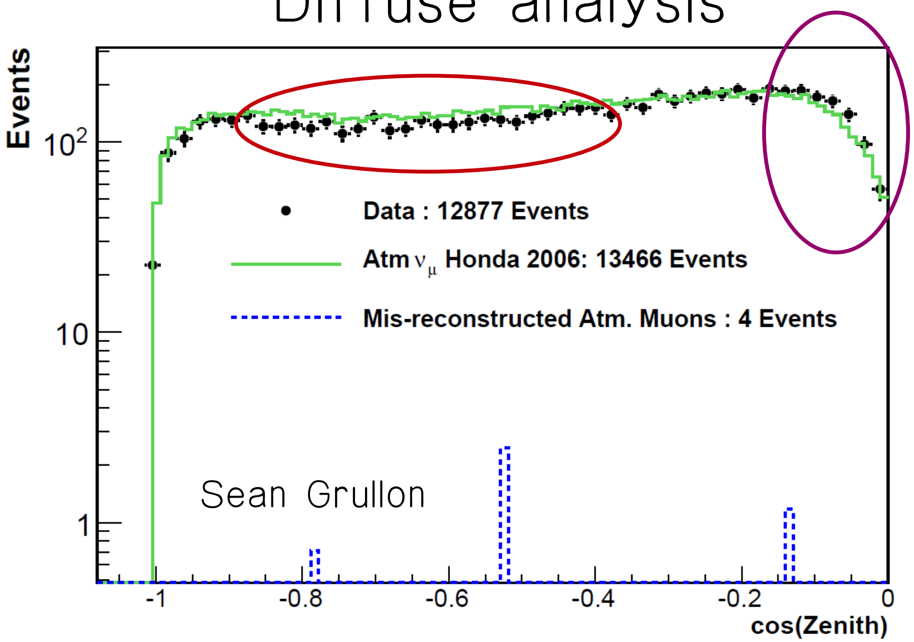


Hit clusters at neutrino level II



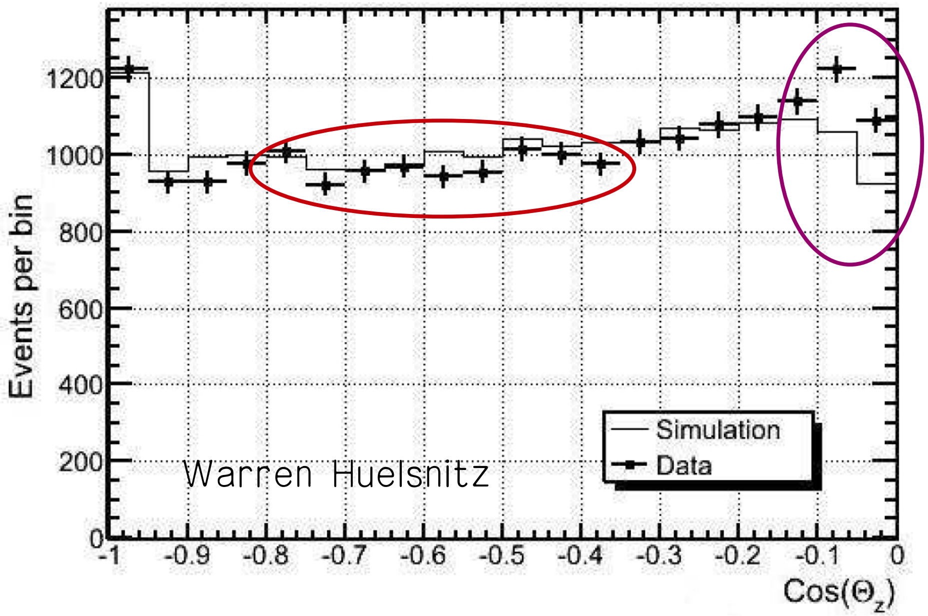
Zenith distribution in IC40

Diffuse analysis



Publication accepted by PRD.
arXiv:1104.5187v4

Atmospheric analysis



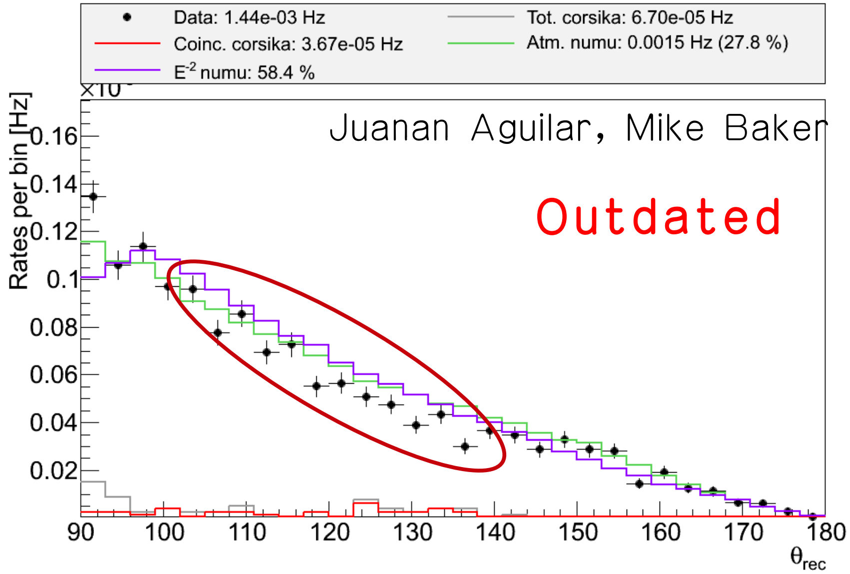
Phys. Rev. D83: 012001, 2011
arXiv:1010.3980v2

Both samples show:

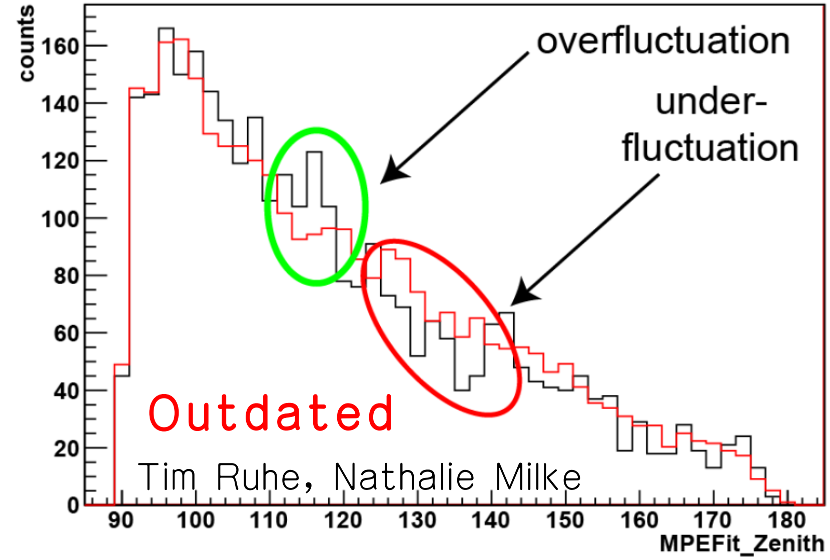
- Underfluctuation between 110° < θ < 140°
- Overfluctuation at the horizon

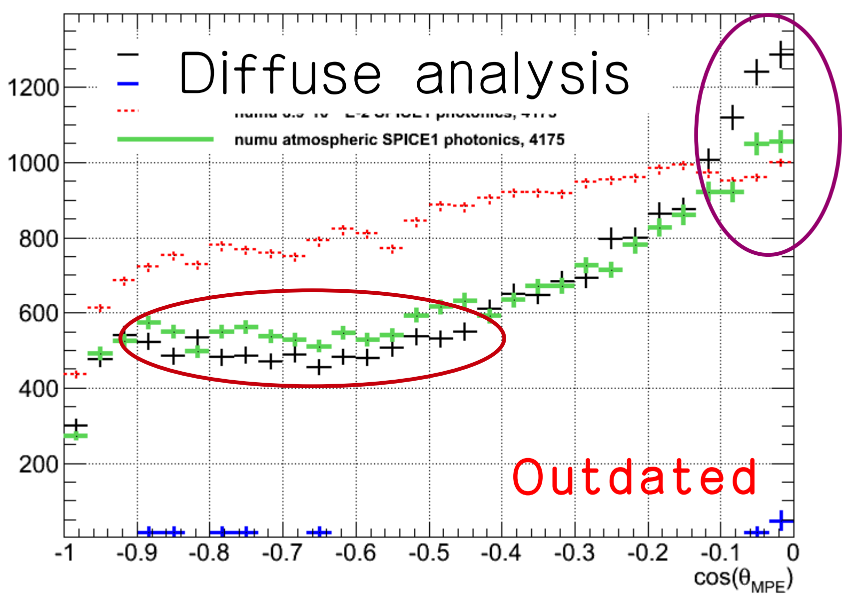
Zenith distribution in IC59

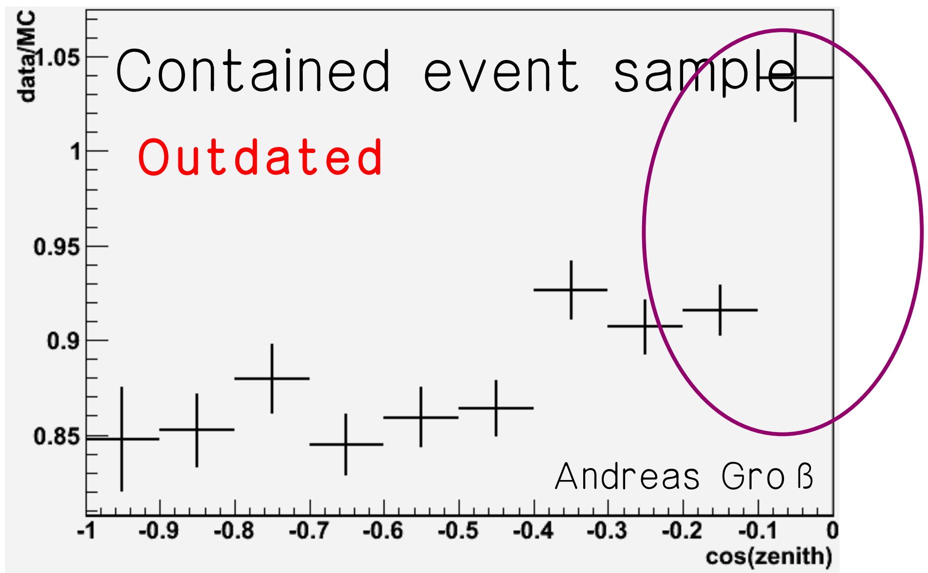
Point source analysis



Atmospheric analysis



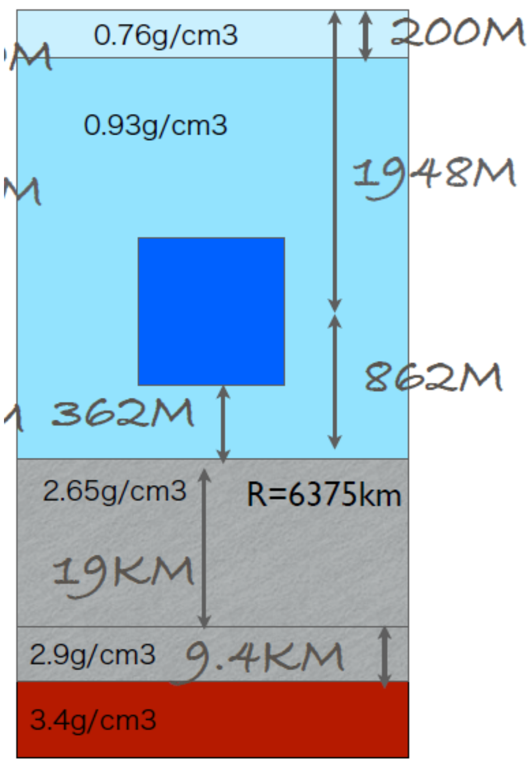




Same (significant!) features in IC59

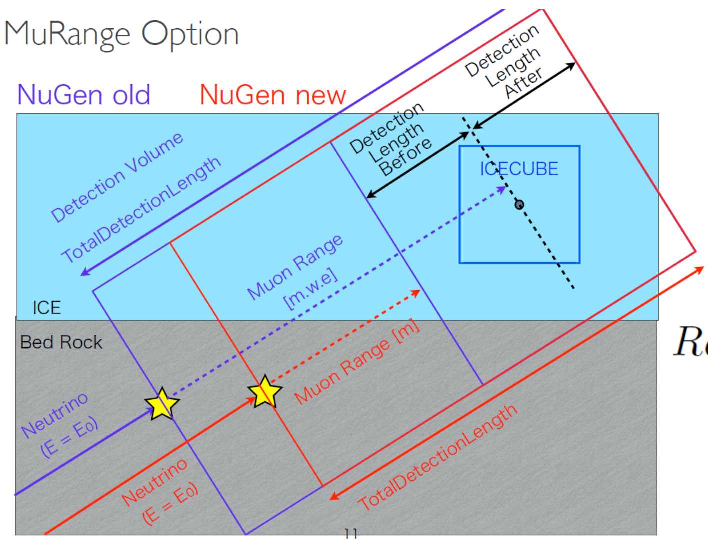
Improvements in neutrino simulation

I. Updated ice geometry



II. Updated muon range

MuRange Option



$$Range = \frac{1}{b} \, log(\frac{bE}{a} + 1) \quad [\mathrm{m.w.e}]$$

b = 0.251e-3 / 1.2 ~ 0.209e-3

a = 0.212/1.2 ~ 0.177

III. Updated weighting equations

(more accurate at high energies)

Old Weight vs New Weight

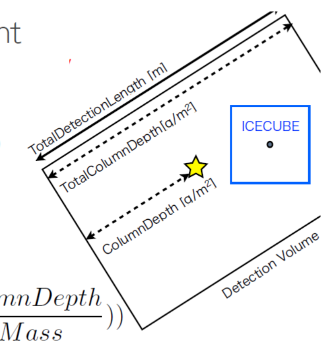
- Old Weight

$$W = (\sigma_{tot} \cdot \frac{TotalColumnDepth}{ProtonMass}) \cdot exp(-\sigma_{tot} \cdot \frac{ColumnDepth}{ProtonMass})$$

- New Weight

$$W = (1 - exp(-\sigma_{tot} \cdot \frac{TotalColumnDepth}{ProtonMass})) \cdot Norm \cdot exp(-\sigma_{tot} \cdot \frac{ColumnDepth}{ProtonMass})$$

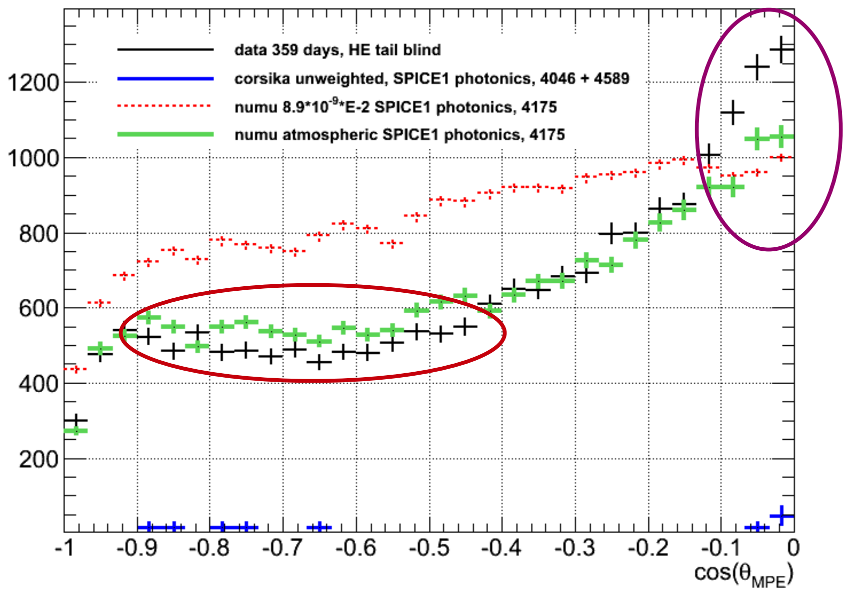
$$Norm = 1 \,/ \int_0^{TotalColumnDepth} exp(-\sigma_{tot} \cdot \frac{X}{ProtonMass})dX \,/\, (1 \,/\, TotalColumnDepth)$$



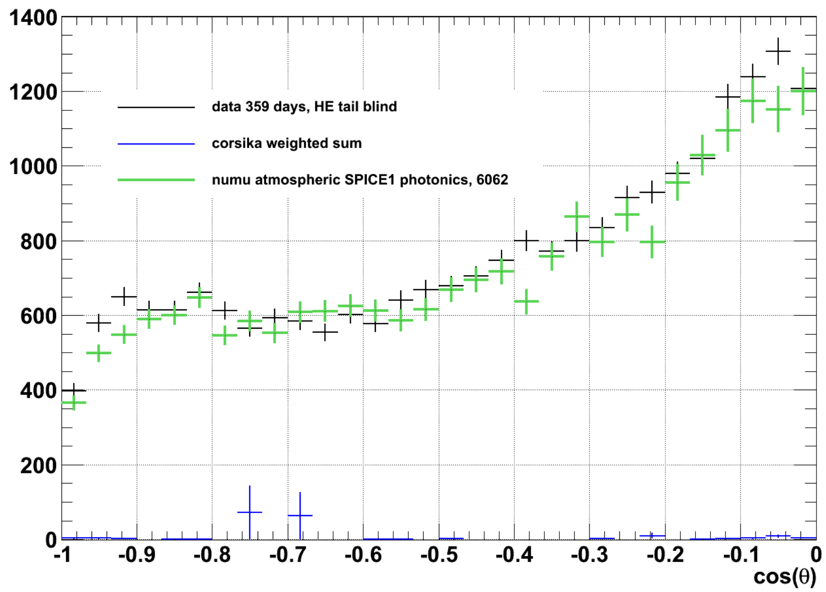
Kotoyo Hoshina

Updated zenith distribution

Old



New



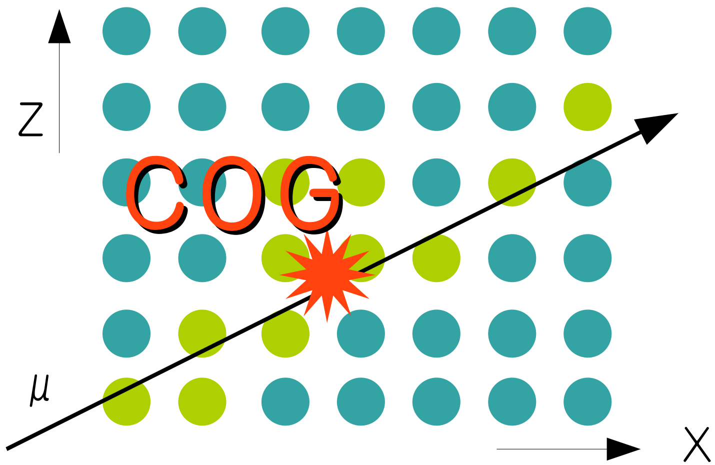
No significant structures after neutrino simulation update.

Our lesson:

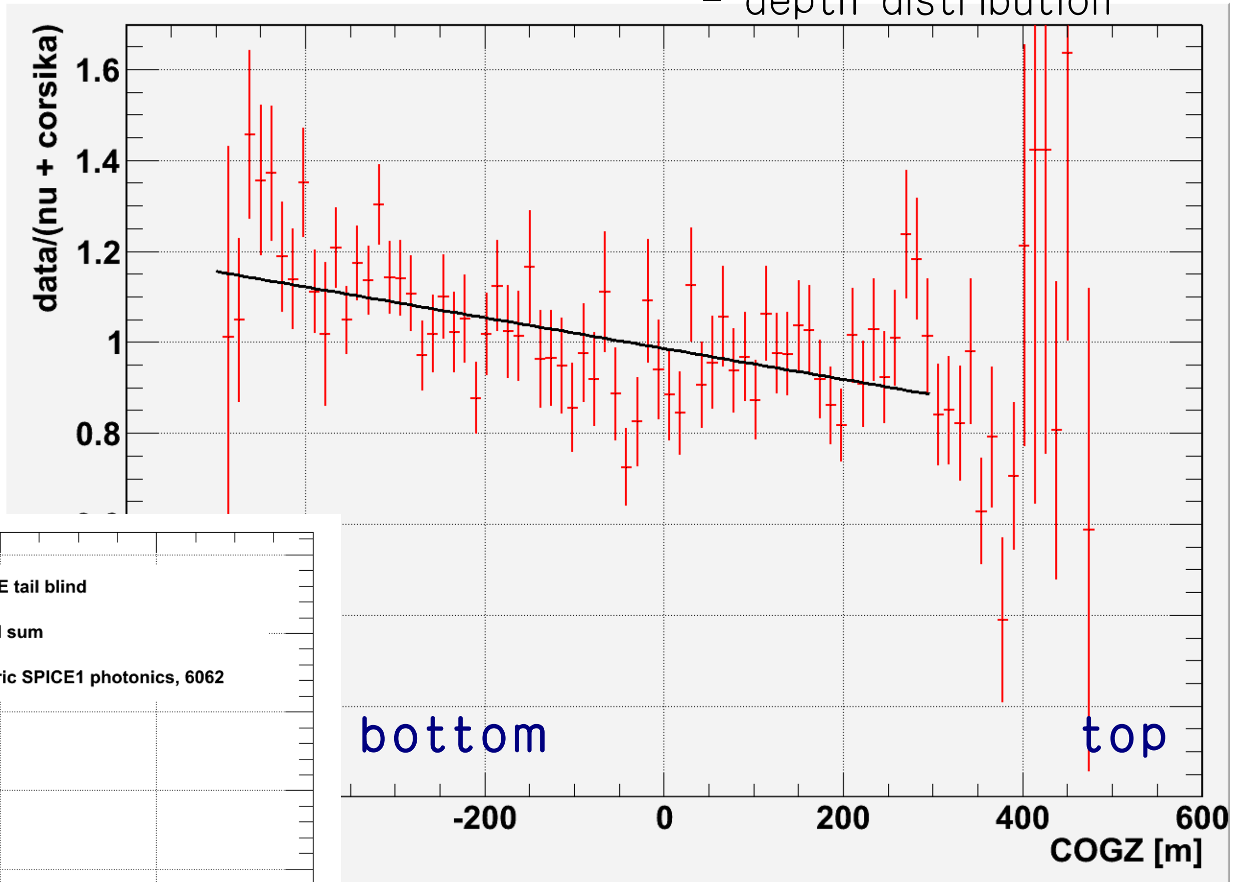
Small changes to the simulation software can have a huge impact on high level distributions

Ice

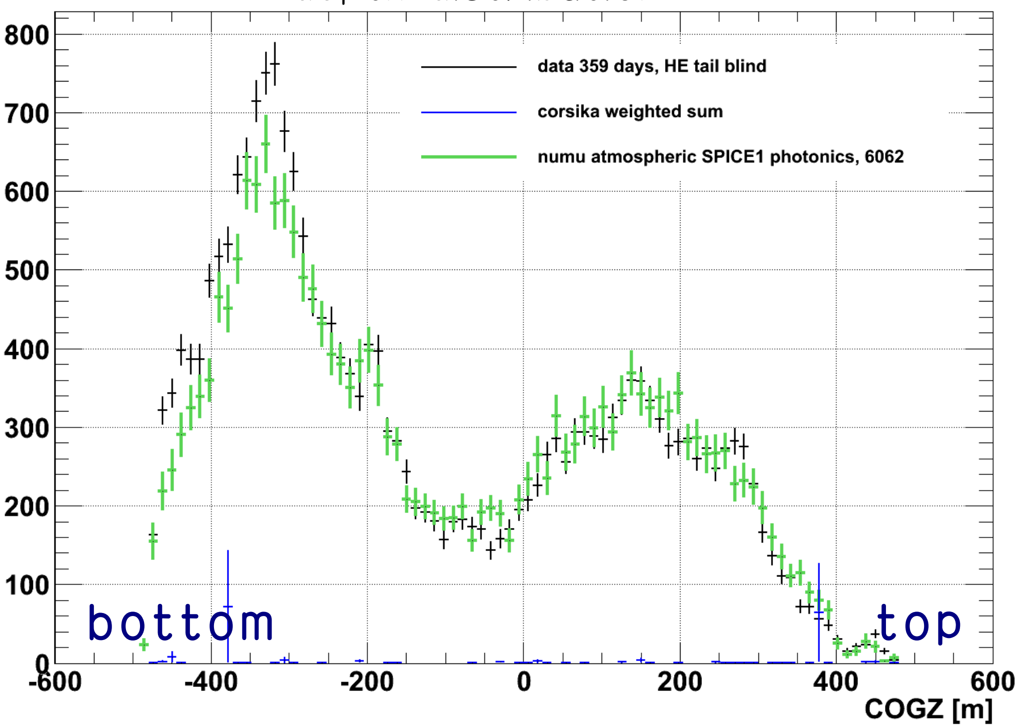
Ice model uncertainties?



Data/MC ratio Center of Gravity
- depth distribution



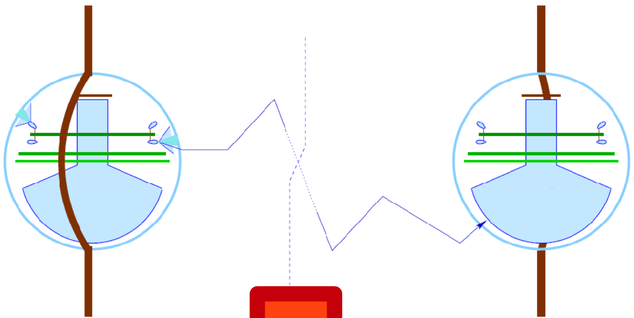
Center of Gravity
- depth distribution



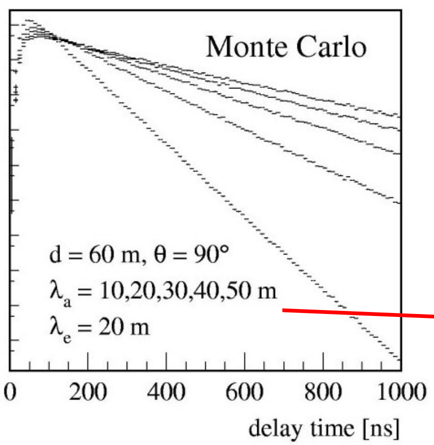
Depth dependent disagreements
are indications for
ice model uncertainties

Ice in our simulation chain

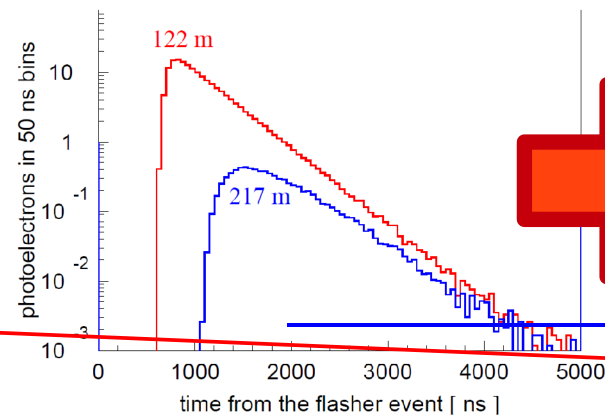
Flasher measurements to determine optical ice properties



Two individual approaches for deriving the optical ice properties

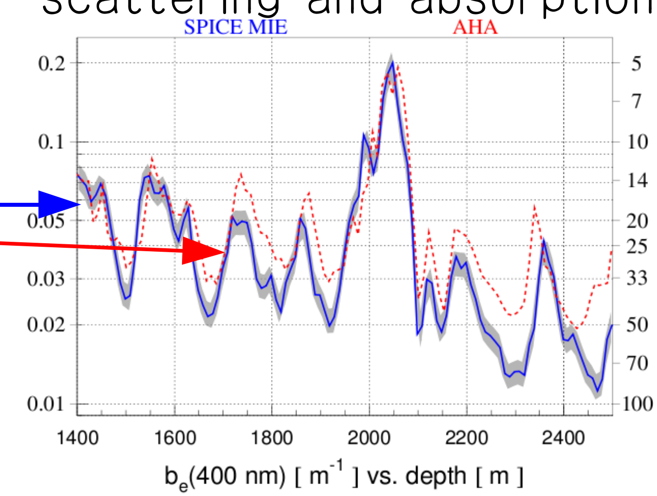


Fit to single photoelectron time distributions of flasher pairs (Kurt Woschnagg)

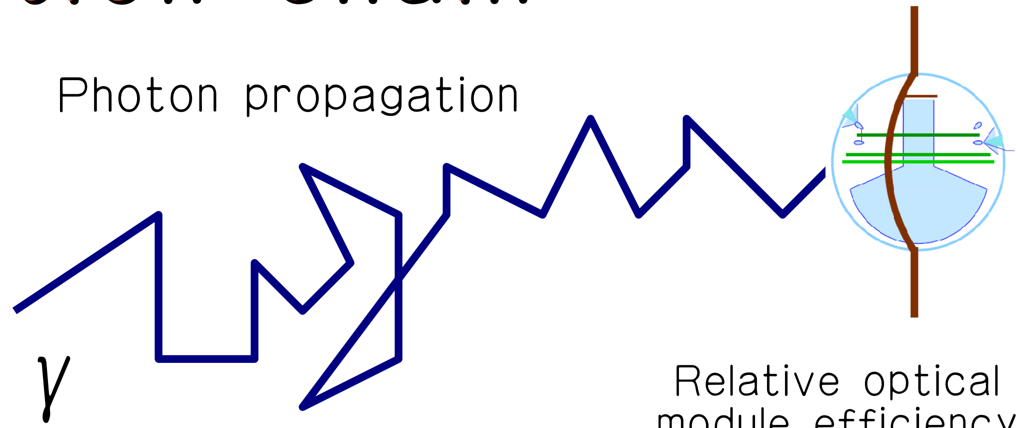


Global fit to charge over time distributions (Dmitry Chirkin)

scattering and absorption



Photon propagation



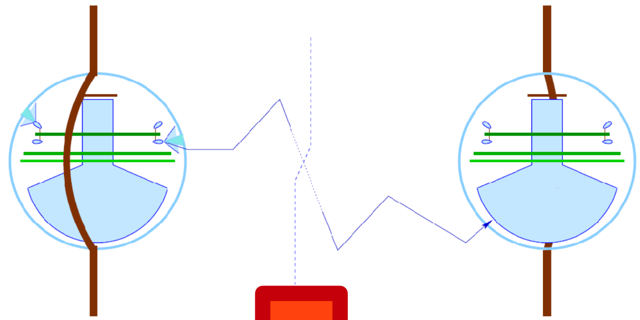
Photonics
- tabulated probabilities

ppc
- direct photon tracking

Relative optical module efficiency (simulation scaling factor)

Ice related uncertainties

Flasher measurements to determine optical ice properties



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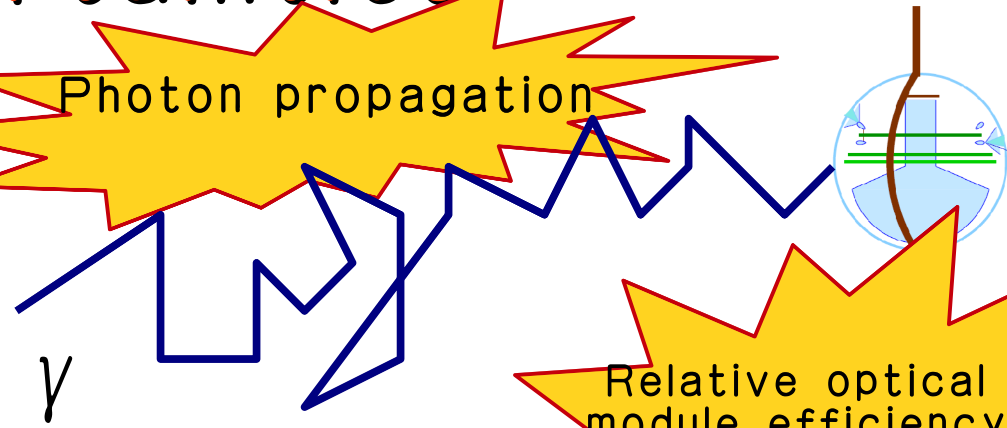

Photonics
- tabulated probabilities

ppc
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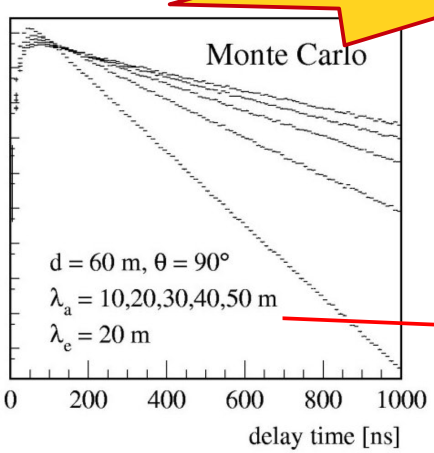
Relative optical module efficiency
(simulation scaling factor)

Two individual approaches for deriving the **optical ice properties**



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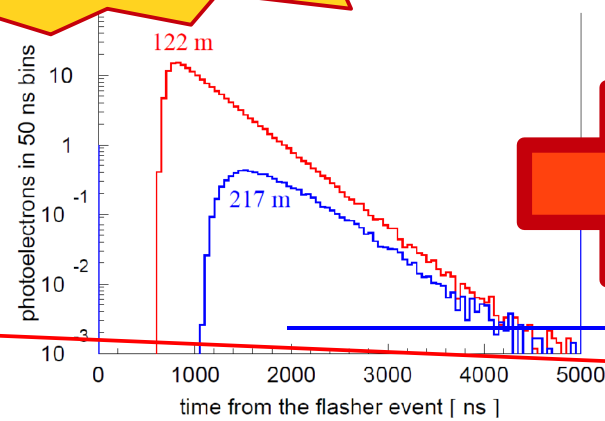

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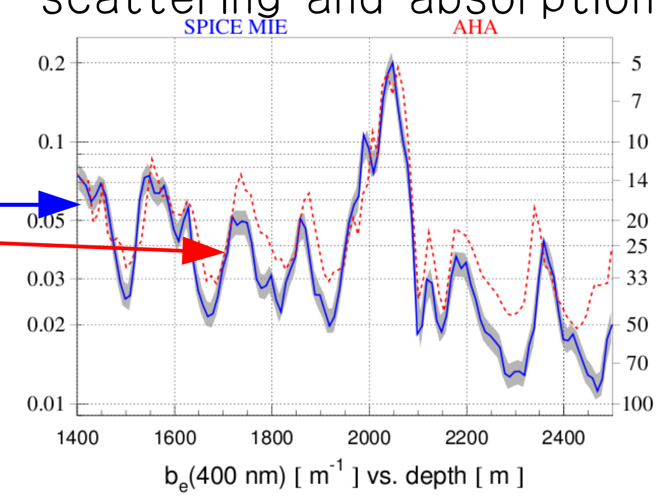
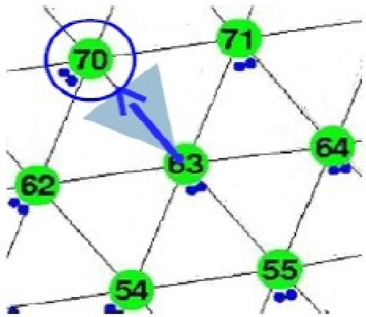
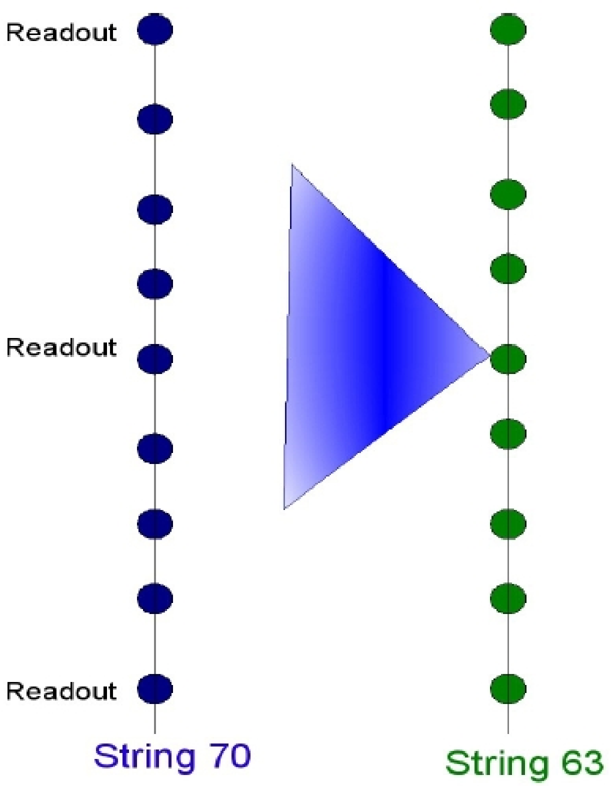
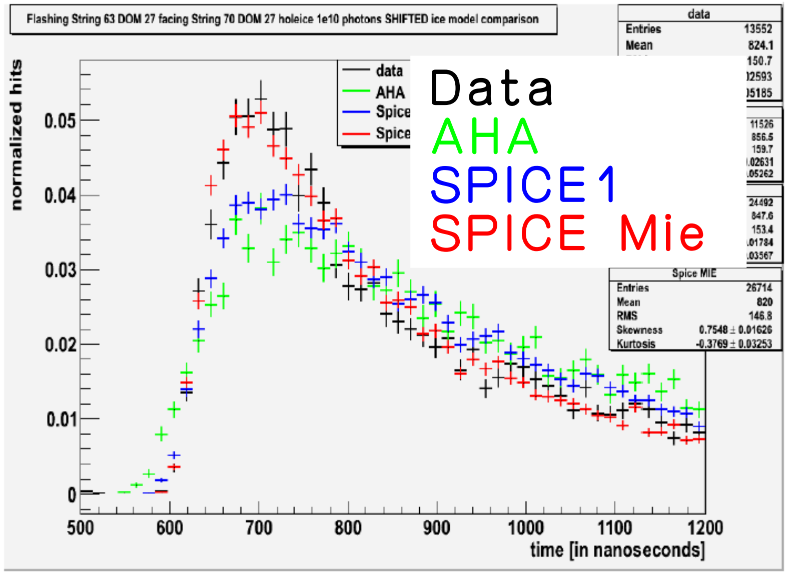


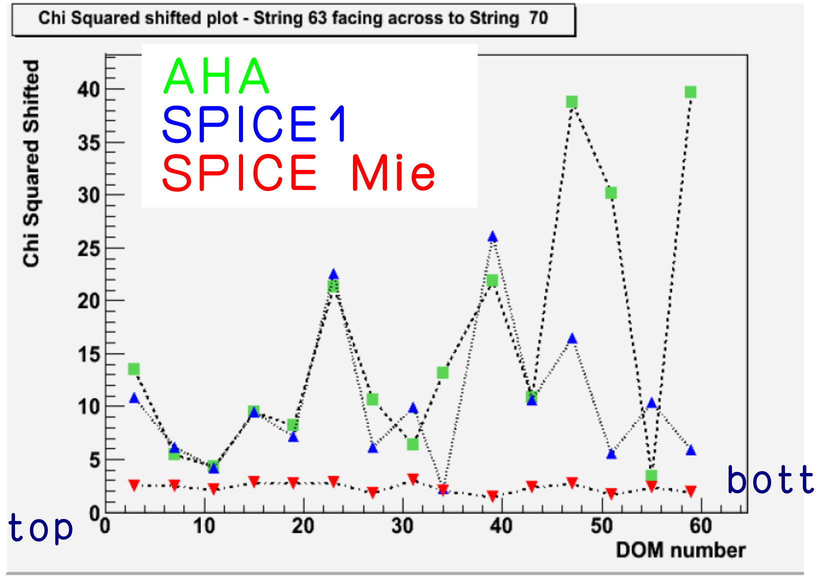
Flasher tests





A full circle test: compare measured and simulated flasher timing distributions for different ice models





SPICE Mie describes data best

– only if varaible time shift (~ 100ns) allowed!

Calculate χ^2 for timing distributions in dependence of depth

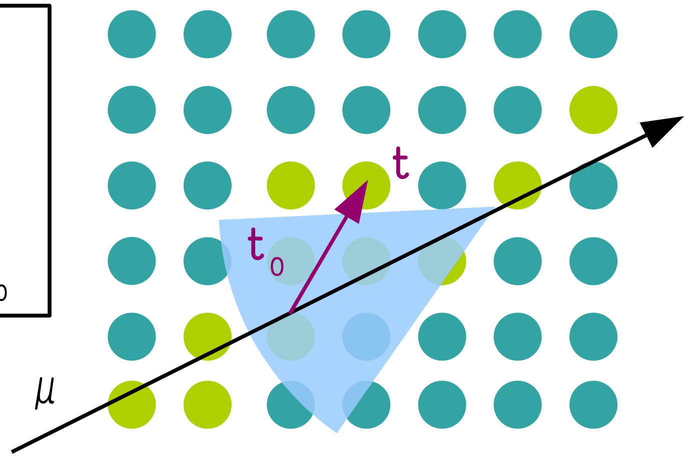
SPICE Mie shows best agreement over all depths

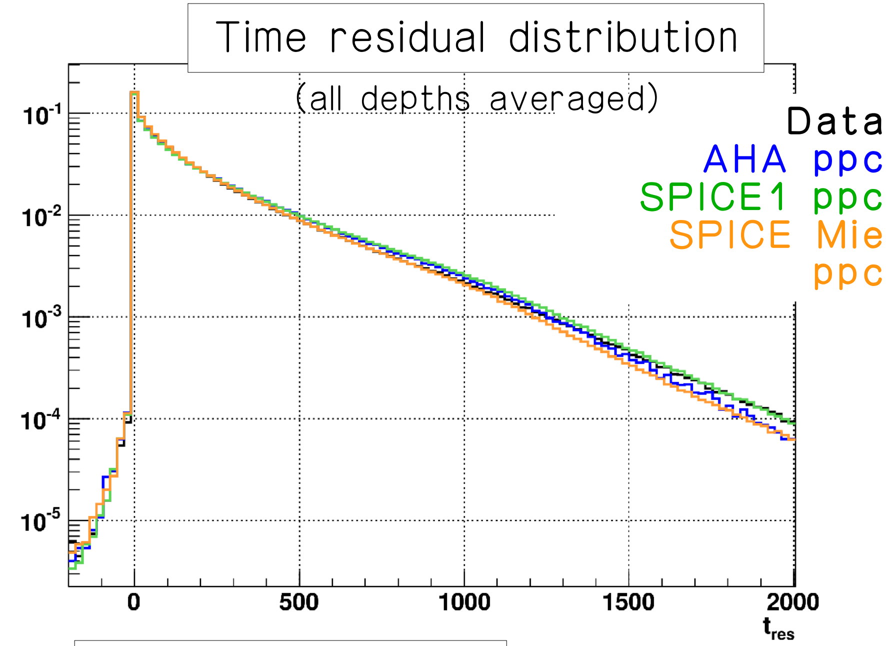
Sarah Bouckoms

Muon time residuals

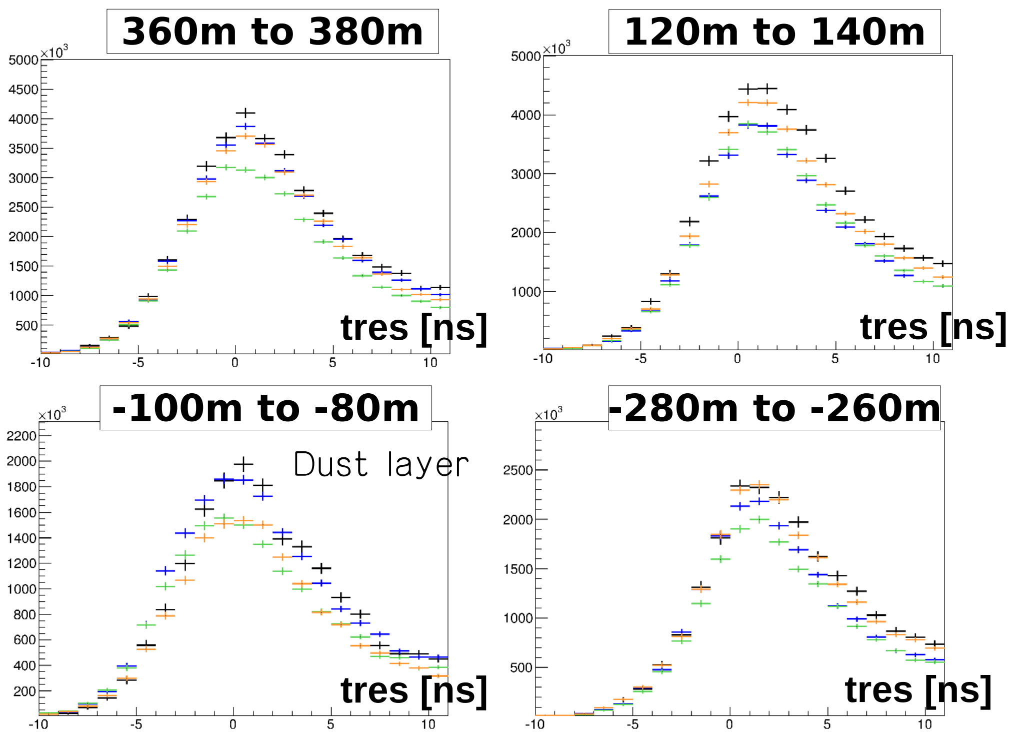
Measured arrival time: t
Expected arrival time: t_0

Time residual:
$$t_{res} = t - t_0$$

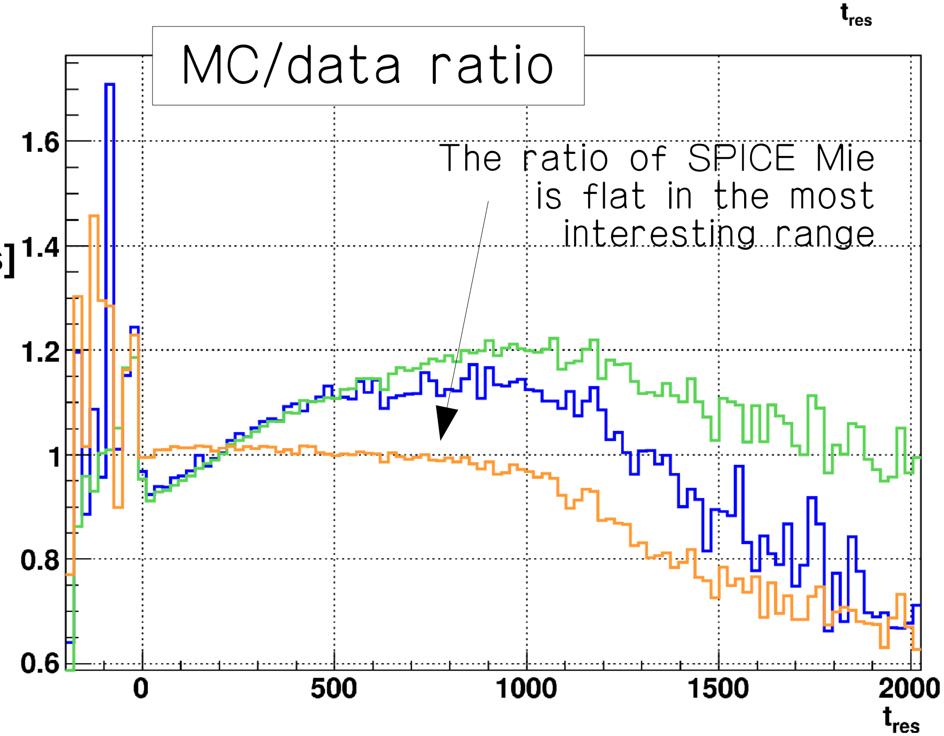




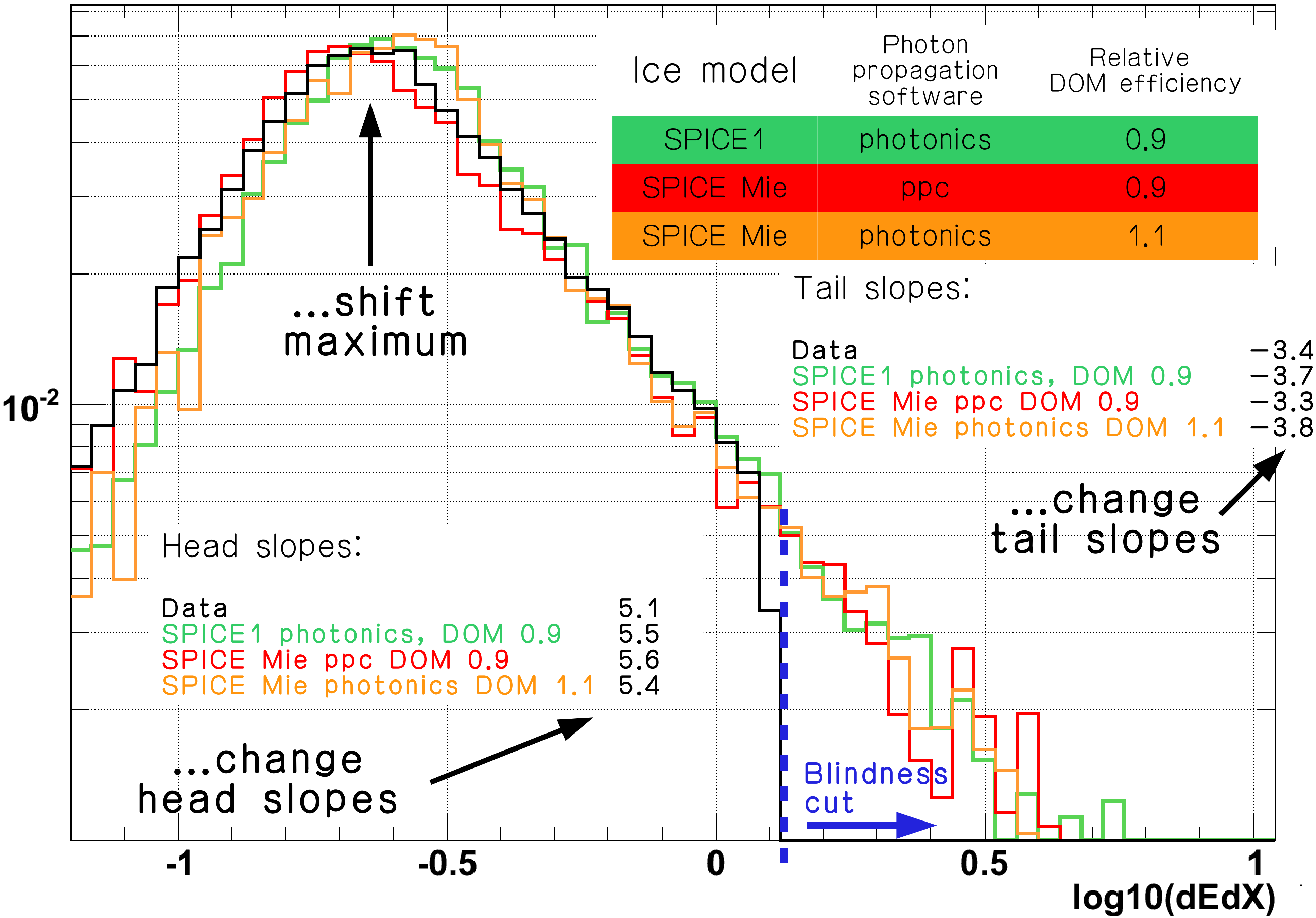
Time residual distributions for hits between −10ns and 10ns



No ice model fits data perfectly

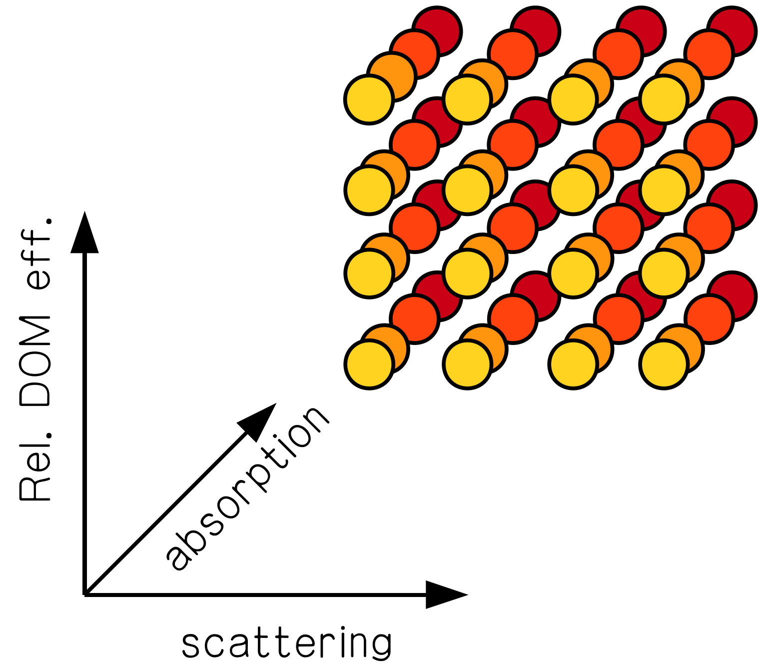


High level impacts



How to implement this in analysis

"Discrete approach"

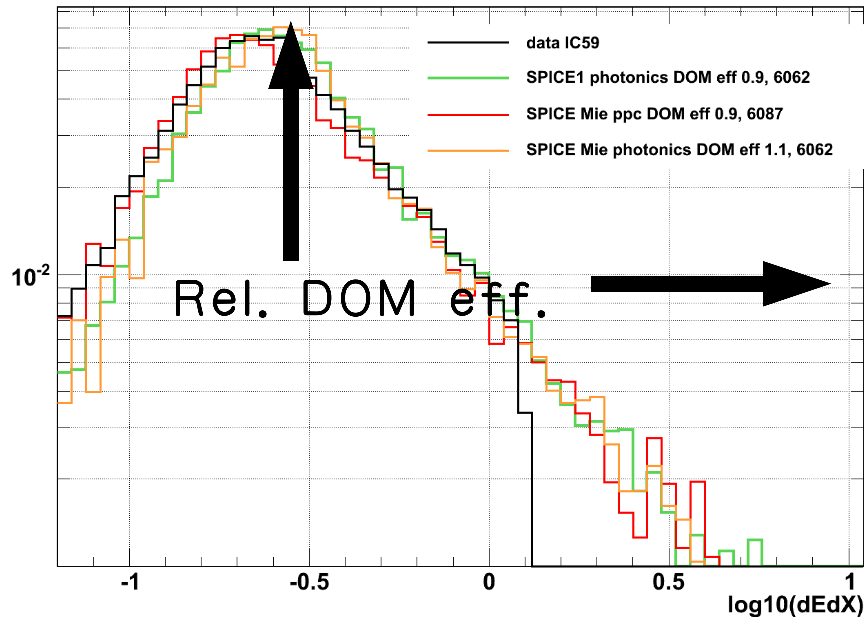


Simulate a whole grid of datasets with varied parameters

Repeat analysis for every dataset

Choose e.g. the most conservative limit as default

"Fitting approach"



Parametrize the influence on pdfs

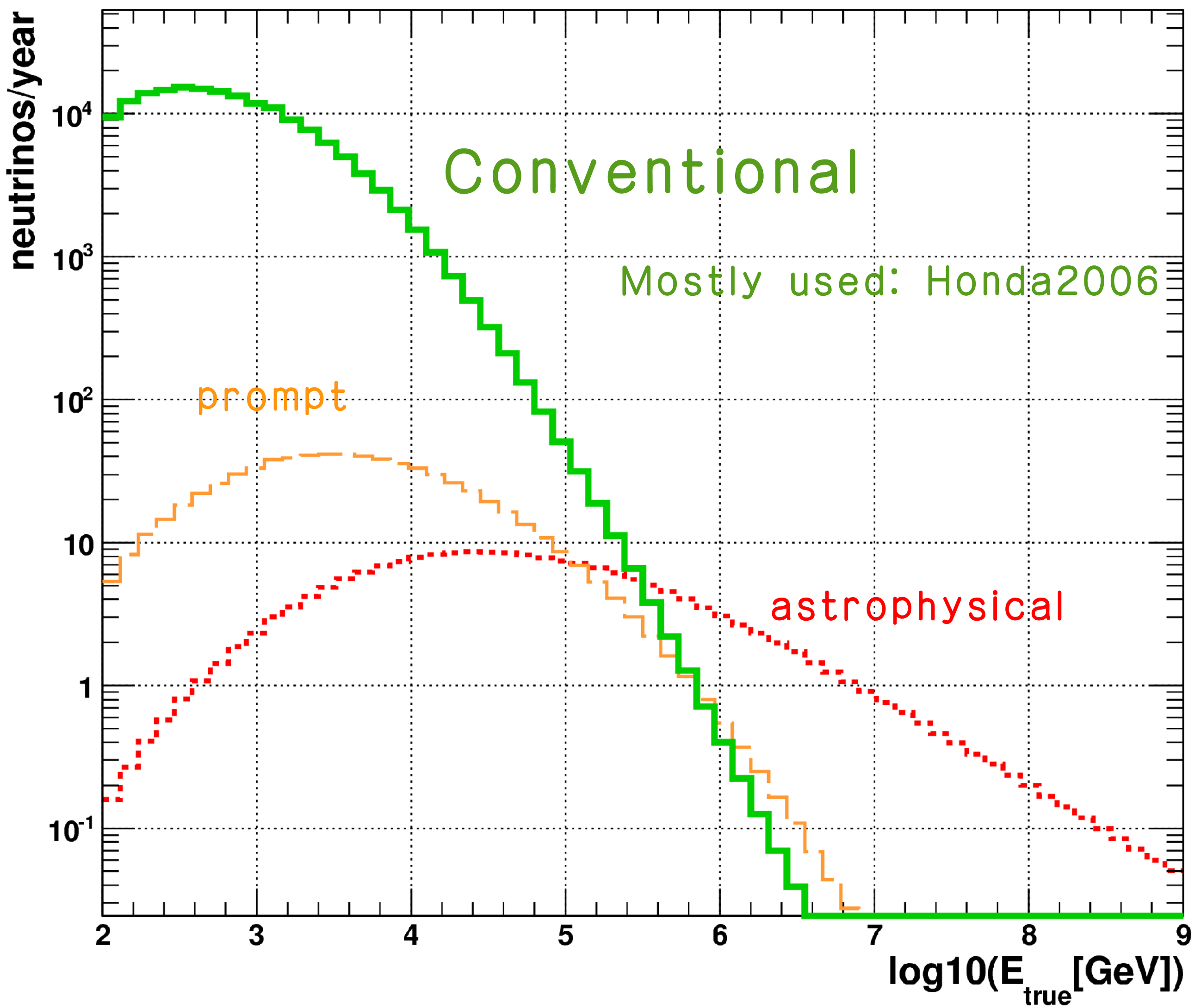
$$\mathcal{L} = \mathcal{L}\left(N_a, N_p, N_c\right) \longrightarrow \mathcal{L}\left(N_a, N_p, N_c, \epsilon\right)$$

Constrain the uncertainty

$$\mathcal{L} = \left(\prod \frac{\mu_{ij}^{n_{ij}}}{n_{ij}!} \cdot e^{-\mu_{ij}}\right) \cdot e^{-\frac{1}{2}\frac{(\epsilon-\epsilon_0)^2}{\Delta\epsilon}}$$

Atmospheric neutrino fluxes

Simulated neutrino energy distribution



The fluxes at our energies are only extrapolated from lower energy measurements

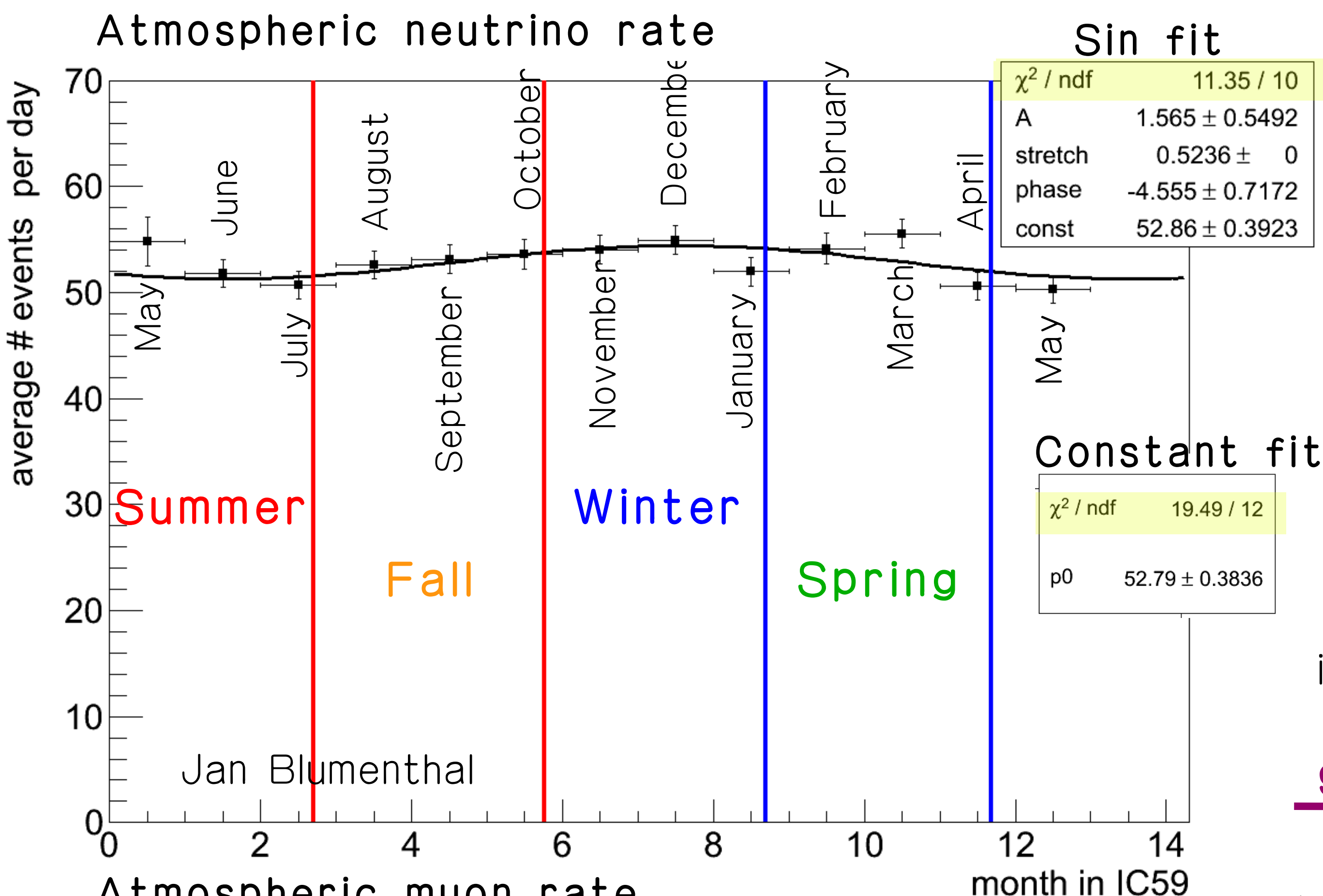
primary pion

$$\frac{dN_\nu(E_\nu,\theta)}{dE_\nu} = \frac{\phi_N(E_\nu)}{(1-Z_{NN})(\gamma+1)} \left\{ \left[\frac{Z_{N\pi}(1-r_\pi)^\gamma}{1+B_{\pi\nu}\cos\theta E_\nu/\epsilon_\pi} \right] + 0.635 \left[\frac{Z_{NK}(1-r_K)^\gamma}{1+B_{K\nu}\cos\theta E_\nu/\epsilon_K} \right] \right\},$$

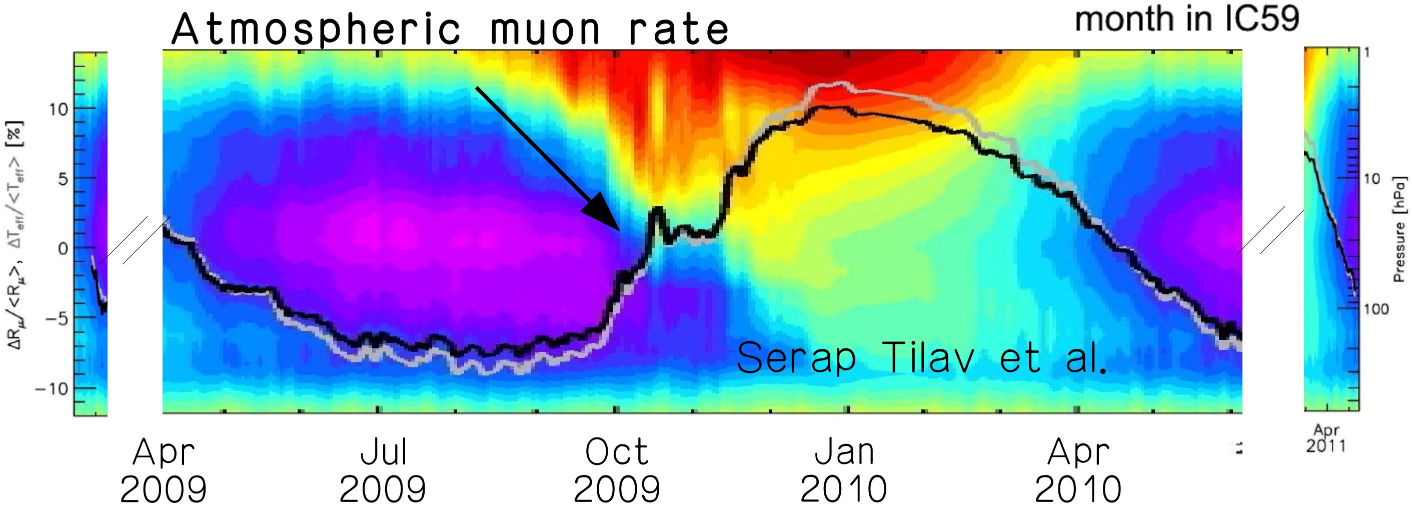
kaon

How reliable are these predictions?

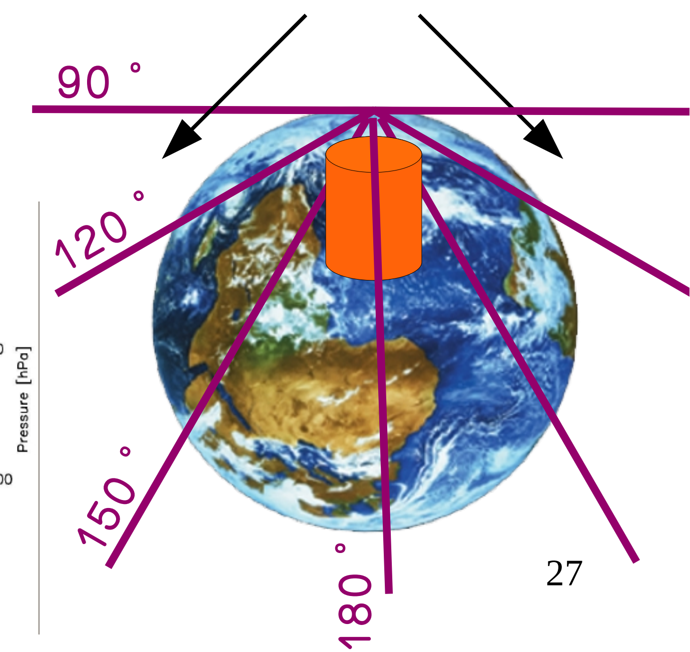
Seasonal variations



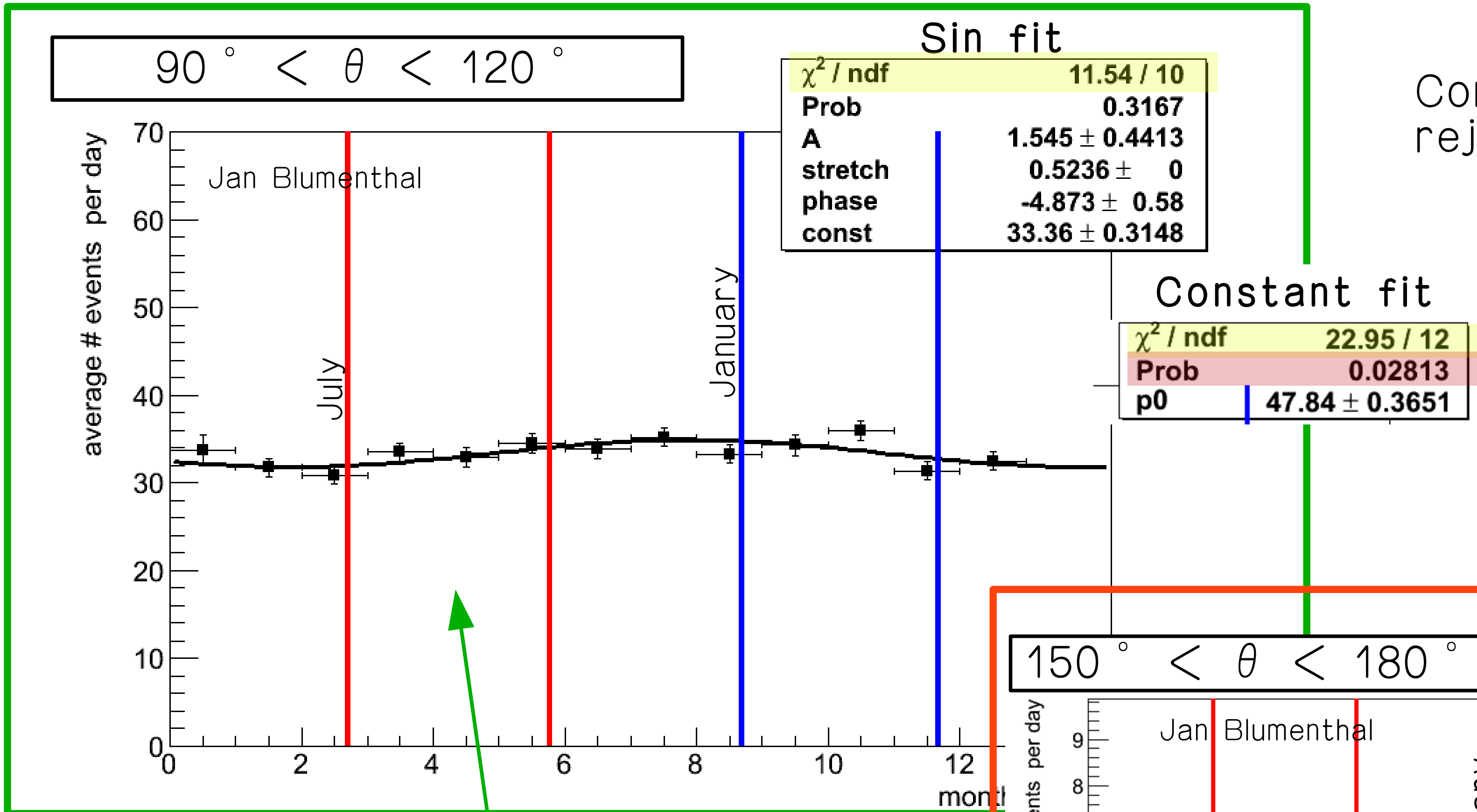
Neutrino rate is correlated with downgoing muon rate!



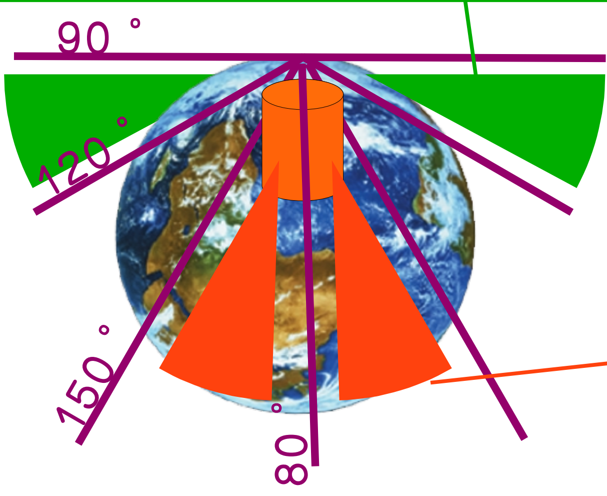
Largest solid angle
(= most neutrinos)
in the Southern atmosphere

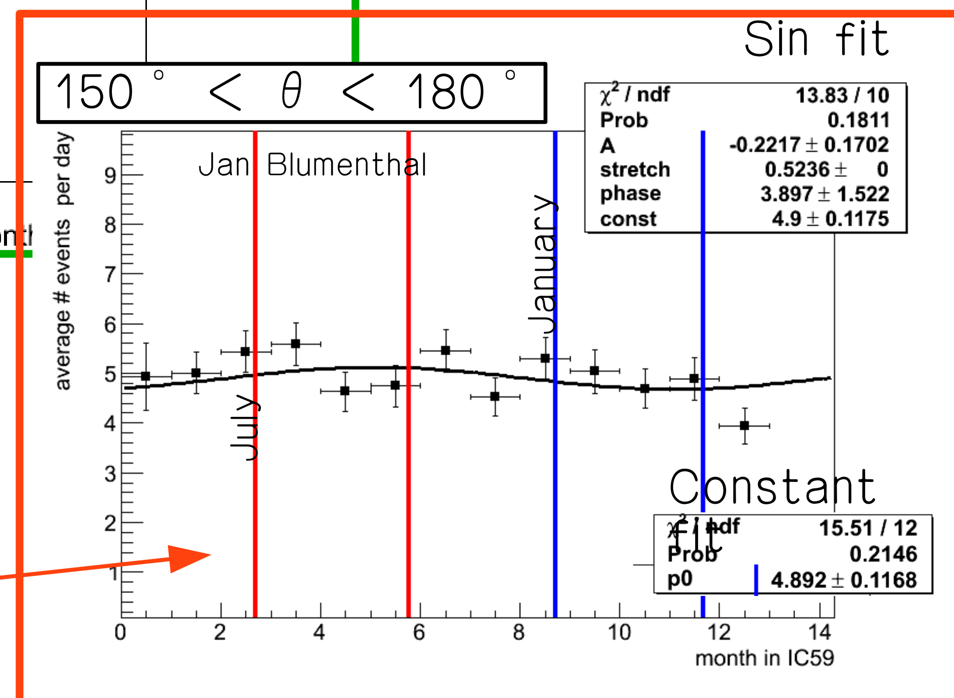


Seasonal variations - zenith dep.



Constant rate rejected with ~ 2σ



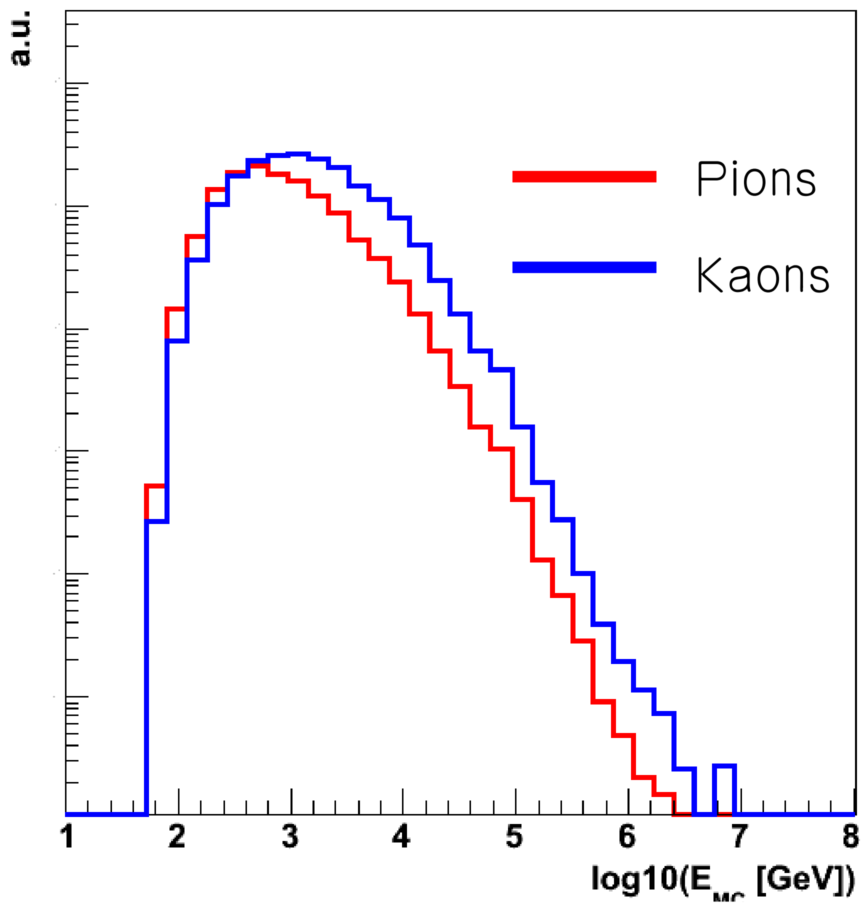


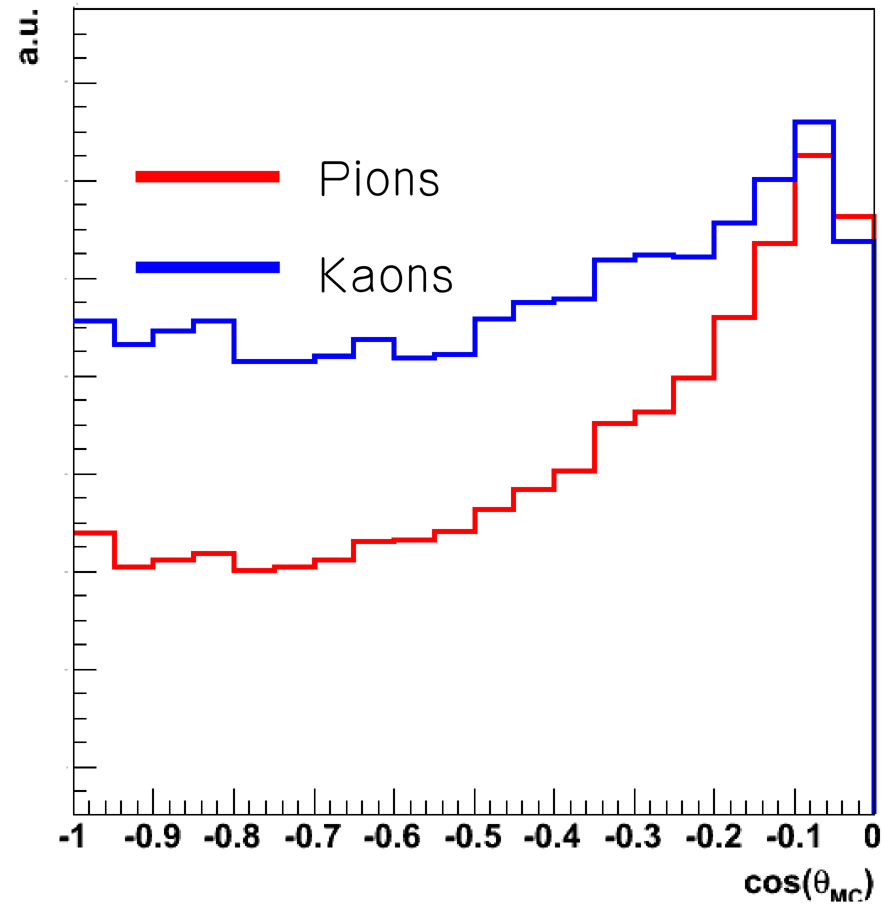
Less statistics but phase looks shifted

Pions and Kaons

Atmospheric neutrino weighting

$$\Phi_{\nu}(\cos(\theta), E, type) = (\Phi_{\pi}(\cos(\theta), E, type) + \Phi_{K}(\cos(\theta), E, type))$$





The flux expectations Bartol/Honda are extrapolated from measurements at energies < 1 TeV.

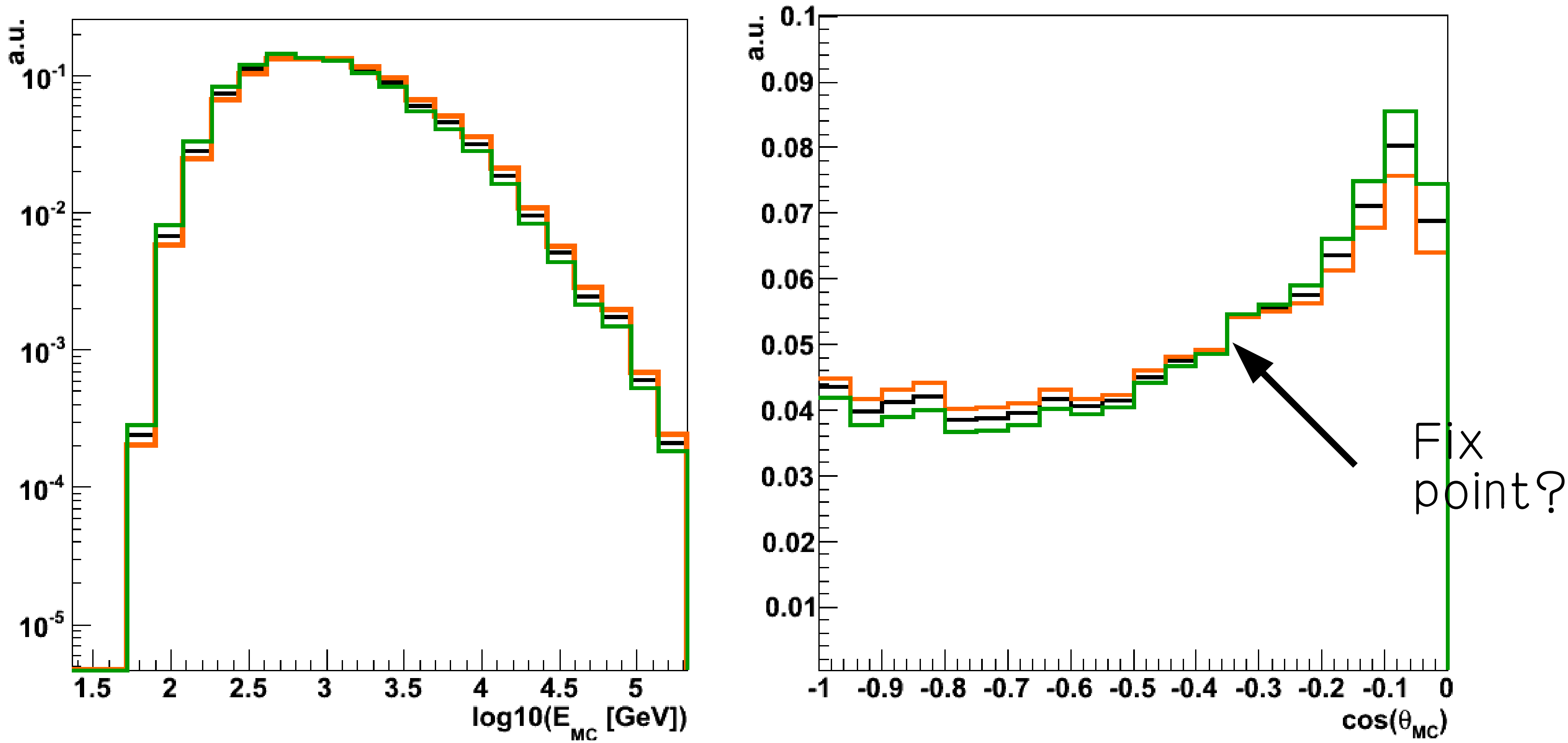
The Kaon/Pion ratio

Nominal Φ_K/Φ_π

$0.5 * \Phi_K/\Phi_\pi$

$2 * \Phi_K/\Phi_\pi$

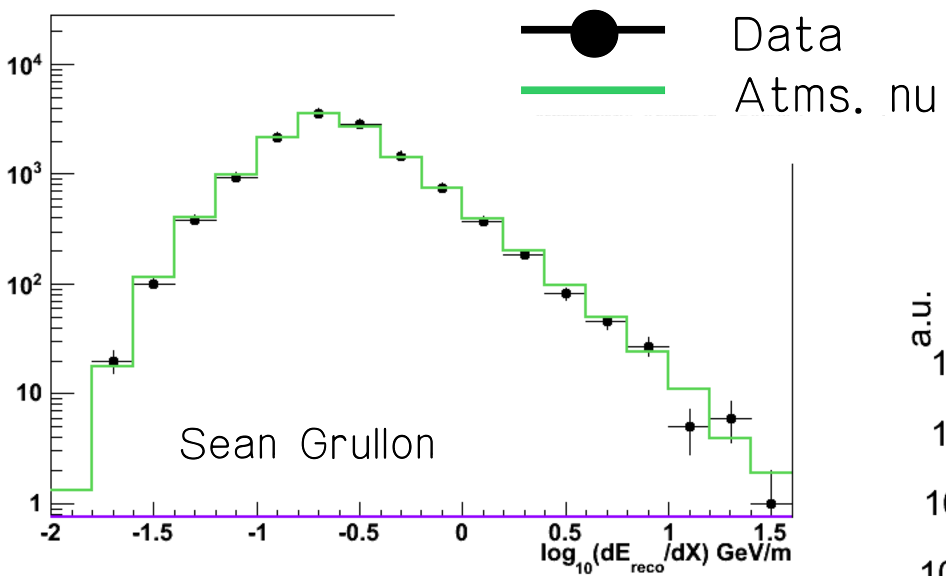
Varying the Kaon/Pion ratio has an impact in particular on the zenith angle distribution.



Another good candidate to be implemented as a free systematic fit parameter in the likelihood function!

The neutrino knee

The IC40 diffuse energy spectrum



arXiv:1104.5187v4

A first hint on a knee in atmospheric neutrinos?

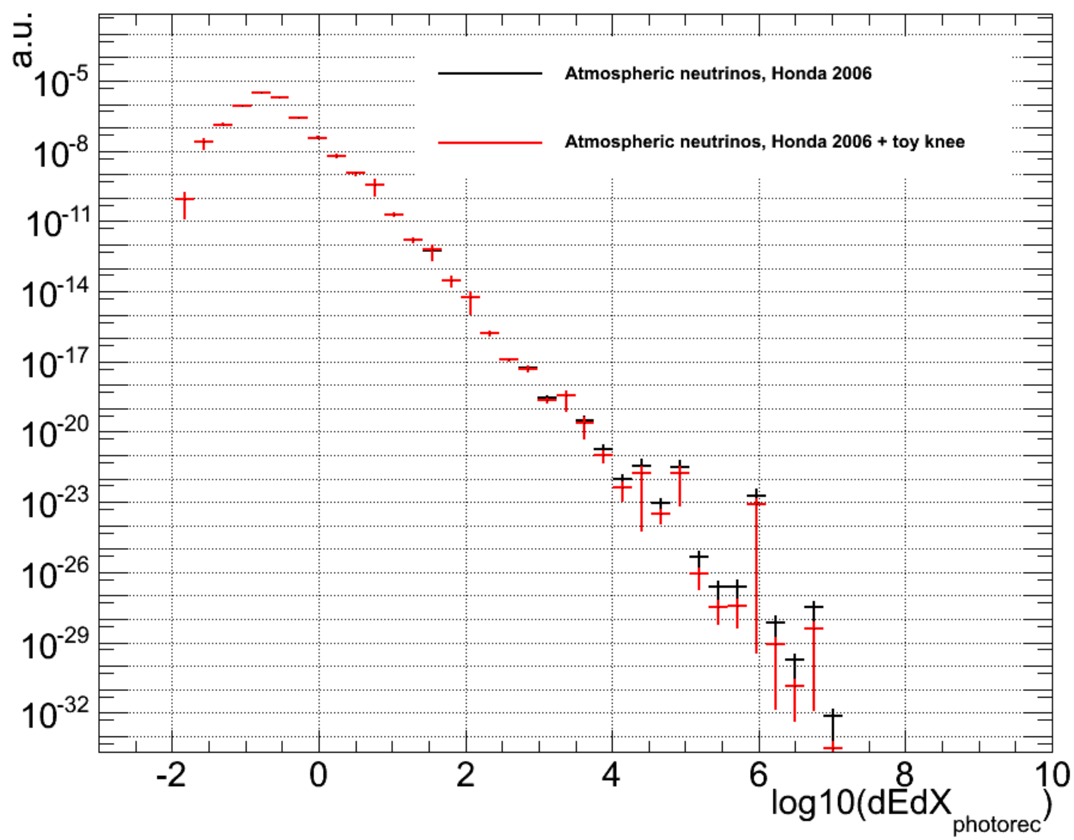
A knee in cosmic rays is not included in our atmospheric neutrino MC, yet.

A cosmic ray knee makes us more sensitive to an astrophysical flux.

Simulating a "simple knee"

(spectrum steepening at fixed energy)

Visible in our reconstructed energy distribution



Impact on diffuse analysis

Strategy:

Recalculate the nucleon flux from the Honda neutrino flux

Build ratios between Honda nucleon flux and different cosmic ray flux parameterizations

Reweight the Honda neutrino flux with a “knee factor”

Change in sensitivity compared to no-knee Honda2006

Bindig et al. (18%)

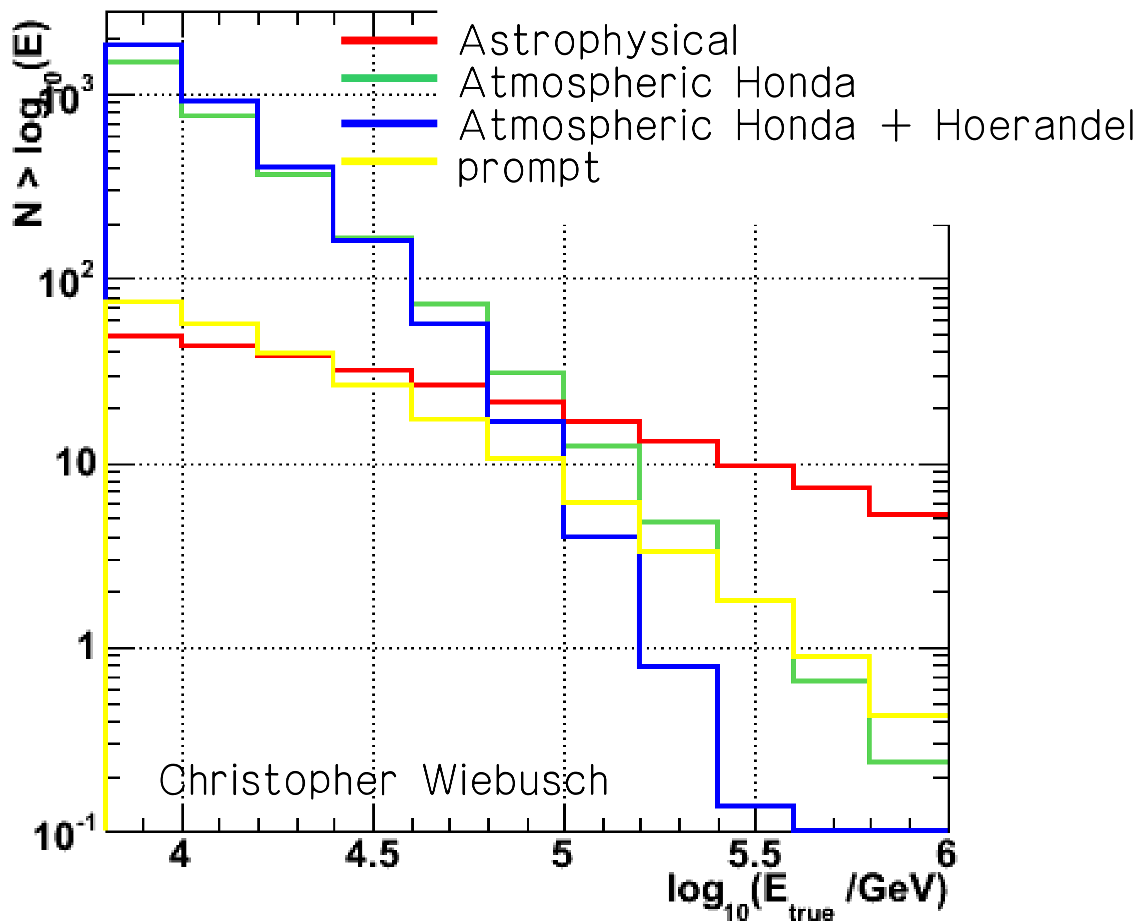
Gaisser et. al. (14%)

Hoerandel et al. (15%)

Significant impact!

Cumulative event distribution

(e.g. Hoerandel model)



Another “discrete” nuisance parameter
→ repeat the likelihood analysis for different knee models

Summary

IceCube is becoming more and more sensitive
 – not only to neutrino signals, but also to systematic effects!

Different sources for uncertainties:
 Detector, software, simulation, theory

Those systematics can be identified and taken into account in analysis

Working hard to have systematics under control for our first neutrino discovery!