Downgoing Muons in the IceCube experiment:

Final presentation for Phys 735, Particle, Prof. Sridhara Dasu

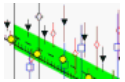
L.Gladstone
2008 Dec 3

Outline

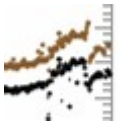
Shower Basics

IceCube Basics

Muon Measurements:



-Muon Energy Spectrum



-Air Temperatures

-Resolution Calibration

Conclusions

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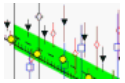

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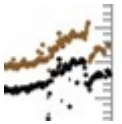

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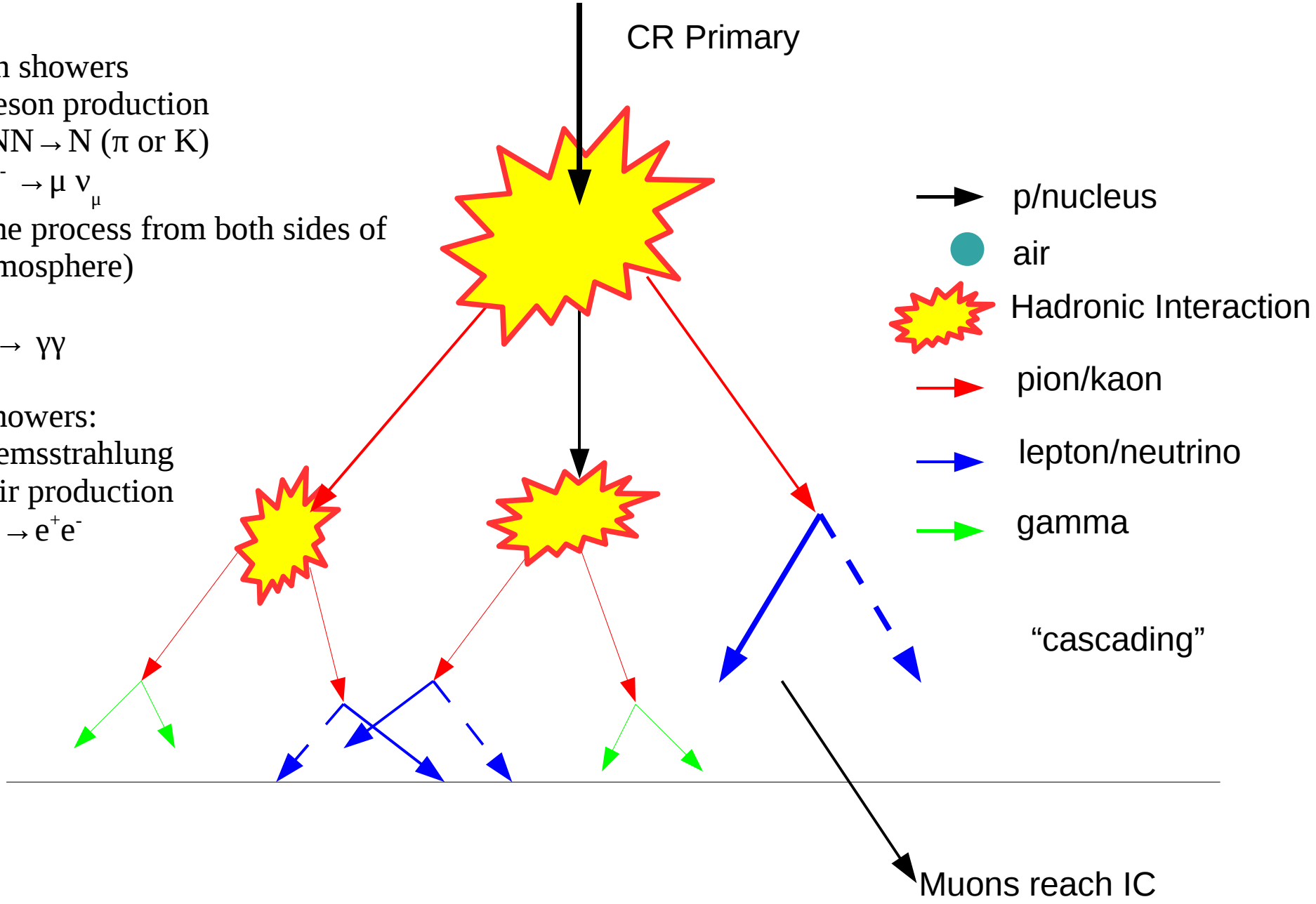
Air Showers

Meson showers
(1) meson production
$NN \rightarrow N$ (π or K)
(2) $\pi^{+/-} \rightarrow \mu\ \nu_{\mu}$
(see the process from both sides of the atmosphere)

(3)$\pi^{o} \rightarrow \gamma\gamma$

EM showers:
(1) bremsstrahlung
(2) pair production
$\gamma \rightarrow e^{+}e^{-}$



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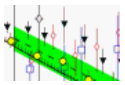

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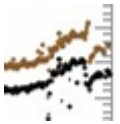

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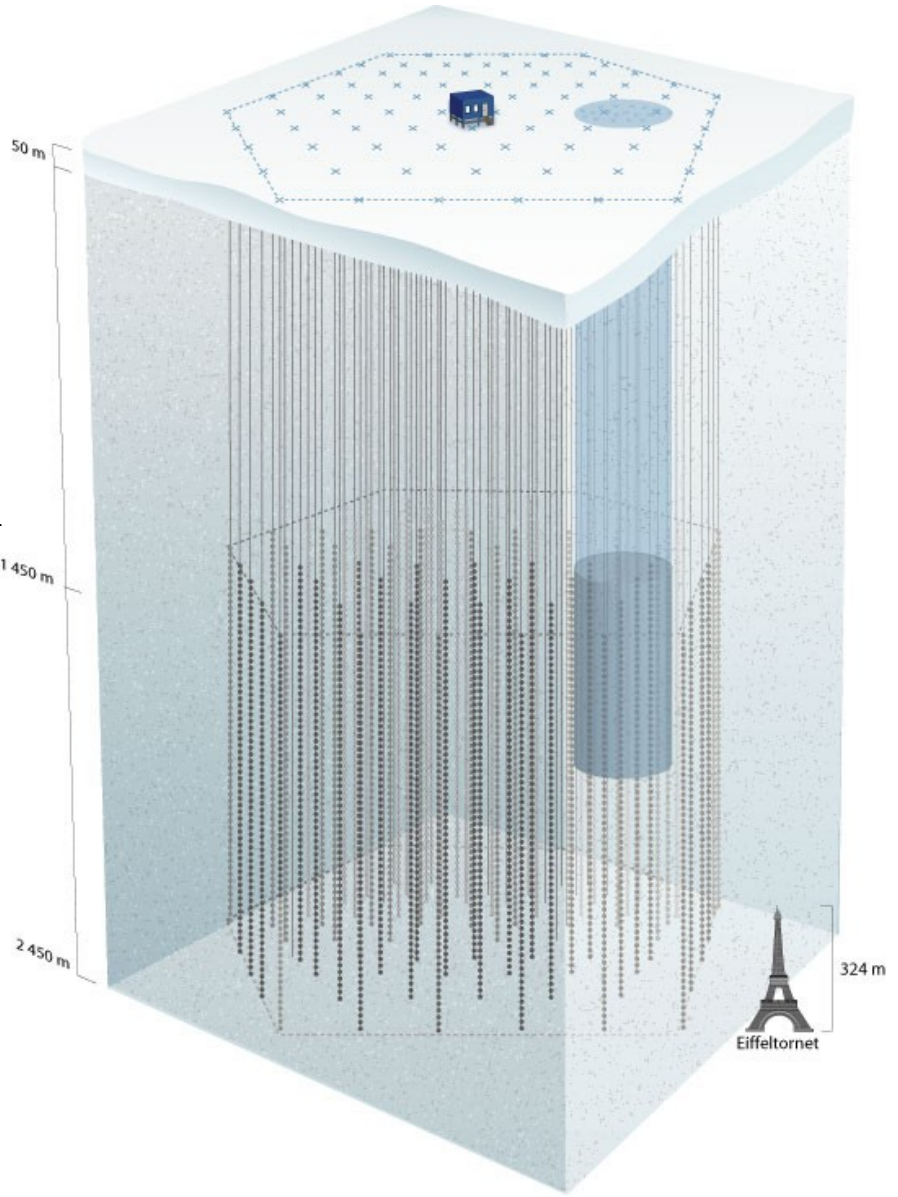
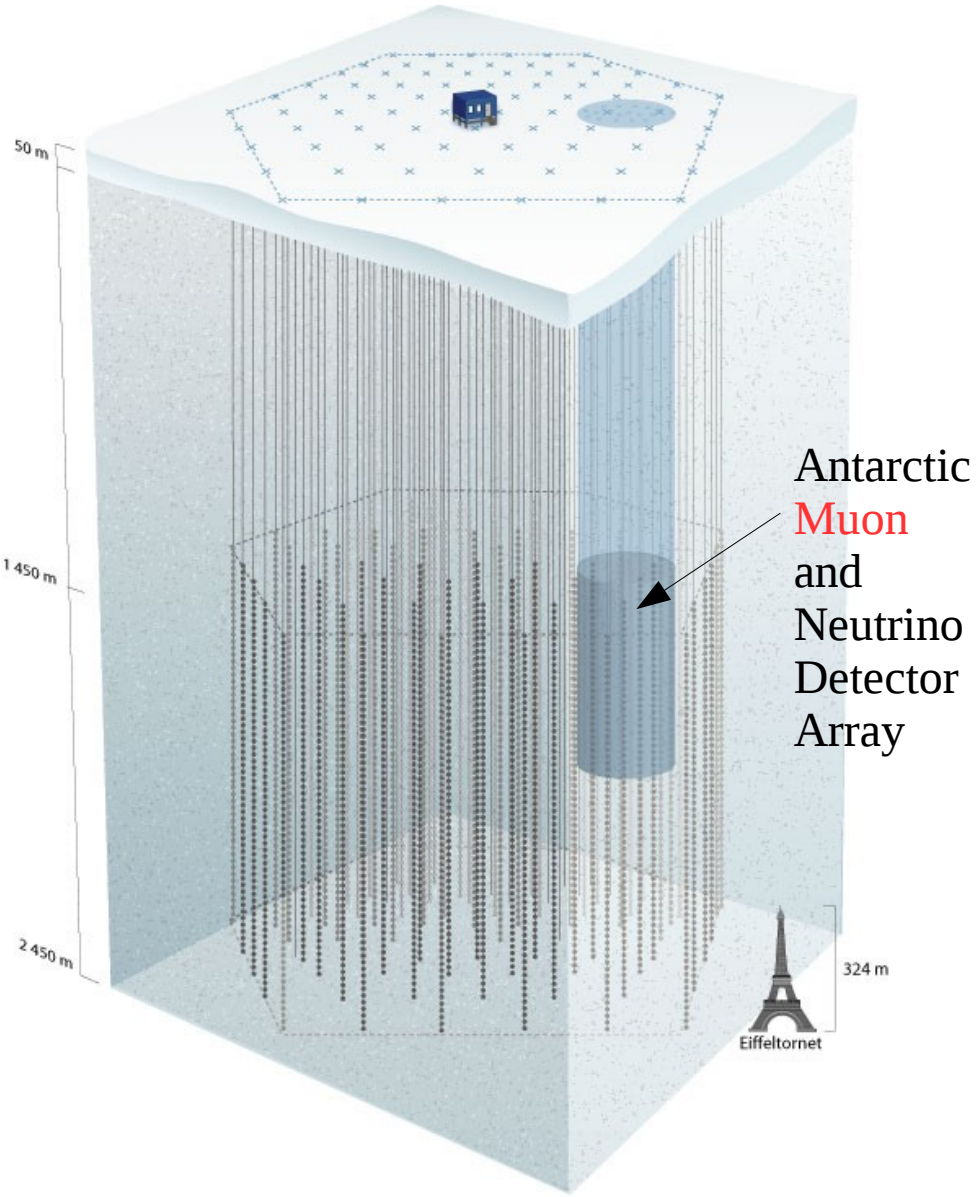


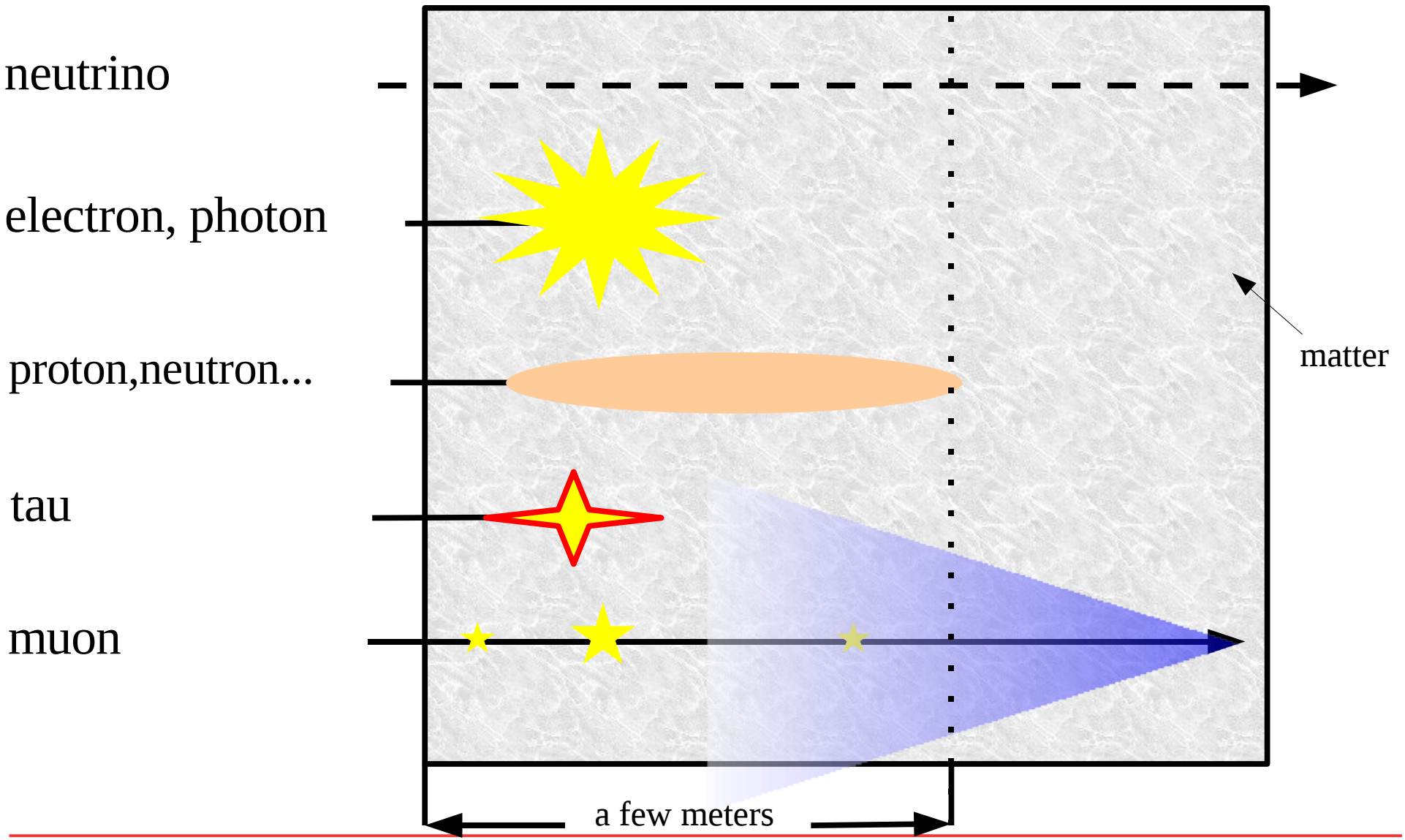
IceCube Basics

- Cubic-kilometer scale Cherenkov detector
- Designed for neutrino astronomy
  - Energy: low GeV to EeV (stat. limit)
  - DOMs (Digital Optical Modules) point downward
- Main signal:
  - upgoing μ from astrophysical ν (~20/hr in full detector)
- Major background:
  - Atmospheric μ from air showers
  - ~KHz
  - ~25Hz coincident

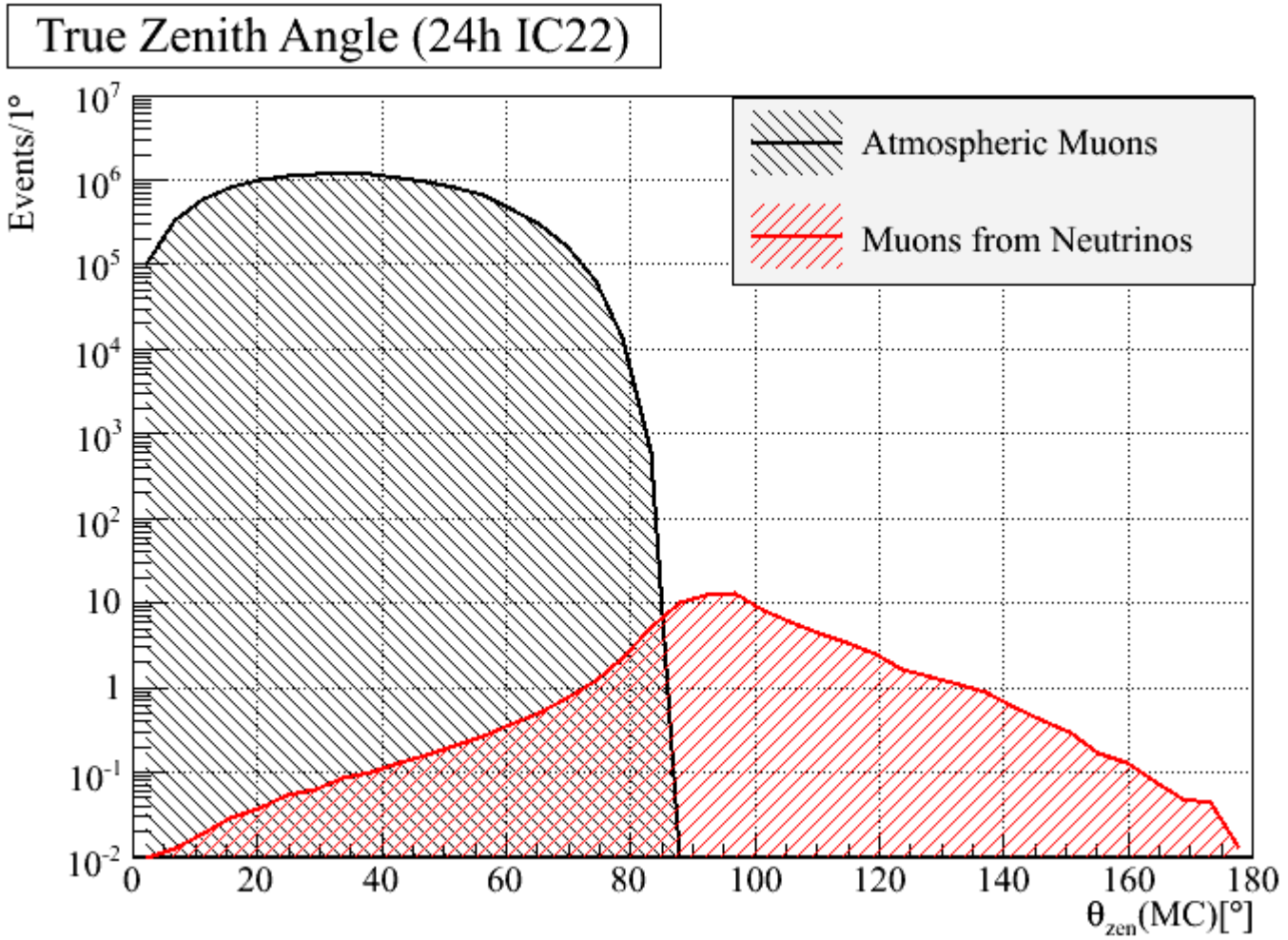


Muons make visible tracks

We like muons because they can penetrate the 17m between DOMs and ~125m between strings.

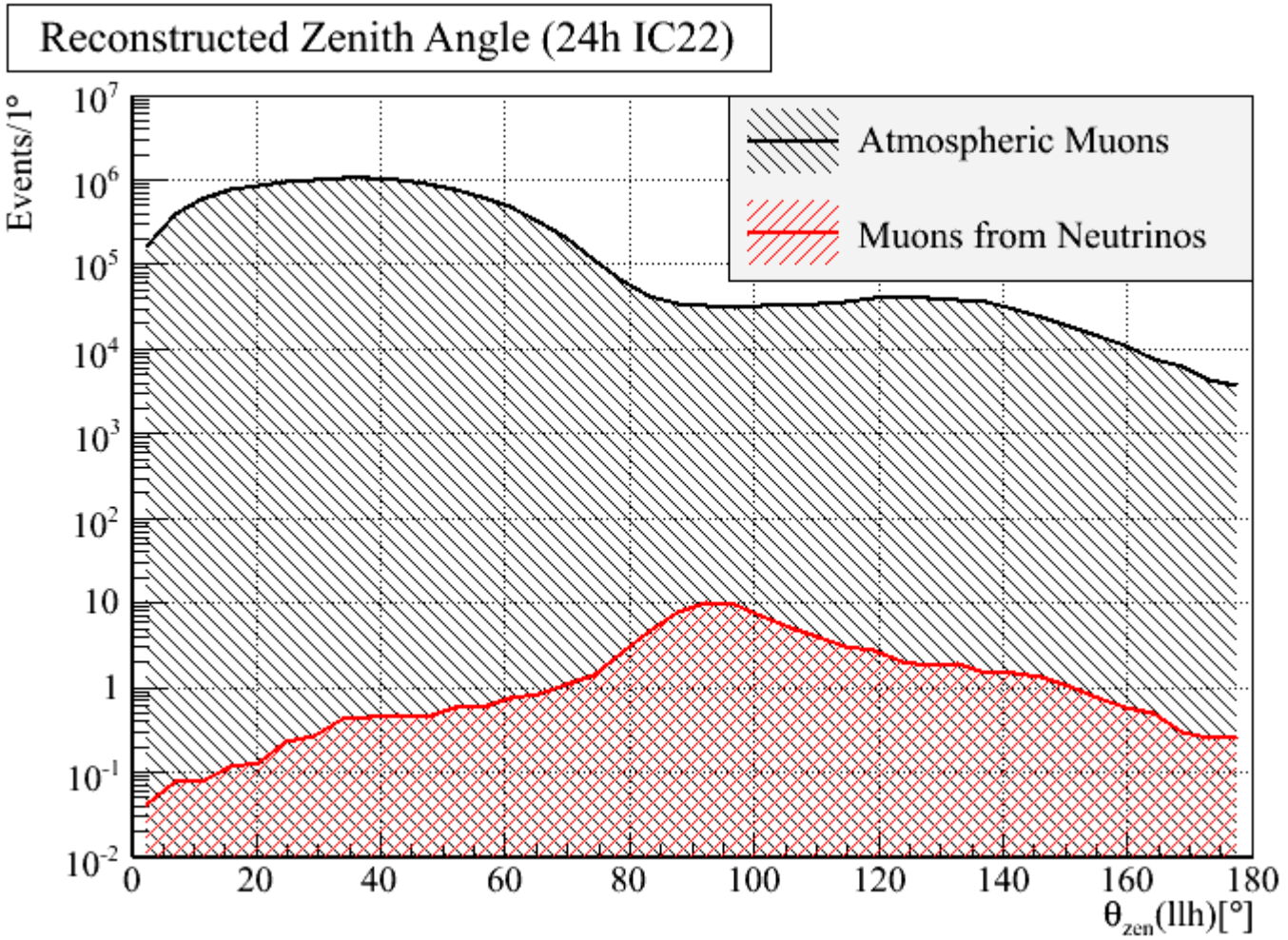


If our reconstruction were perfect...



- Atmospheric μ are blocked by the earth
  - i.e., only downgoing
- Signal μ from astrophysical ν can go through the earth
  - can be upgoing

If our reconstruction is off by a couple %...



- Signal ν can easily be swamped by atmospheric μ
- Careful reconstruction and cuts are needed
  - But those are the concern of ν point source talks
- We can use μ for calibrations!

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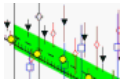
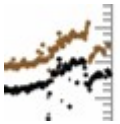


-Muon Energy Spectrum



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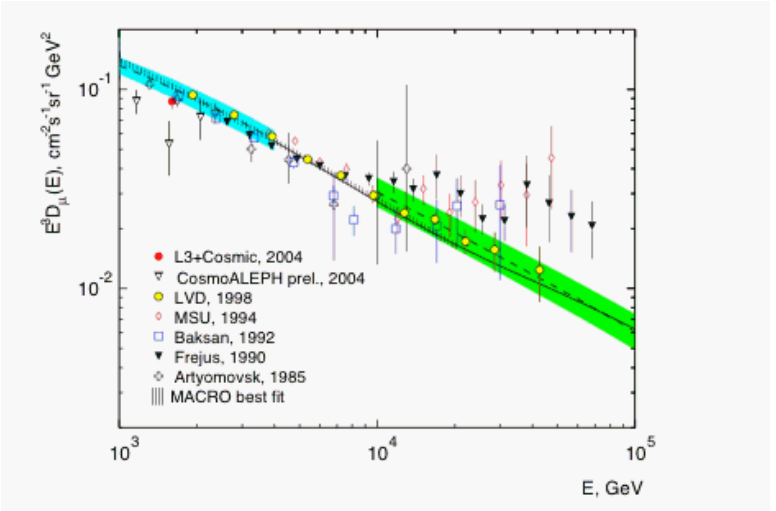
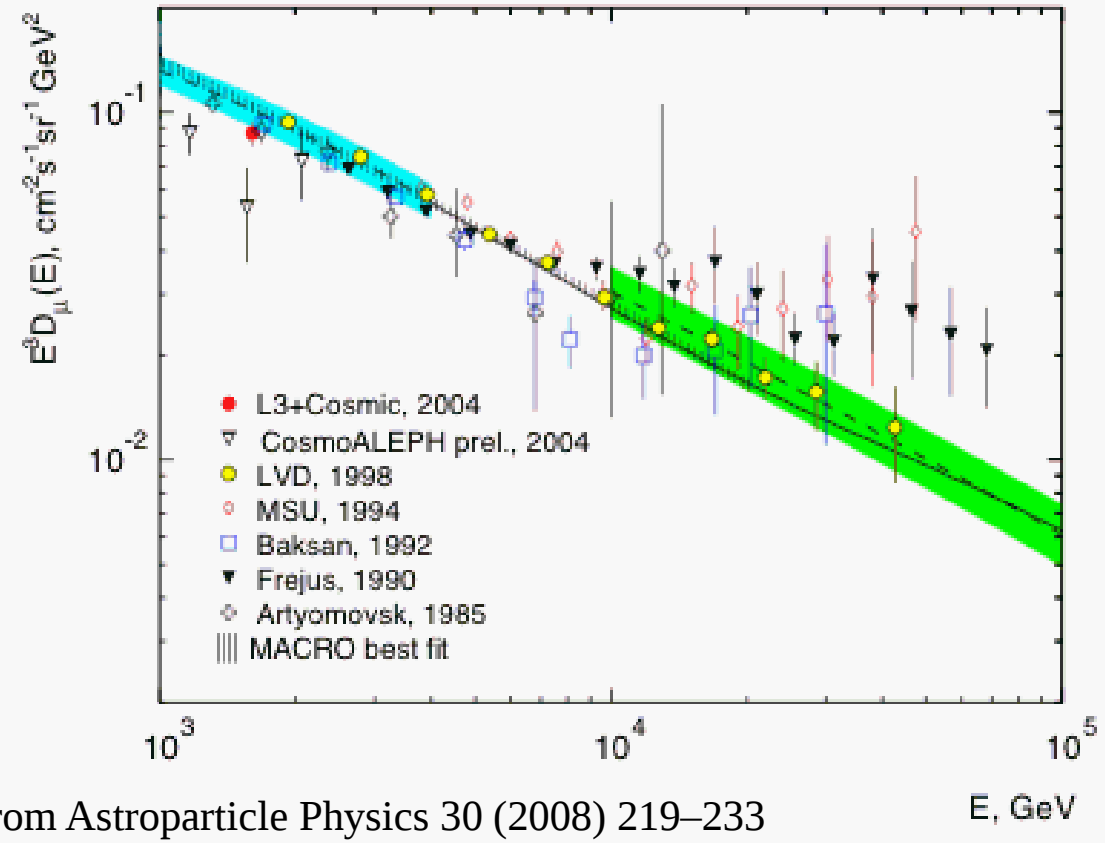


Muon Energy Spectrum

- IceCube is designed for highest energies
- IceCube gets a lot of μ flux

- We can extend μ flux measurements to high energies
  - constrain cosmic ray production models



From Astroparticle Physics 30 (2008) 219–233

Models for HE interactions not probed in accelerators

Convolve:
CR spectrum (measured),
CR composition,
HE cross sections,
=> this plot

Major research question

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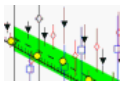

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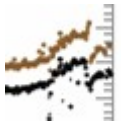

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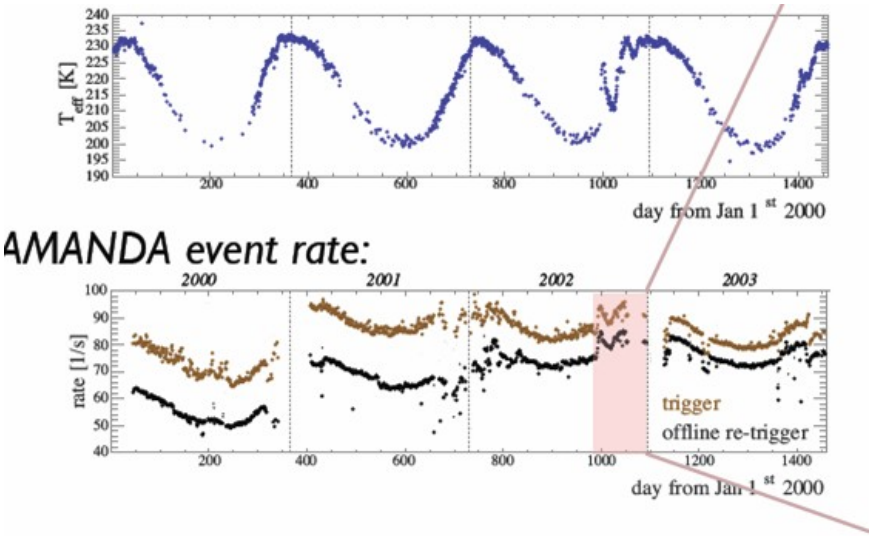
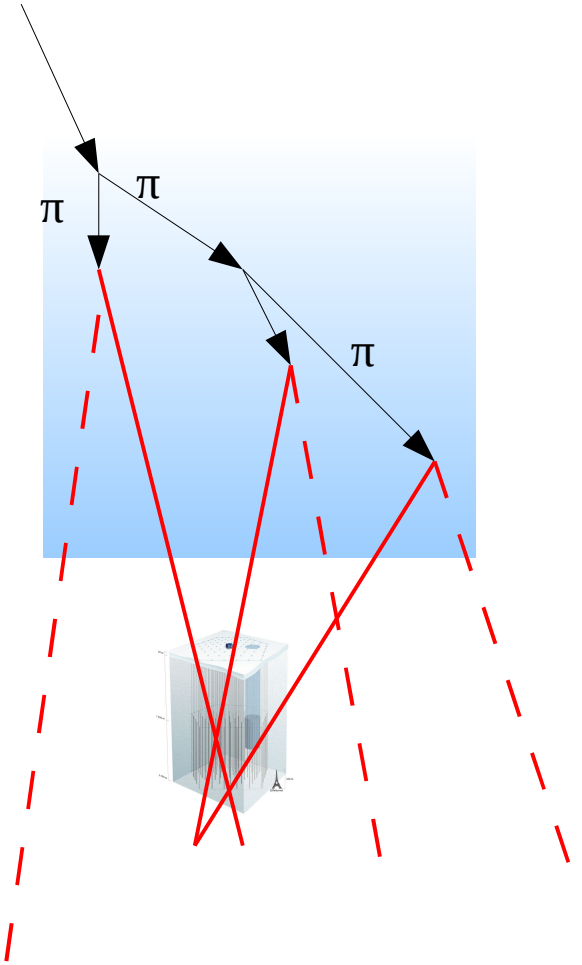
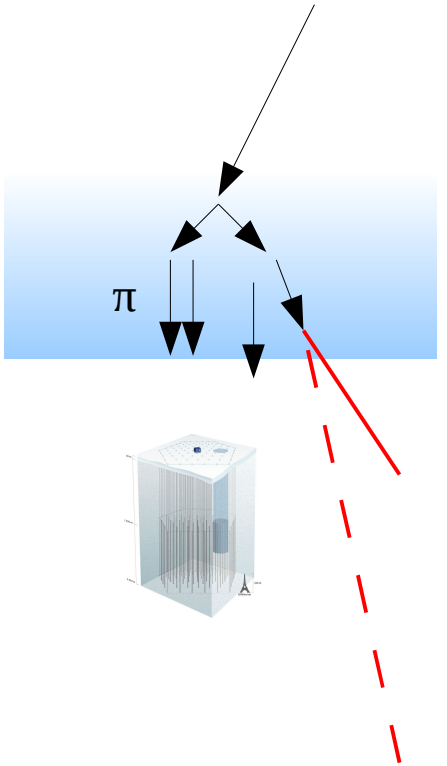


Conclusions

Atmospheric Temperature Measurements

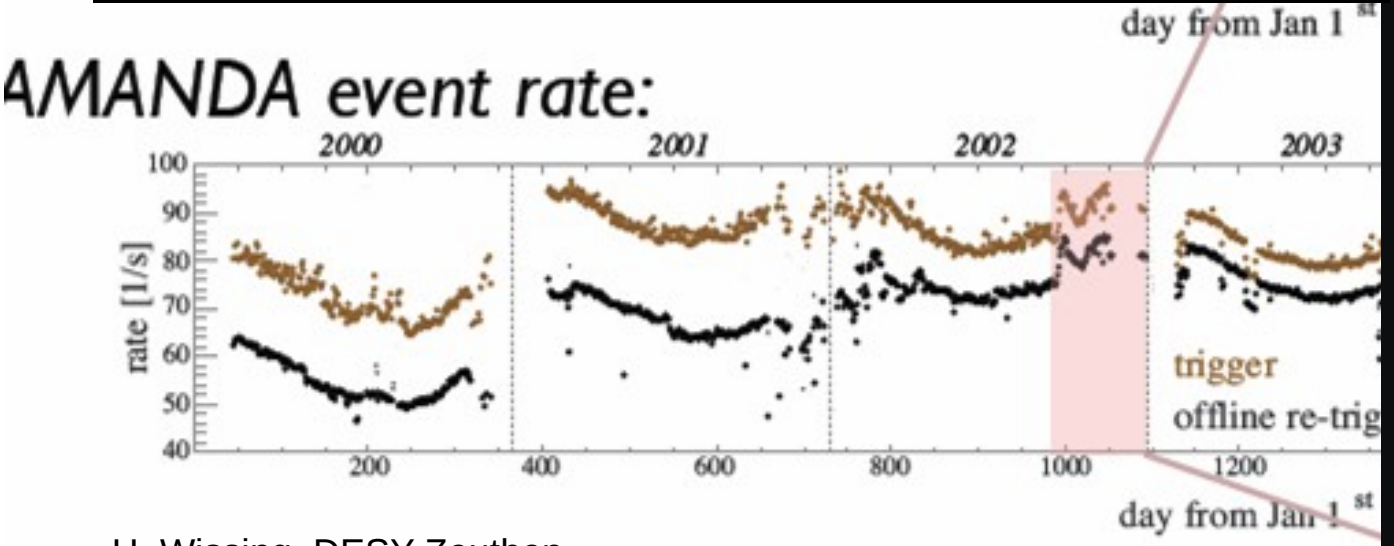
- Summer atm is less dense
  - Pi and k less likely to react with nucleus before decay to μ
  - More μ reach detector depth
- Winder atm is colder & denser
  - Pi and k more likely react in atm or hit ground before decaying
  - Fewer μ

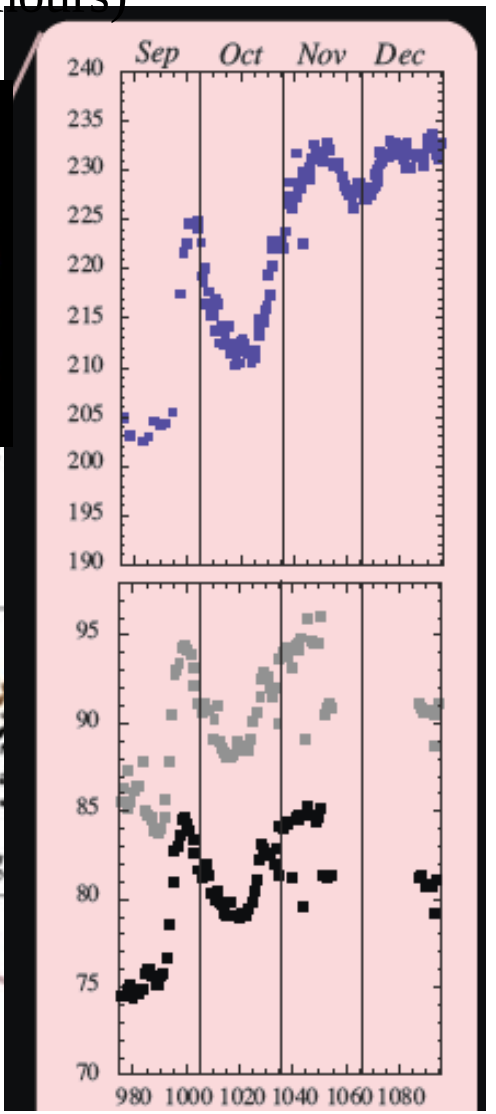




Atmospheric Temperature Measurements

- Correlation noticed in Amanda:
  - Balloon flights track atmospheric temperatures daily
  - Amanda/IceCube records μ rate (in small bins, usually hours)





H. Wissing, DESY Zeuthen

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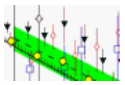

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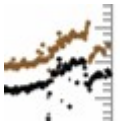

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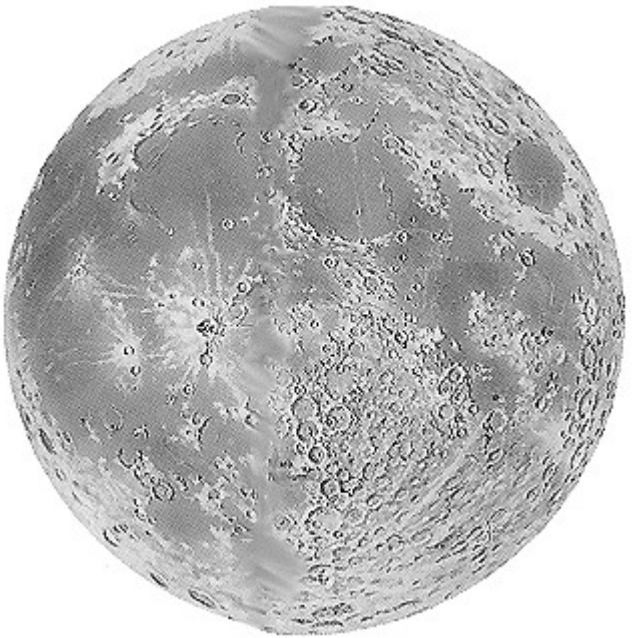
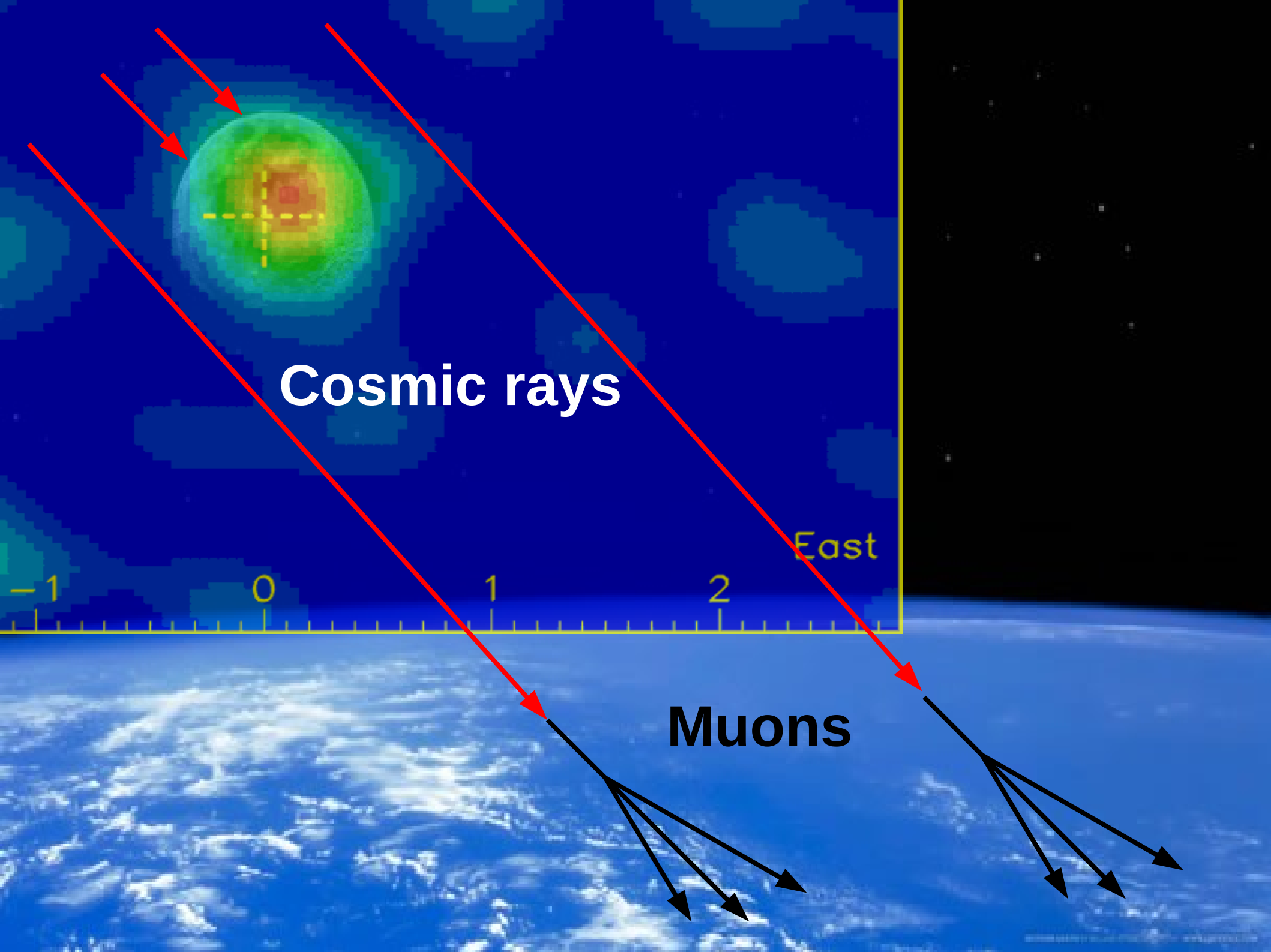
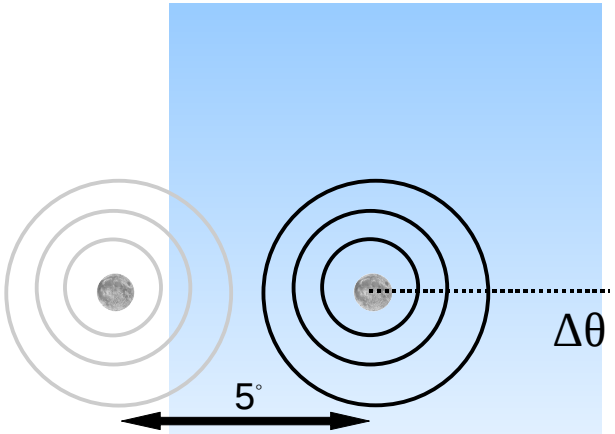


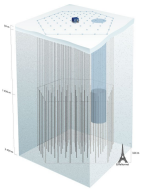

Cosmic rays
East
−1
0
1
2
Muons

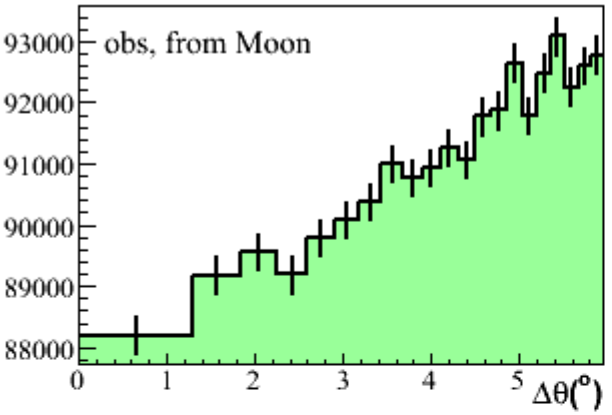
Moon Shadow

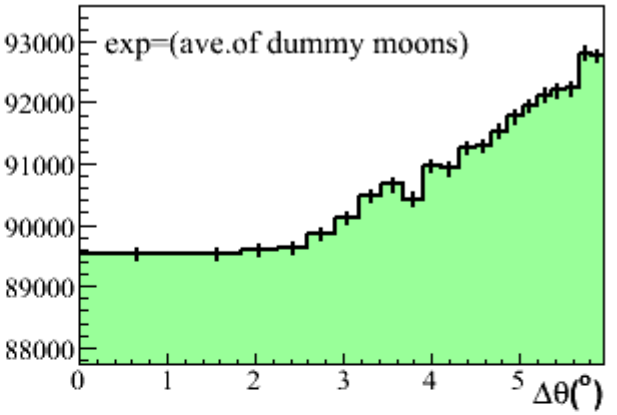
- Data-based (simulation-independent) check of systematic errors
- “Standard candle” observation for gamma telescopes (HESS, Milagro etc)
- Easiest-to-find point source
  - This is the first setup of Amanda/IceCube which can see the Moon, which indicates that other point sources are now possible

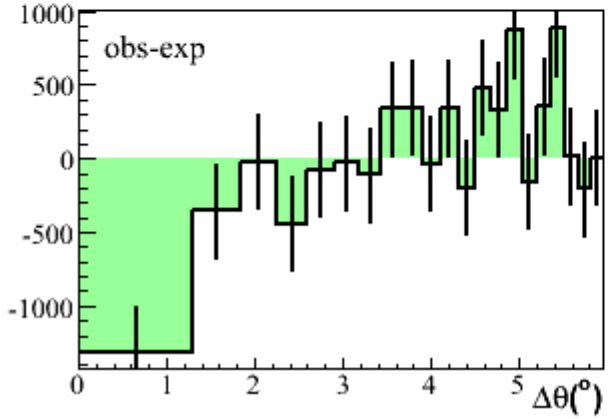


Dummy moon for off-source measurement









observed: 88202 events

expected: 89522 events

deficit: -1320 events

error: 315 events

significance: -4.2σ

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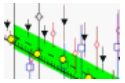

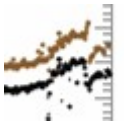

- IceCube can observe a large sample of atmospheric muons
- Using this sample, we can measure
  - Muon energy spectrum
  - Upper atmospheric temperatures
  - Detector angular resolution

- Conclusion: downgoing muons are useful to IceCube.

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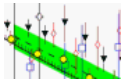

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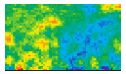
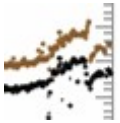


-Large Scale Anisotropies



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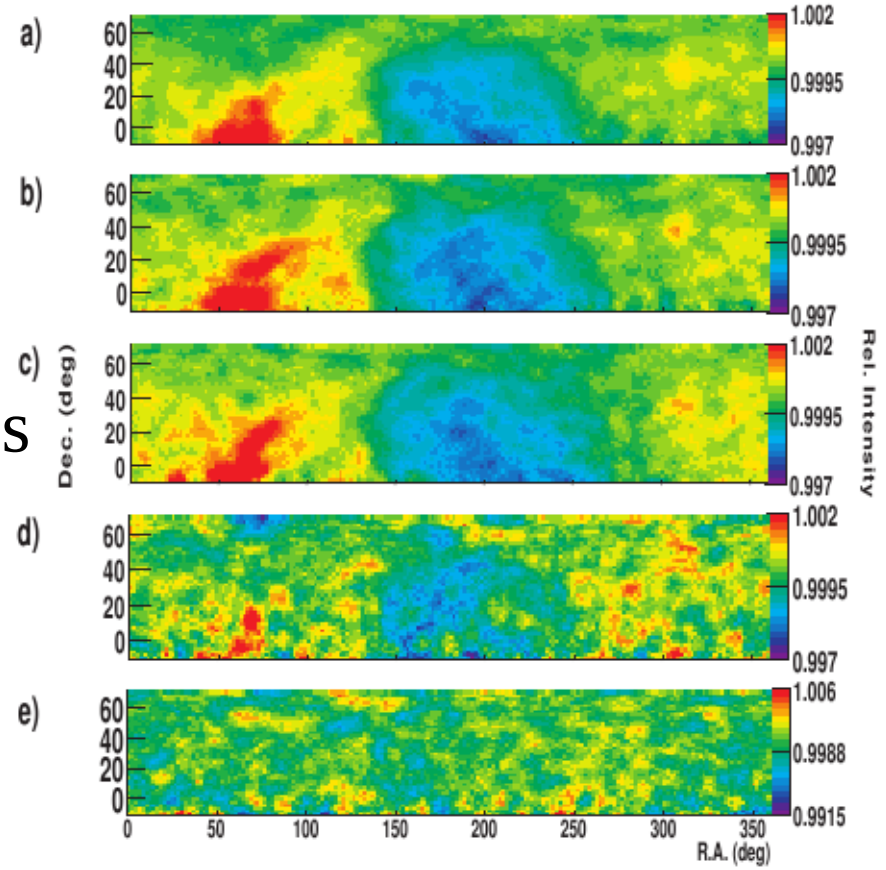


Large Scale Anisotropies

- Muon anisotropies follow cosmic ray anisotropies
- Anisotropies only seen at low energies <10 TeV
  - So we map the southern sky
- Two major effects seen:
  - Heliomagnetic tail (shown below)
  - Galactic magnetic field effects (next slide)

NB: this “major” effect is ~0.1%

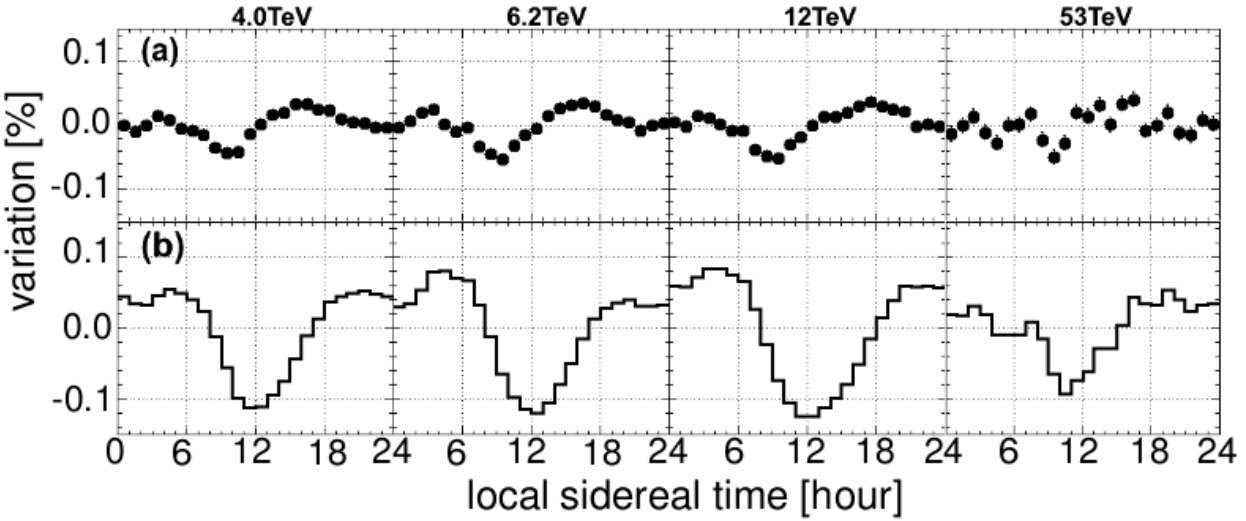


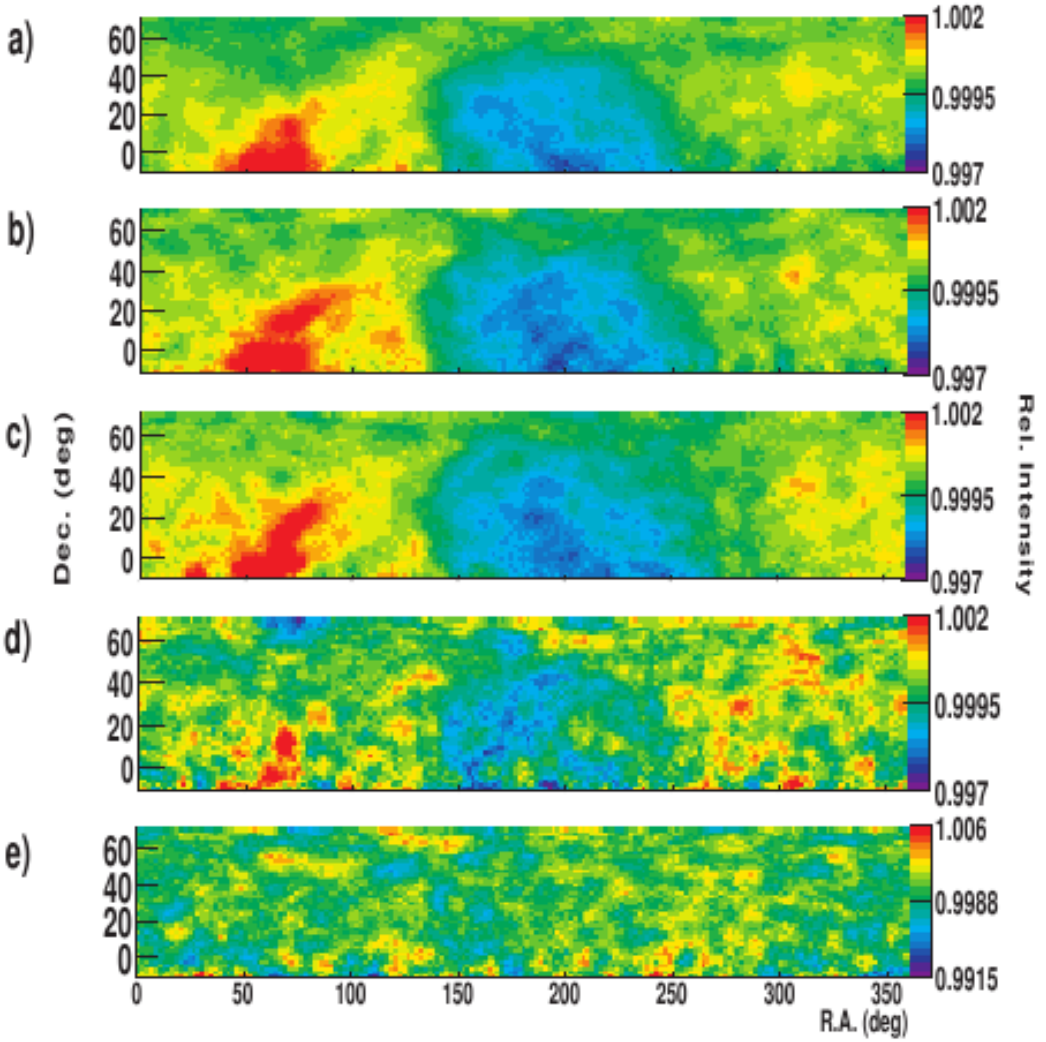
Fig. 1.— The sidereal daily variations averaged over all declinations as a function of representative energies of 4.0, 6.2, 12, and 53 TeV. The upper panels (a) show the differential variations $D(t)$'s, while the lower panels (b) display the physical variations $R(t)$'s. The error bars are statistical.

arXiv:astro-ph/0505114v1

Large Scale Anisotropies

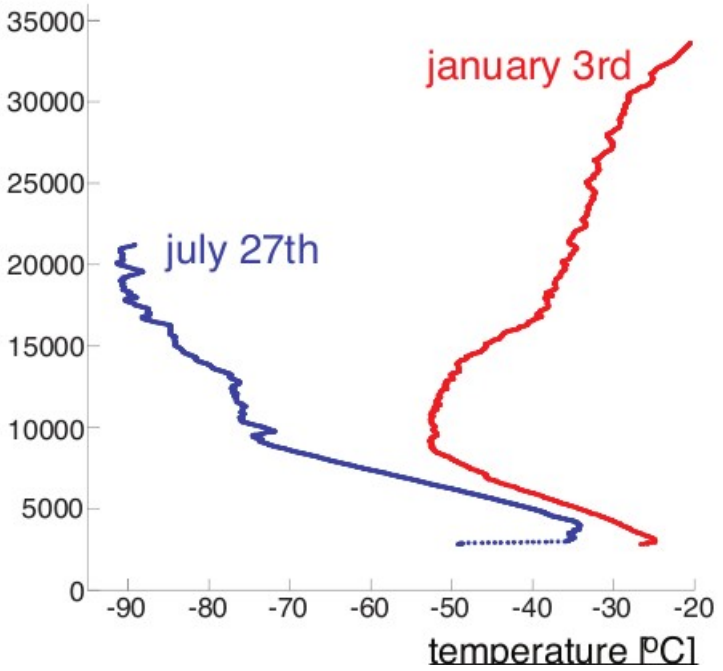
- The Tibet gamma array has seen an anisotropy in events (viewed in galactic coordinates)
- Energy dependence suggests this comes from magnetic fields
- (but high energy is also lower statistics, so less accurate)
- IceCube is looking for this effect
- Galactic fields are hard to map because particles bend and direct probes are impractical

Highest energies have no anisotropy



Atmospheric Temperature Measurements

To look for correlation, describe atm. Temp(height) as single numbers, T_{eff}



<show animation: http://icecube.wisc.edu/~drocco/WeatherVideos/weather.gif>