Muons in IceCube

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Abstract: The IceCube muon and neutrino detector represents a unique combination of shielding matter and instrumented volume that will for the first time ever allow measurement of the atmospheric muon spectrum up to the PeV range. As a result, a wide range of physics topics can be investigated. These include particle physics, such as measurement of charm and kaon production cross sections in regions not accessible to accelerators, as well as astrophysics, since the muon flux distribution is sensitive to the primary cosmic ray composition and spectrum. We present here the measurement of the depth-dependent muon flux using IceCube in its 22-string configuration. As the detector reaches its full planned size during the next few years, the quality of the results will increase correspondingly.

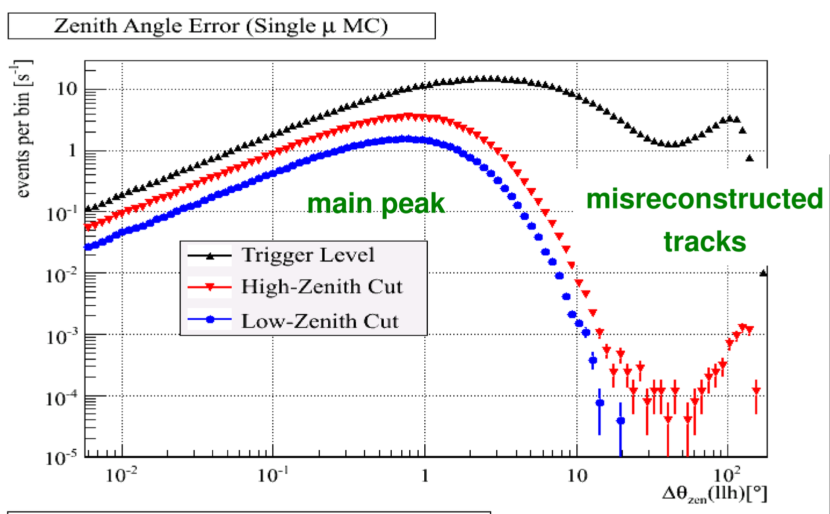
Data and Angular Resolution:

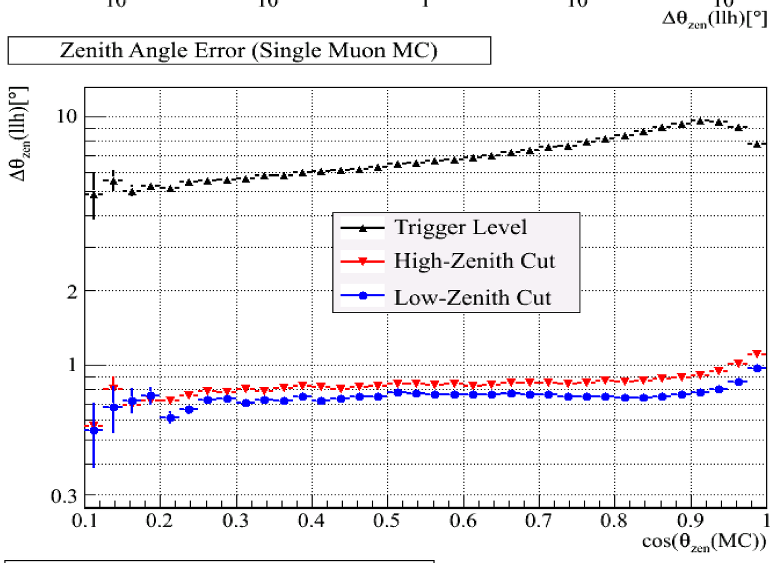
IceCube uses a limited set of filter streams for physics analyses. Above $\cos(\theta_{zen})$=0.25 (75°), this analysis is based on **Minimum Bias** data (every 200th event), applying a loose ("**High-Zenith**") cut, optimized to maximize the ratio between the square root of cut efficiency and the median of the zenith angle error distribution. Below that angle the **Muon Filter** stream, designed for neutrino analyses, and optimized for tracks near and below the horizon, was used. Since suppression of misreconstructed tracks is more important in this region, a stronger ("**Low-Zenith**") cut was applied.

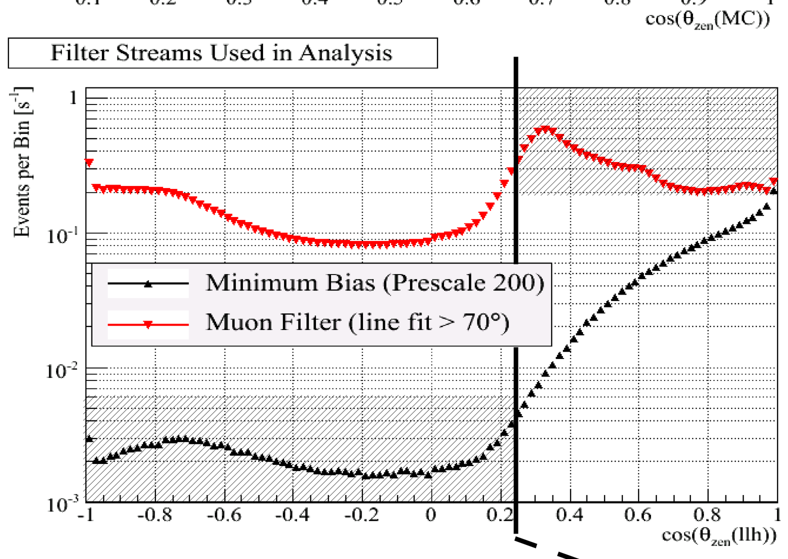
Top: Simulated zenith angle resolution from simulation after high-zenith (loose) and low-zenith (strong) cut, for all atmospheric muons.

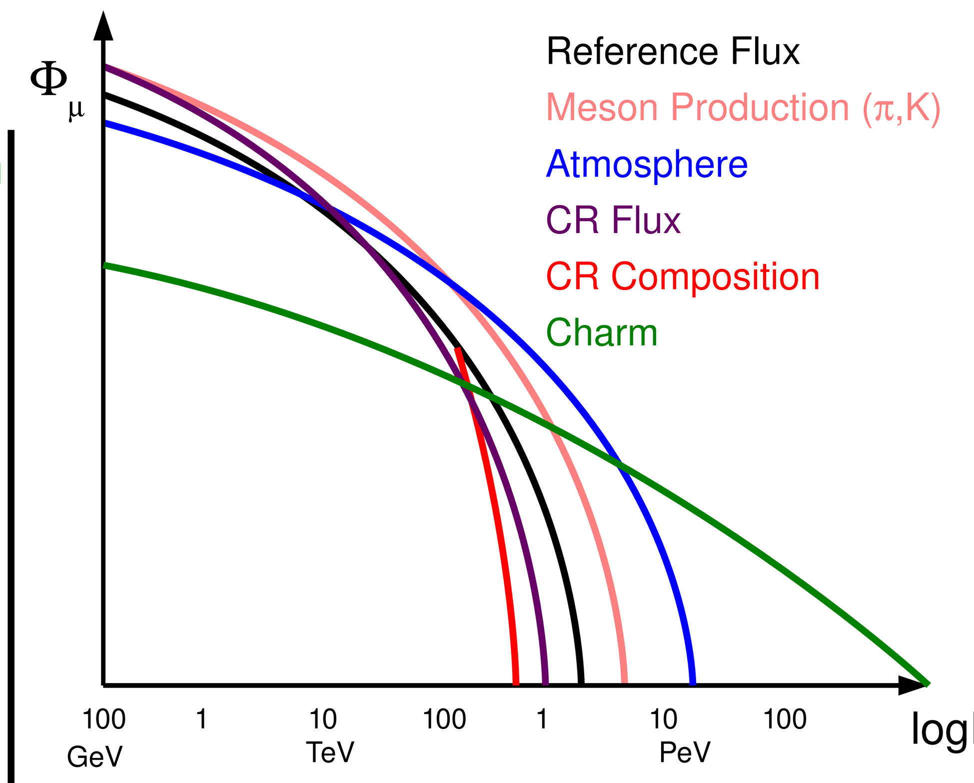
Middle: Simulated zenith angle resolution for atmospheric muons as a function of declination.

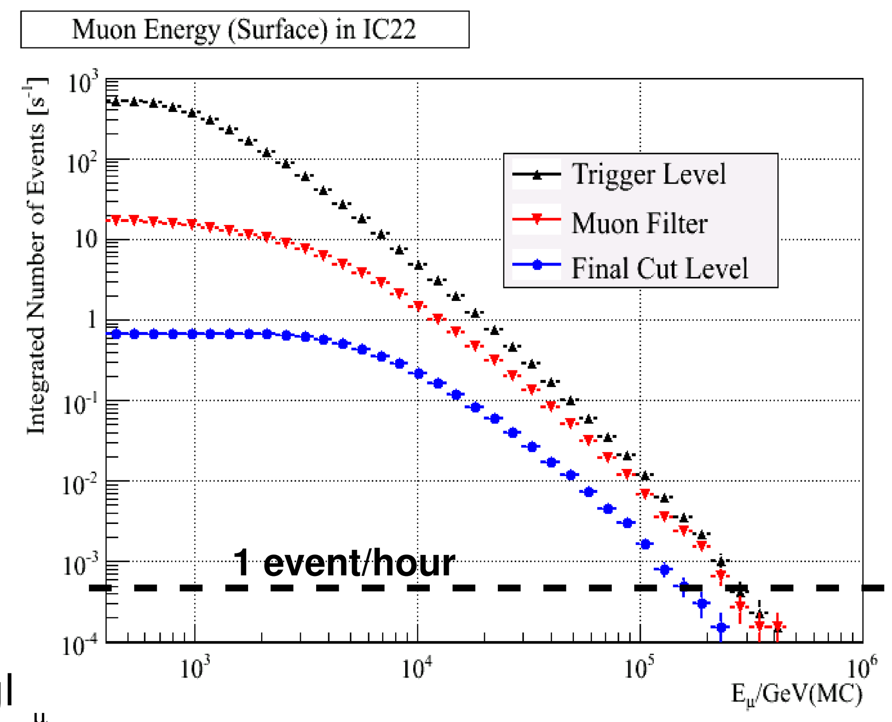
Bottom: Event rates for data streams used in this analysis, at trigger level.

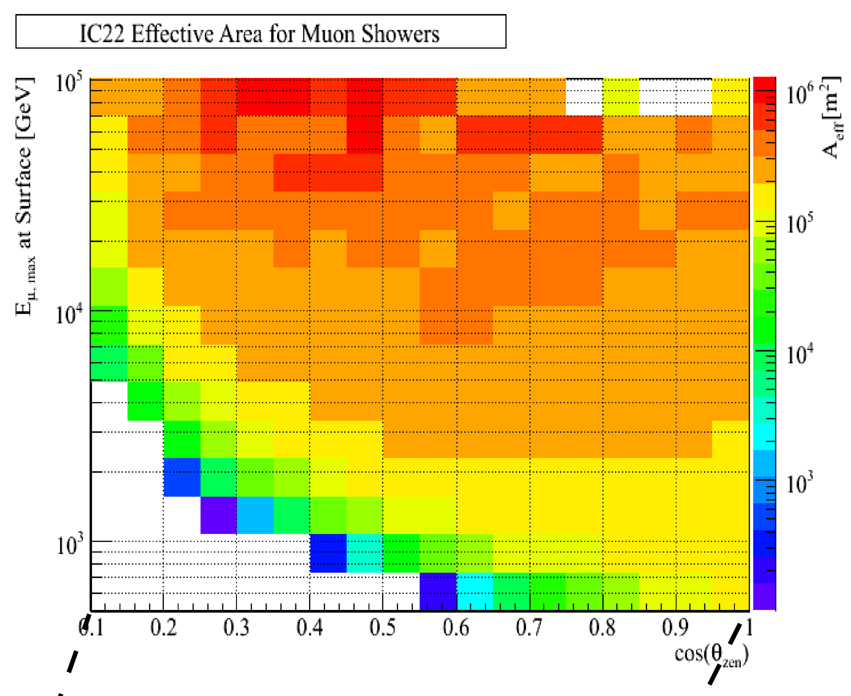












Physics Issues:

Measuring the muon flux accurately allows investigation of various physics topics through modeling of the muon energy spectrum and the total energy in individual showers.

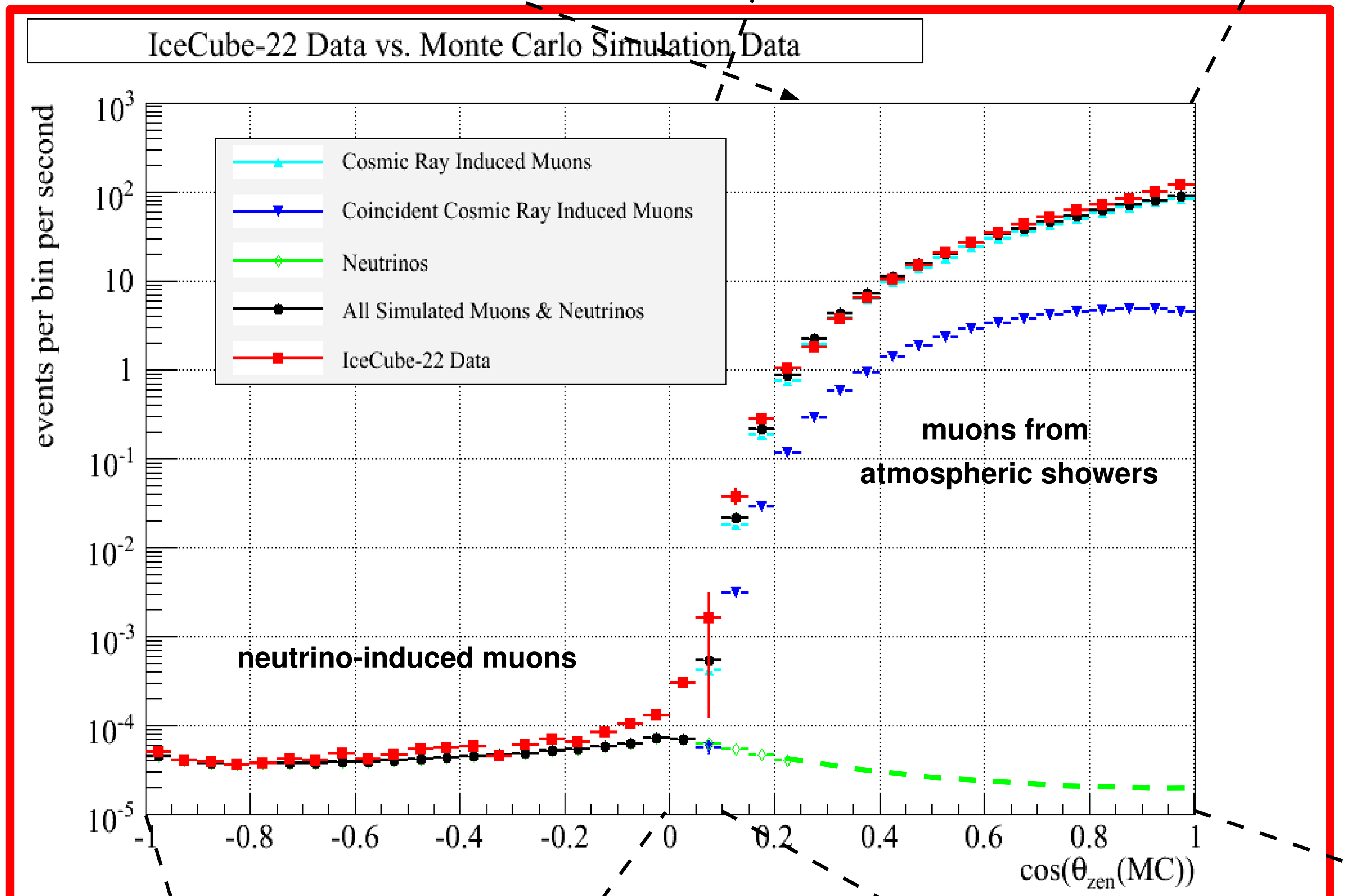
Top Left: Sketch of modifications to the atmospheric muon energy spectrum. The influence of each has been exaggerated for purposes of illustration. Effects that can be investigated are: Differential **meson production cross sections** in air showers [1], **atmospheric density profiles** and variations, **cosmic ray flux** [2] and **composition** around the "knee" [3] as well as **prompt contributions** to the muon flux from charm production in air showers [4].

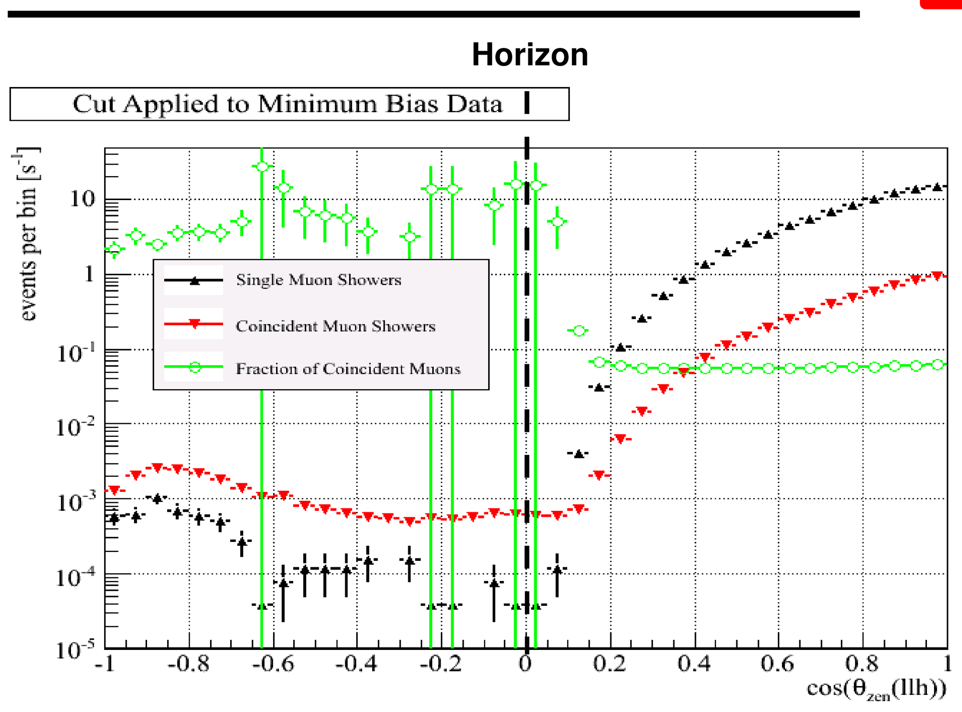
Top Right: Integrated muon flux in IceCube-22 calculated by a Monte-Carlo simulation. Even at energies >100TeV, the large effective area of the IceCube detector provides sufficient statistics for physics analyses.

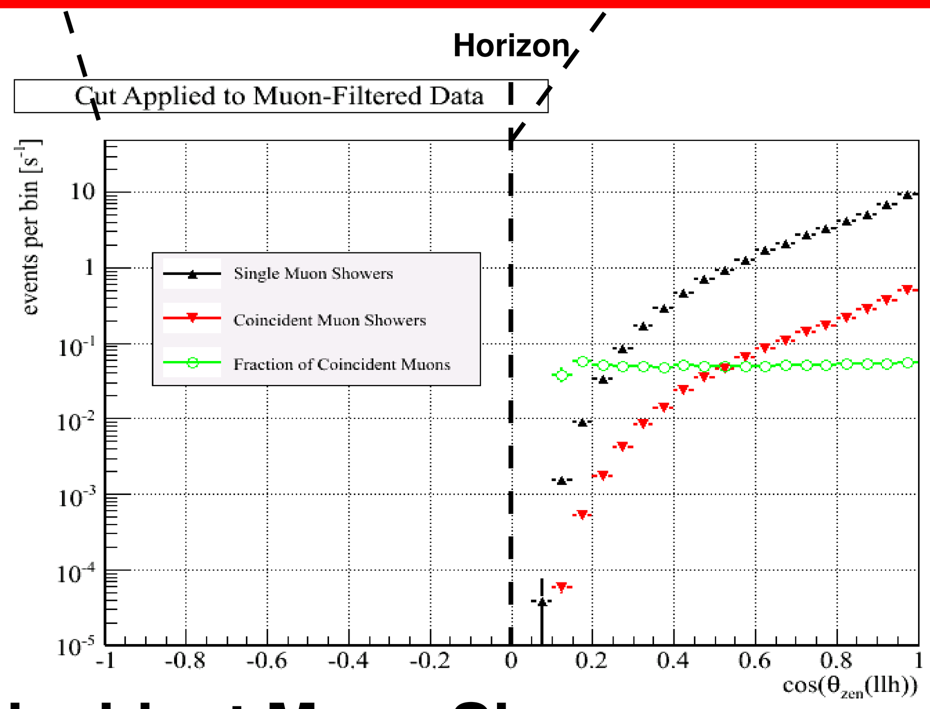
Bottom Left: Effective area of IceCube-22 as a function of muon surface energy and zenith angle.

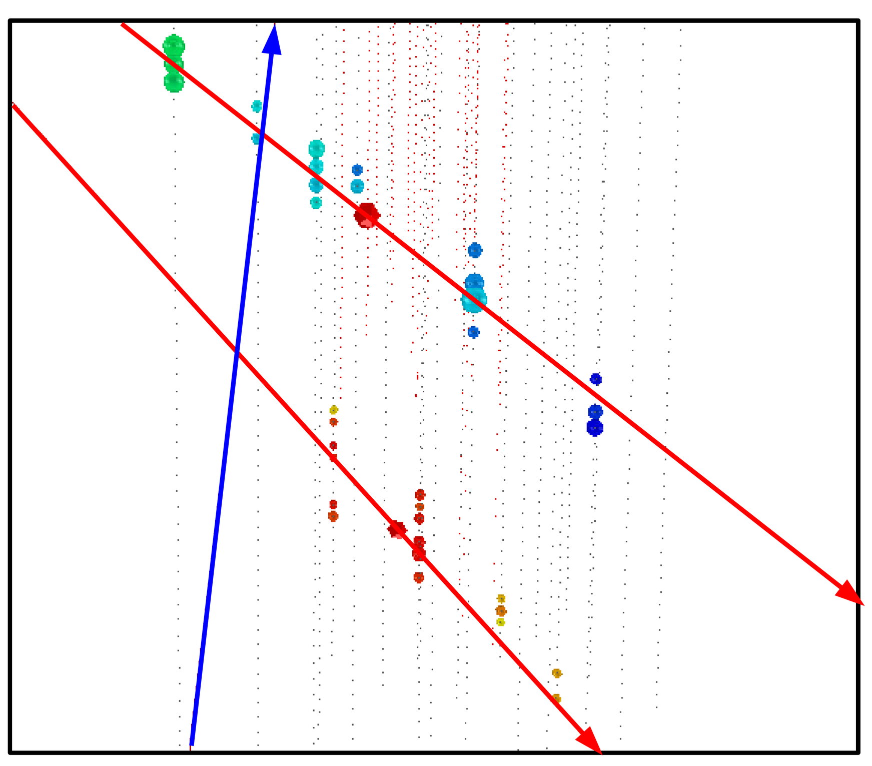
First All-Sky Measurement of Muons with IceCube:

Shown on the right is the first measurement of muons over the whole sky with IceCube. The downgoing flux of atmospheric muons gradually falls off, giving way to upgoing neutrino-induced tracks, which dominate below $\cos(\theta_{zen})$=0.1 (84°). The event rate was renormalized to trigger level, and no systematic error has yet been included.









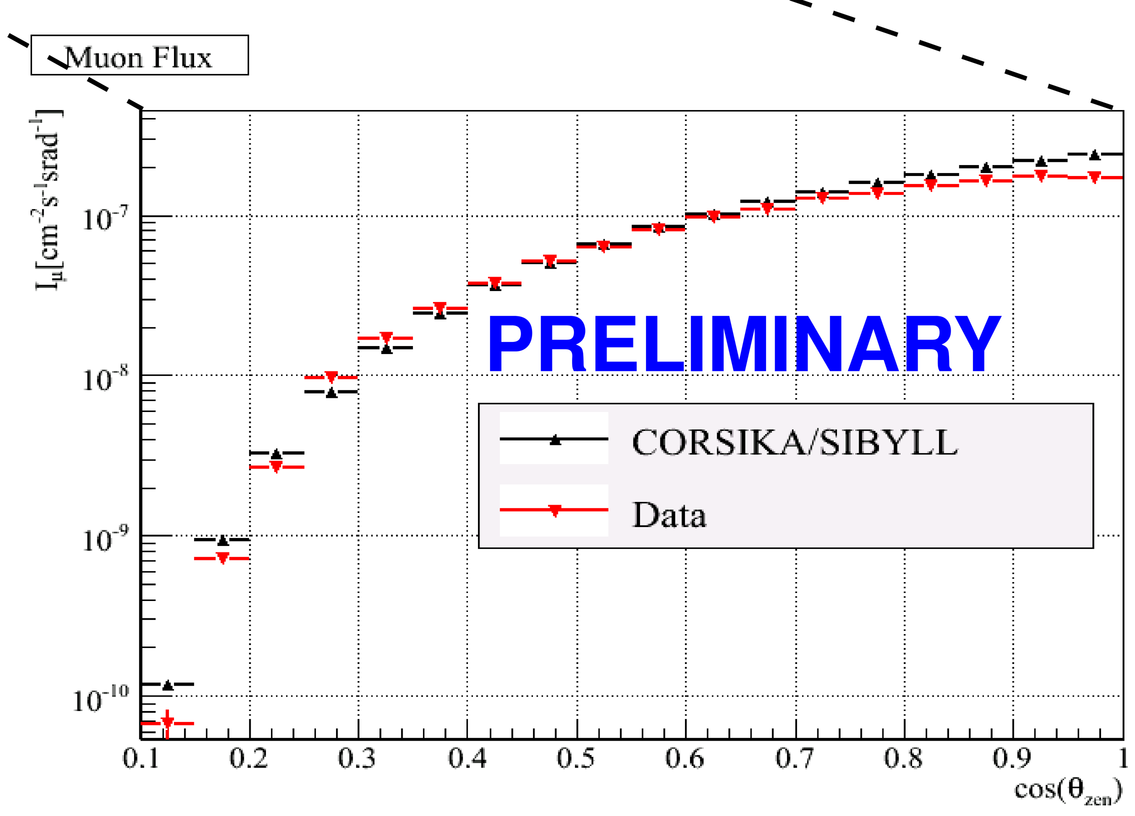
Coincident Muon Showers:

Coincident showers from two or several CR primaries can be misreconstructed as upgoing and form the most persistent background for neutrino searches. In order to avoid biases, the final cuts were only based on muon, and not neutrino simulation.

Bottom Left: In this event, two atmospheric muons (red) were reconstructed as a single upgoing track (blue).

Top Left: With a loose quality cut, large numbers of coincident muons remain below the horizon.

Top Right: A stronger cut eliminates the residual background and leaves only correctly reconstructed muon tracks.



Muon Flux:

In order to allow comparison with other experiments, the measured flux needs to be normalized to an absolute value. The plot above shows the preliminary result for the angular-dependent flux of muons penetrating the surrounding ice to the center of the IceCube detector.

References: [1] G.D. Barr et al., Phys.Rev.D74,094009(2006)
[2] D.Chirkin, ICRC 2003, [3] J.R. Hoerandel, Astropart.Phys. 19,193-220(2003)
[4] see e.g. G. Gelmini et al., Phys.Rev.D67,017301(2003)