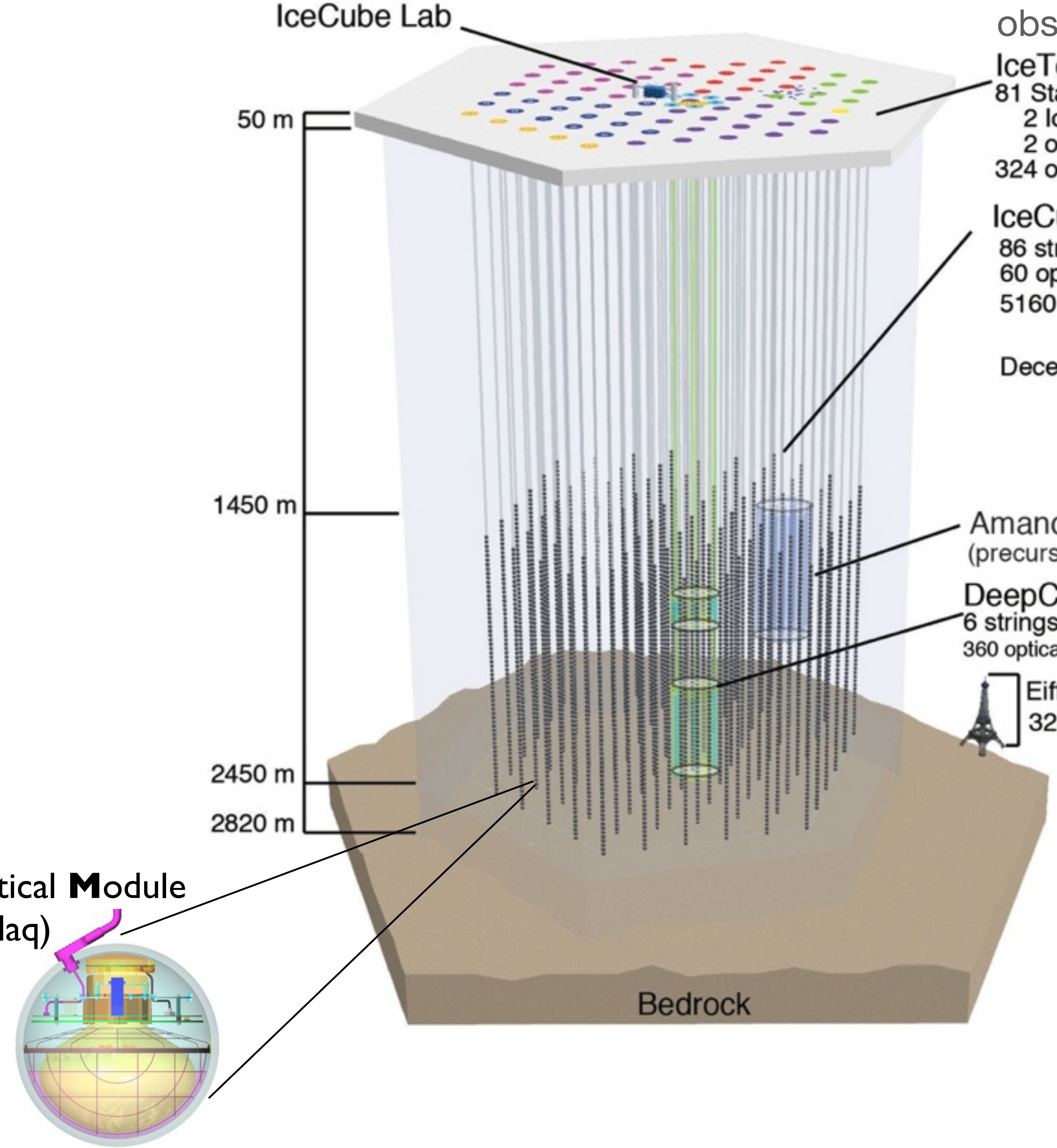
Absolute DOM Efficiency with Muon Data in IceCube

T.Wood for the IceCube Collaboration

CAP Congress 2014

The IceCube Neutrino Observatory

- Very large scale hybrid observatory



IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors

IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors

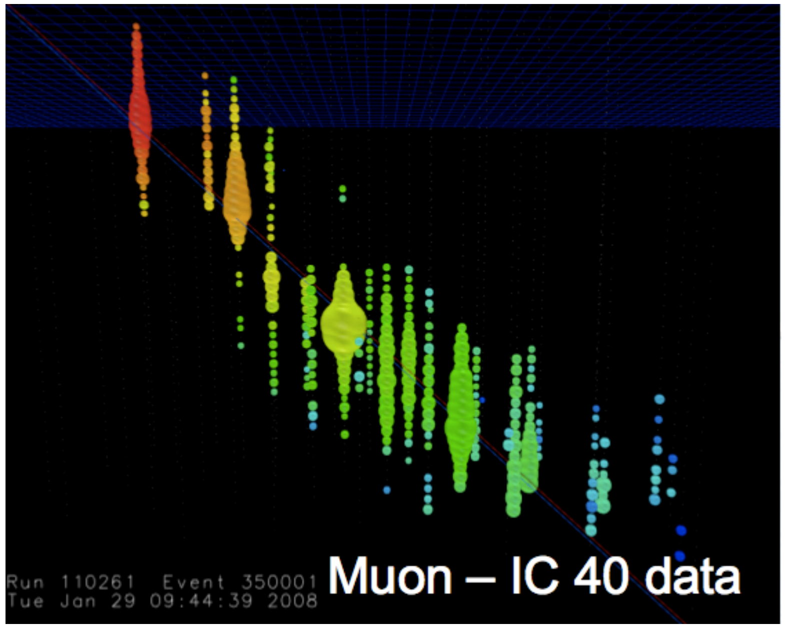
December, 2010: Project completed, 86 strings

Amanda II Array
(precurser to IceCube)

DeepCore
6 strings-spacing optimized for lower energies
360 optical sensors

DOM -**D**igital **O**ptical **M**odule
(PMT + daq)

Neutrino Telescopes - Principle of detection for 3 flavors

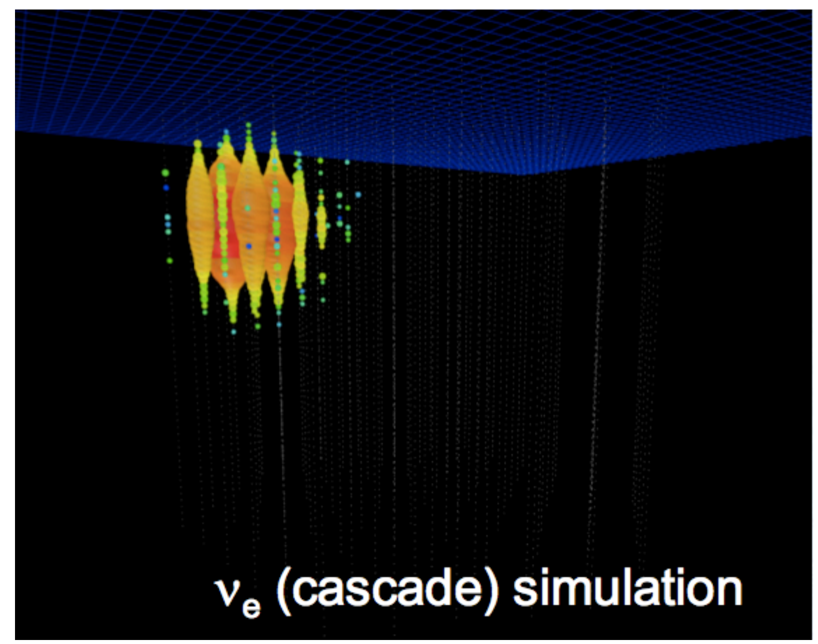


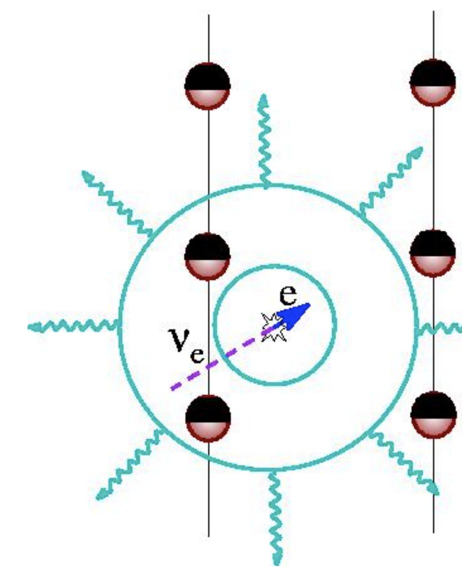
Tracks:

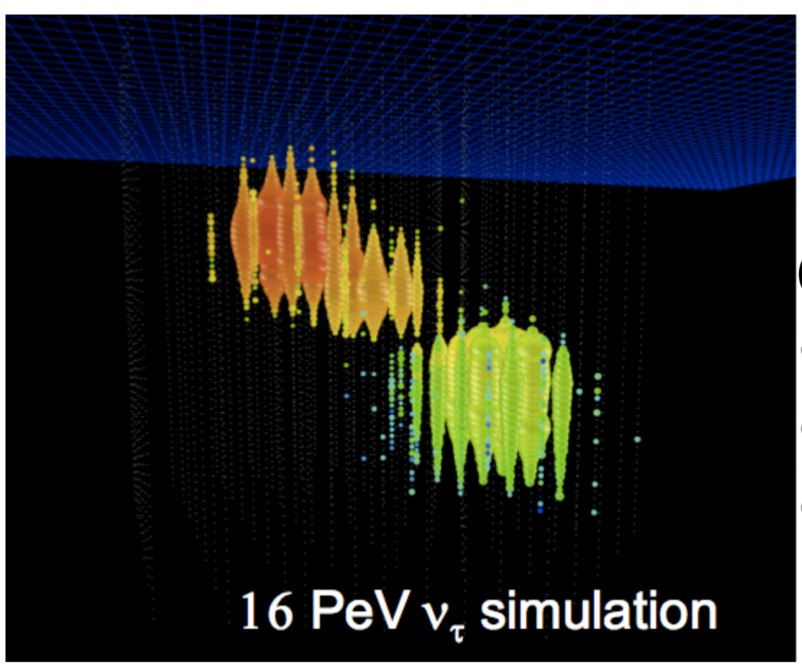
- through-going muons
- pointing resolution ~1°

Cascades:

- Neutral current for all flavors
- Charged current for ν_e and low-E ν_τ
- Energy resolution ~10% in log(E)







Composites:

- Starting tracks
- high-E ν_τ (Double Bangs)
- Good directional and energy resolution

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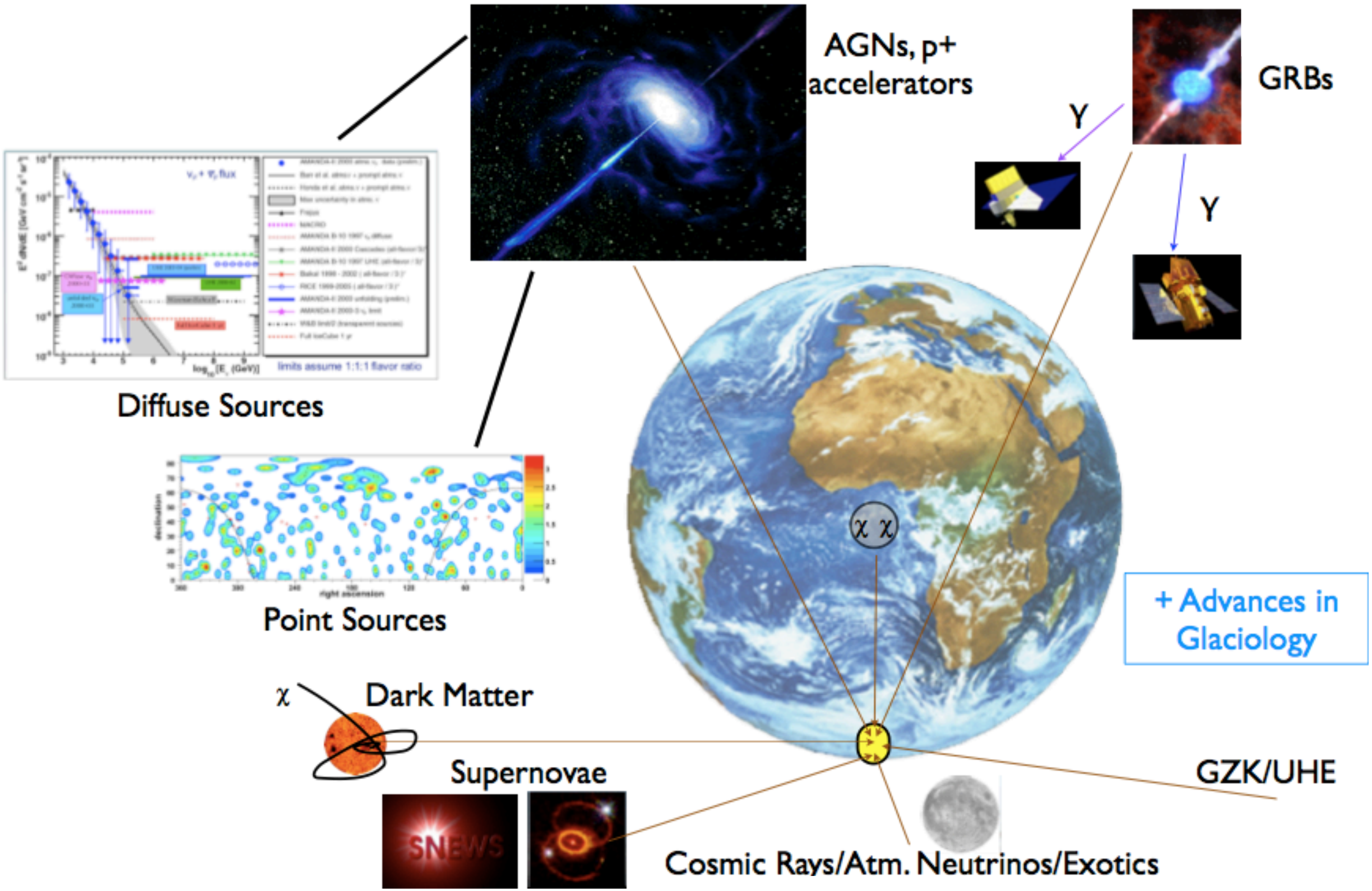
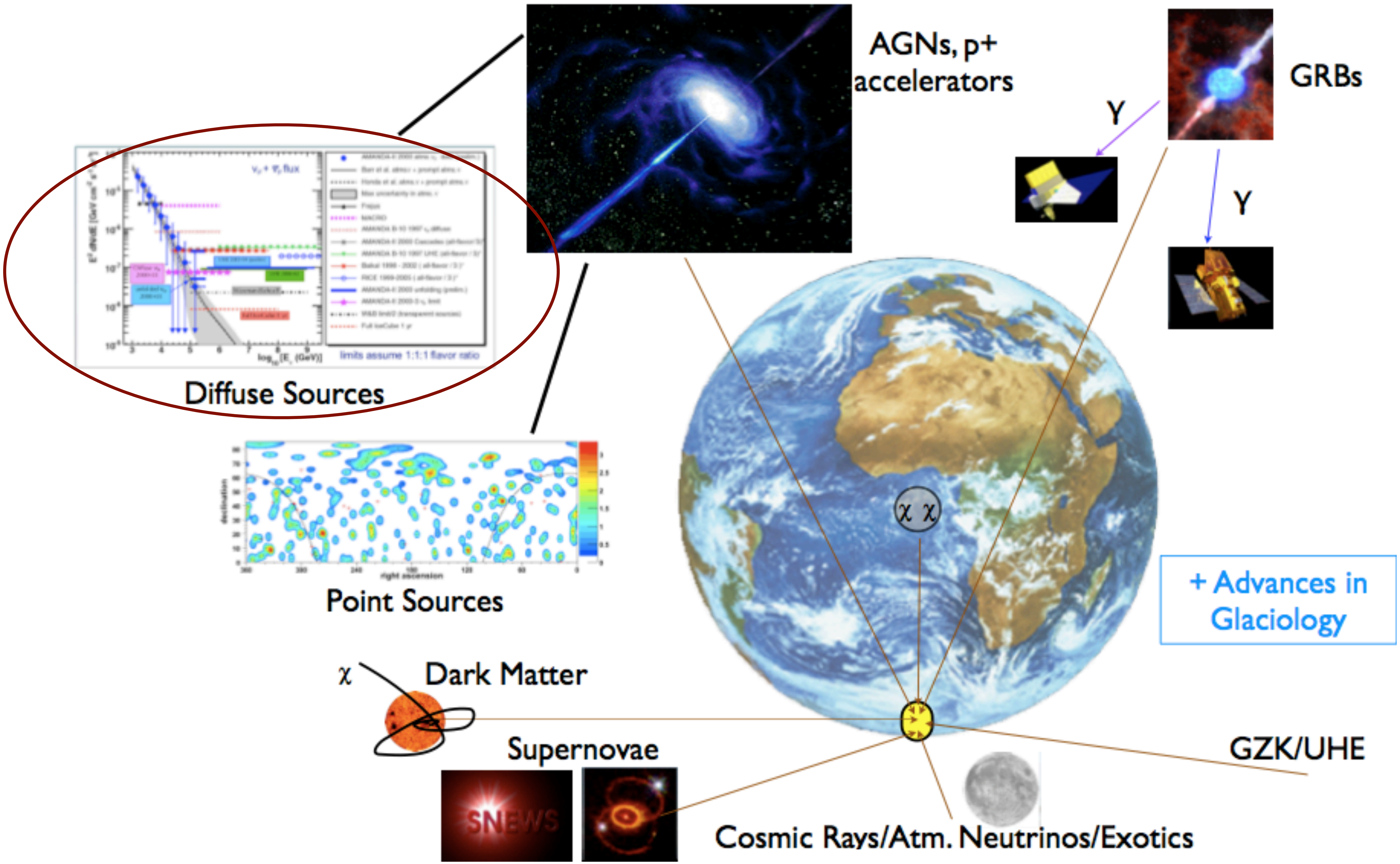
The IceCube Neutrino Observatory - A Wealth of Science...



The IceCube Neutrino Observatory - A Wealth of Science...



Motivation example:

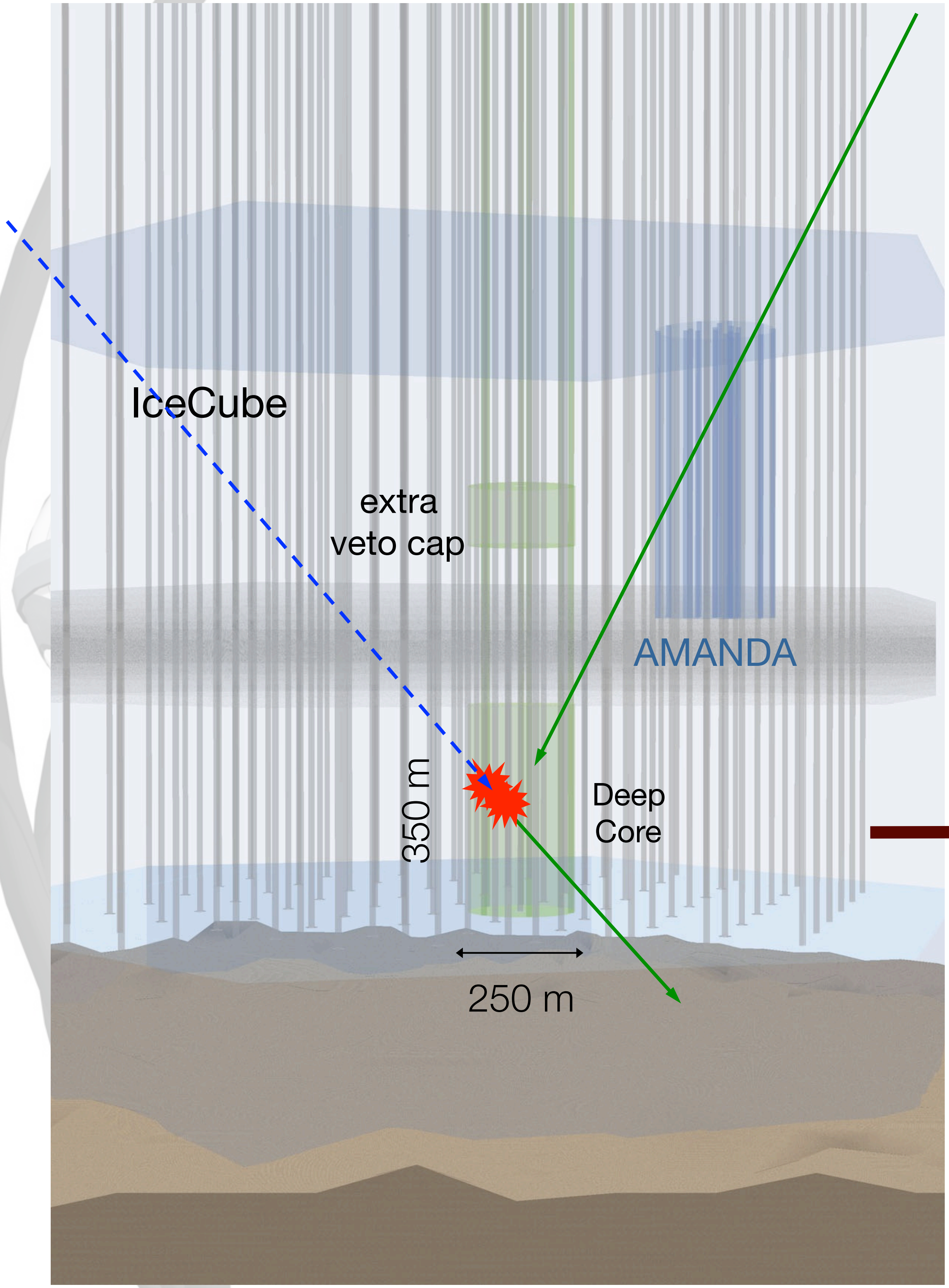
Atmospheric Neutrino Spectrum Measurement

- The Largest systematic uncertainty in the signal prediction comes from light detection efficiency in a DOM in situ (in the Antarctic ice).
- For example, varying the efficiency by 10% in the simulation changes the predicted atmos_nu rate by 11% in this analysis.
- Key is to reduce the systematic
- Challenge, transition from lab to in situ.
- If we have a source we can identify very well then we can identify that energy deposition directly for the DOM in the ice and greatly reduce this systematic.

TABLE II. Systematic uncertainties.

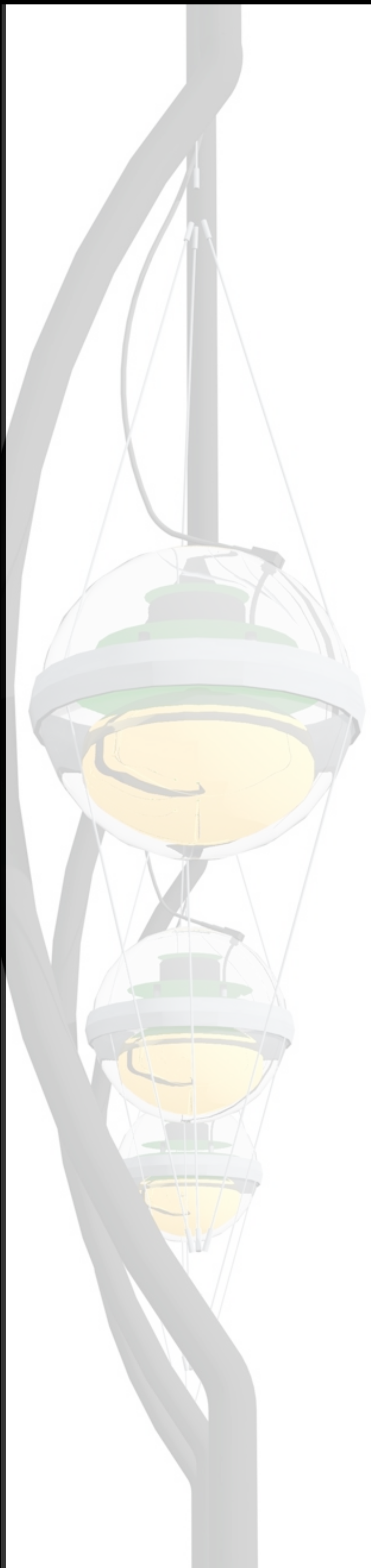
Source of uncertainties	atm. μ	atm. ν_μ	atm. ν_e
Ice properties	8%	6%	2%
DOM efficiency	30%	11%	10%
Cosmic-ray flux	33%	-	-
ν-nucleon cross section	-	6%	6%
Sum	45%	14%	11%

Table taken from '*Measurement of the Atmospheric ν_e flux in IceCube*,' Phys. Rev. Lett. 110 (2013) 151105



Atmospheric Muons

- -Atm. μ/ν trigger ratio is ~10^6
- -Vetoing algorithms expected to reach at least 10^6 level of background rejection for ν physics analysis.
- -We have become experts in identifying muons
- -Turn this around, and you have an excellent, high statistics calibration source



CALIBRATION
WE CAN BELIEVE IN

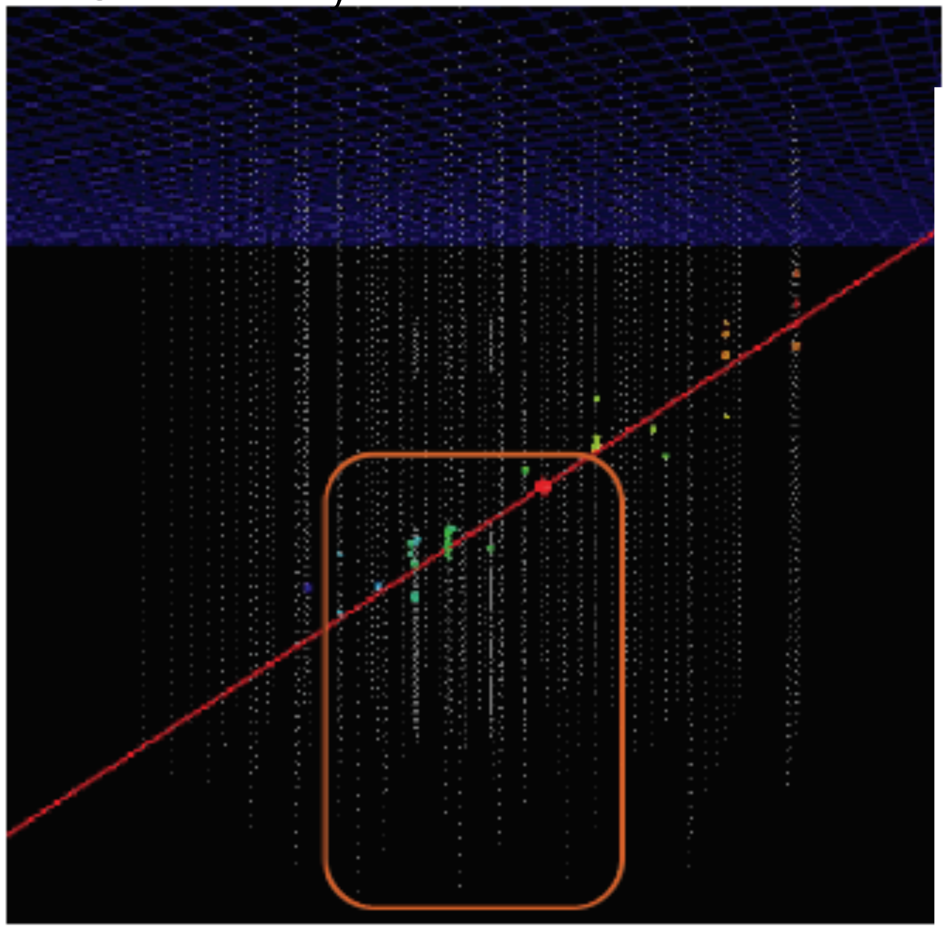
→ Minimum ionizing muons provide a robust calibration source

- Have constant, known light emission
- Are abundant: high statistics
- Can be reconstructed to high precision

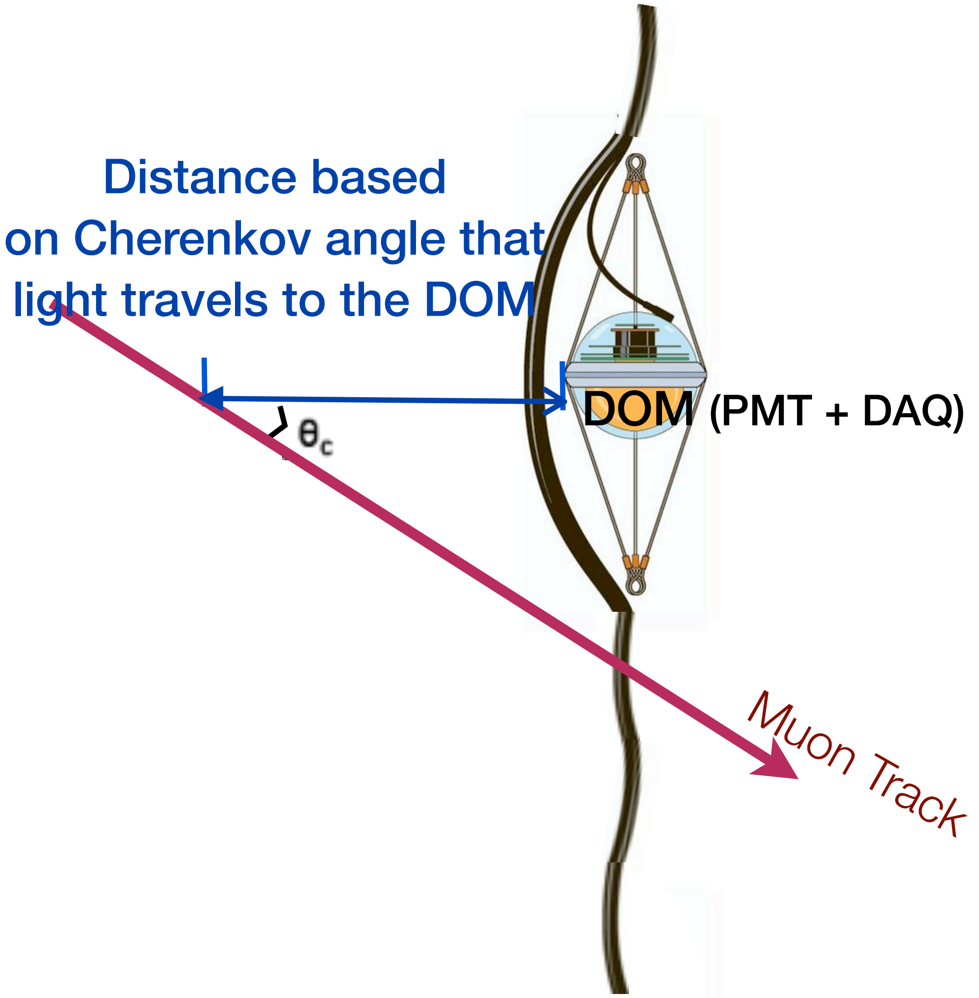
DOM efficiency is calculated using DOMs in deep ice on center strings

- Use only charge from DOMs in the study region
- Bin collected charge on a given DOM (PMT + DAQ modules) based on the track-to-DOM Cherenkov distance

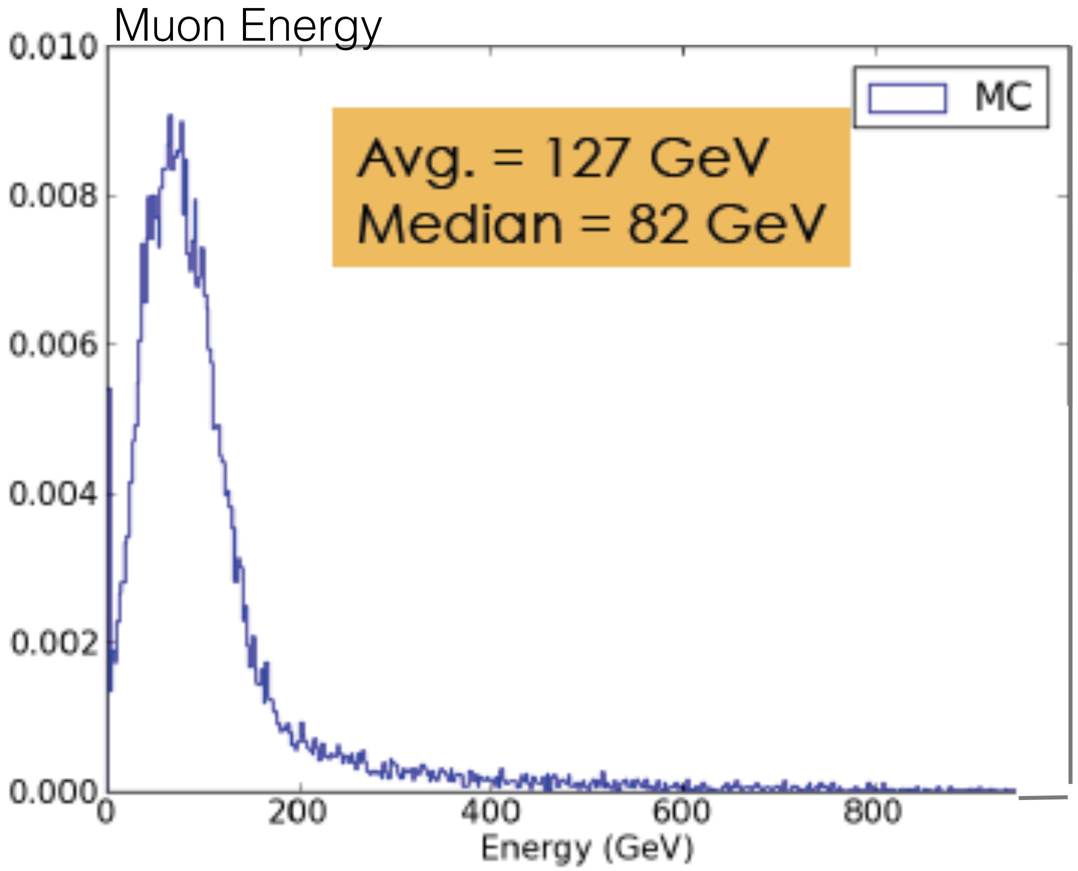
IceCube Array



study region



Event selection isolates an unbiased sample of high-quality, minimum-ionizing, single muons



- Inclined tracks: zenith ~45°
- Well-reconstructed stopping tracks
- Single muons, E ~ 80 GeV

- Use well reconstructed muons that have an end point of their track within 50m of our detector boarders, ie '***stopping tracks***'

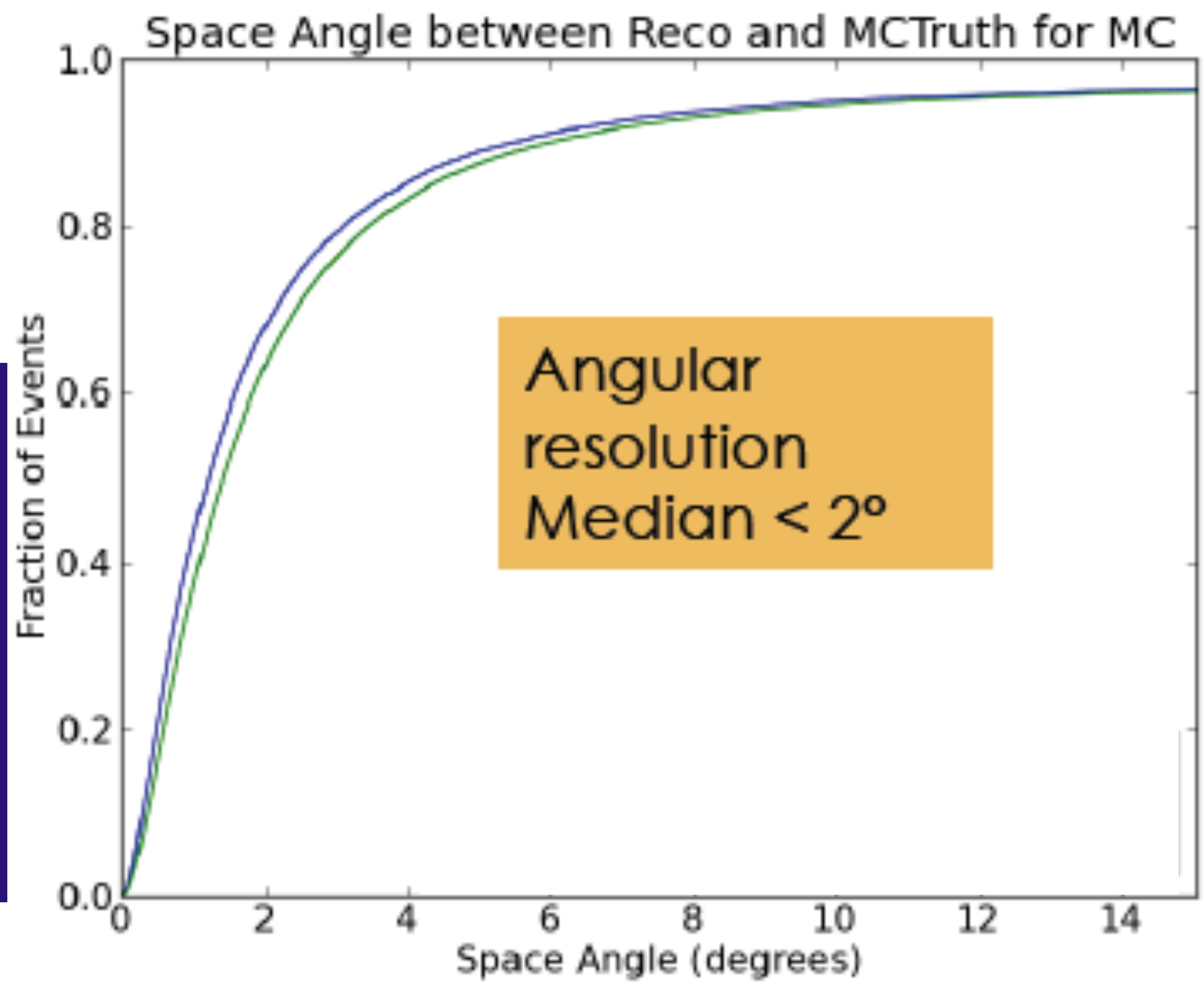
- Systematic effects are a larger issue at lower energy where we have less event information.

- Use as low an energy as possible a sample which can still take advantage of our High Energy tools and have very good (~2deg) track direction resolution

-Energy~80GeV

Event selection isolates an unbiased sample of well reconstructed, minimum-ionizing single muons

Monte Carlo (MC) event direction reconstruction vs Monte Carlo true direction:



Event selection:

Data – IceCube with 79 out of 86 strings detector configuration

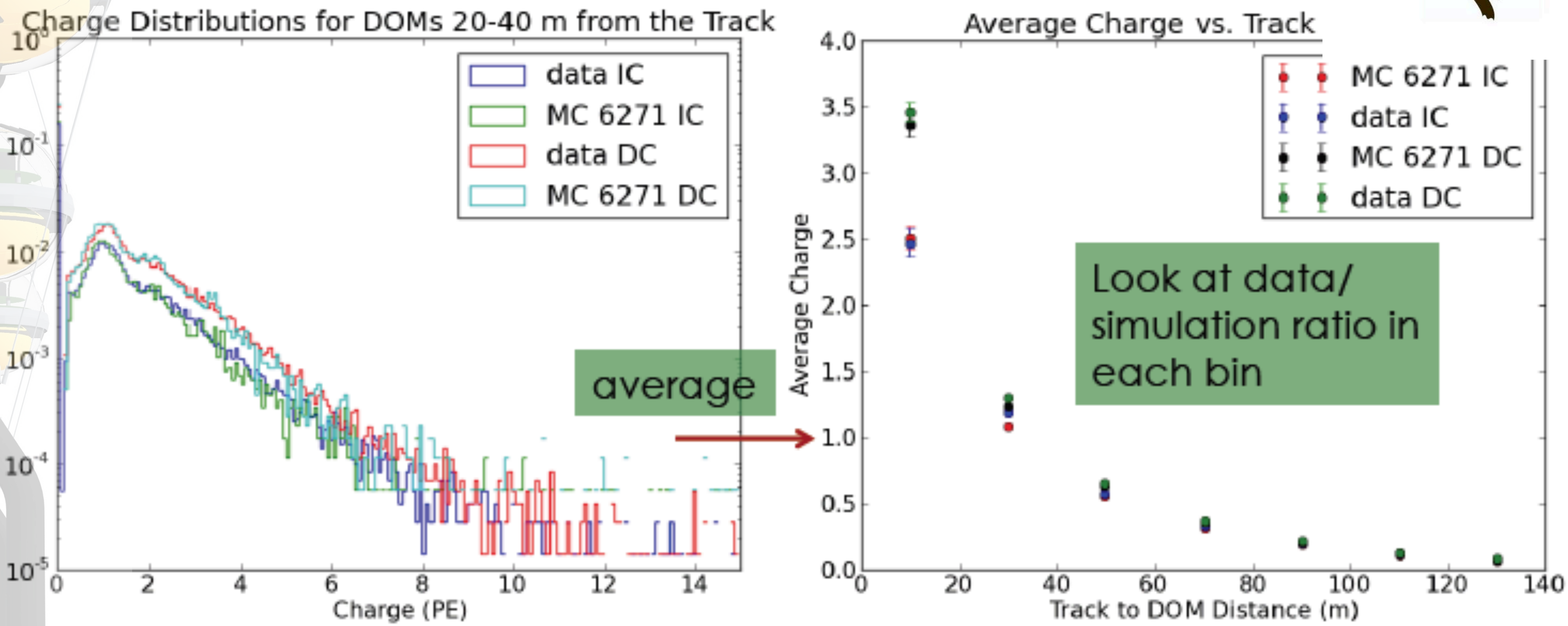
- 37.3 days of data
- 0.6% passing rate
- 70 000 muons in sample

MonteCarlo:

~17 000 muons

Event DOM efficiency is calculated by comparing charge in data to Monte Carlo

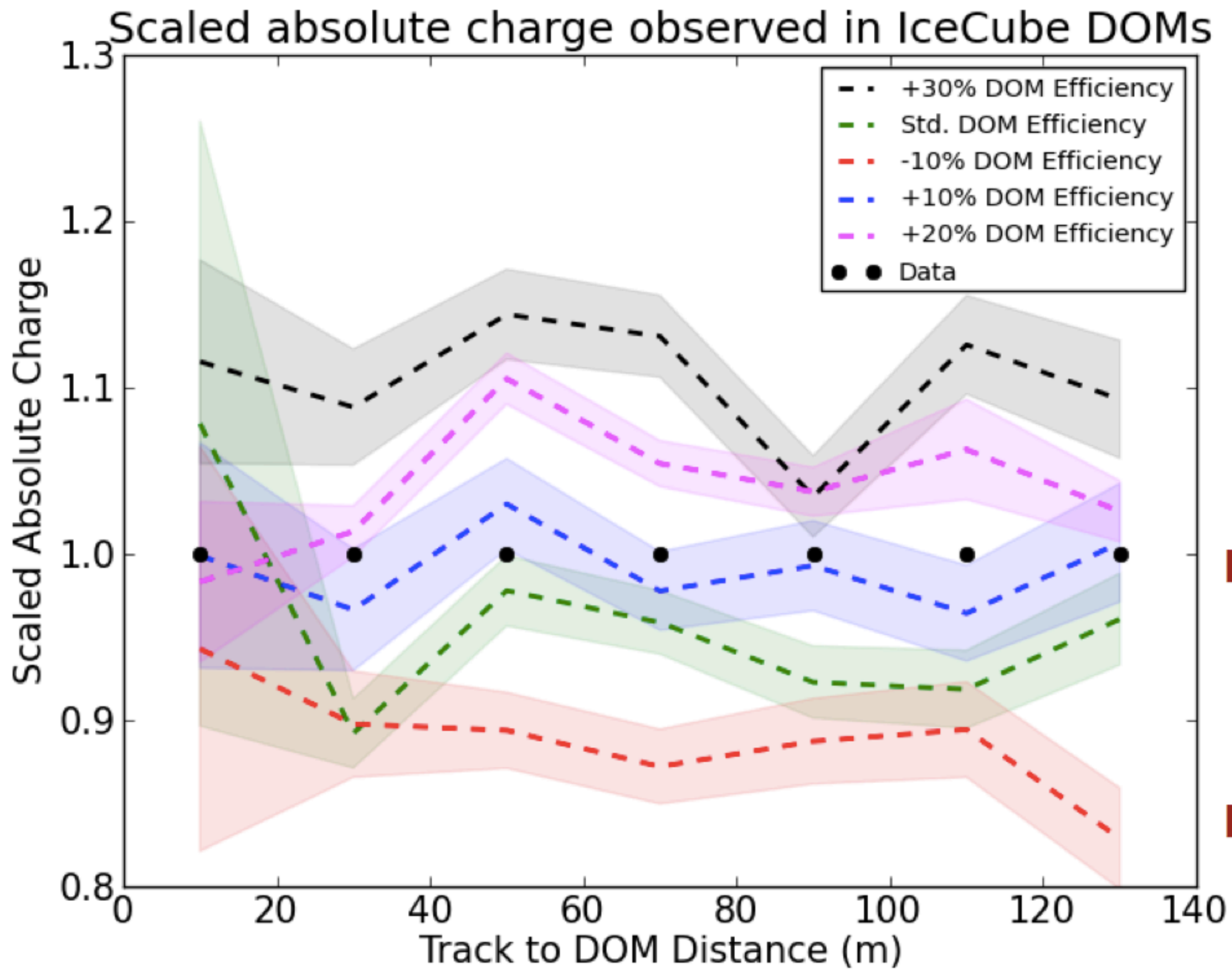
- Bin DOMs depending on their track-to-DOM Cherenkov distance
- Average charge in each distance bin



Data has more charge than simulation:

- Charges are scaled to standard simulation, corrected for SPE peak offset

- Charge roughly scales with the DOM sensitivity



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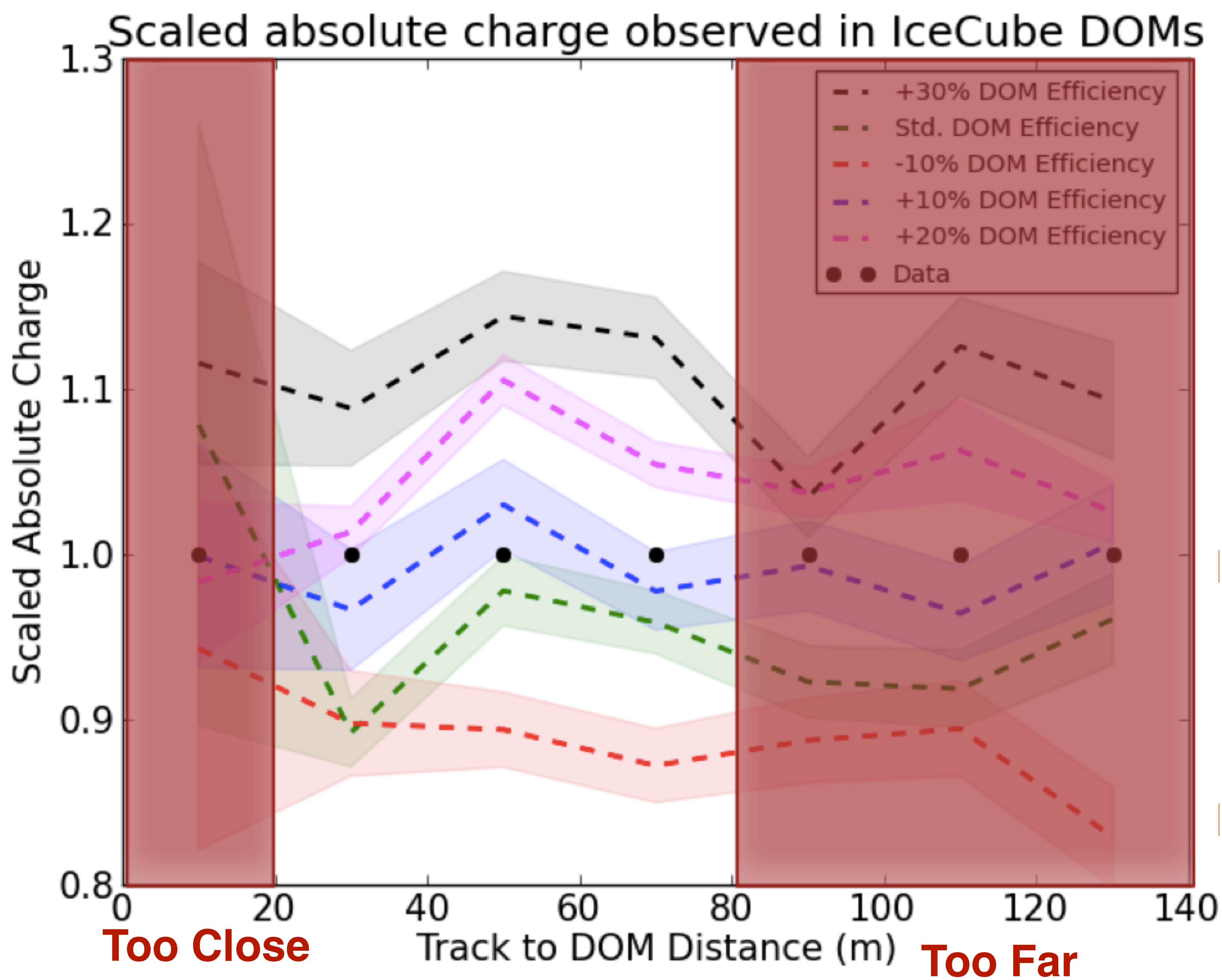
Average and analyze 20-80m bins



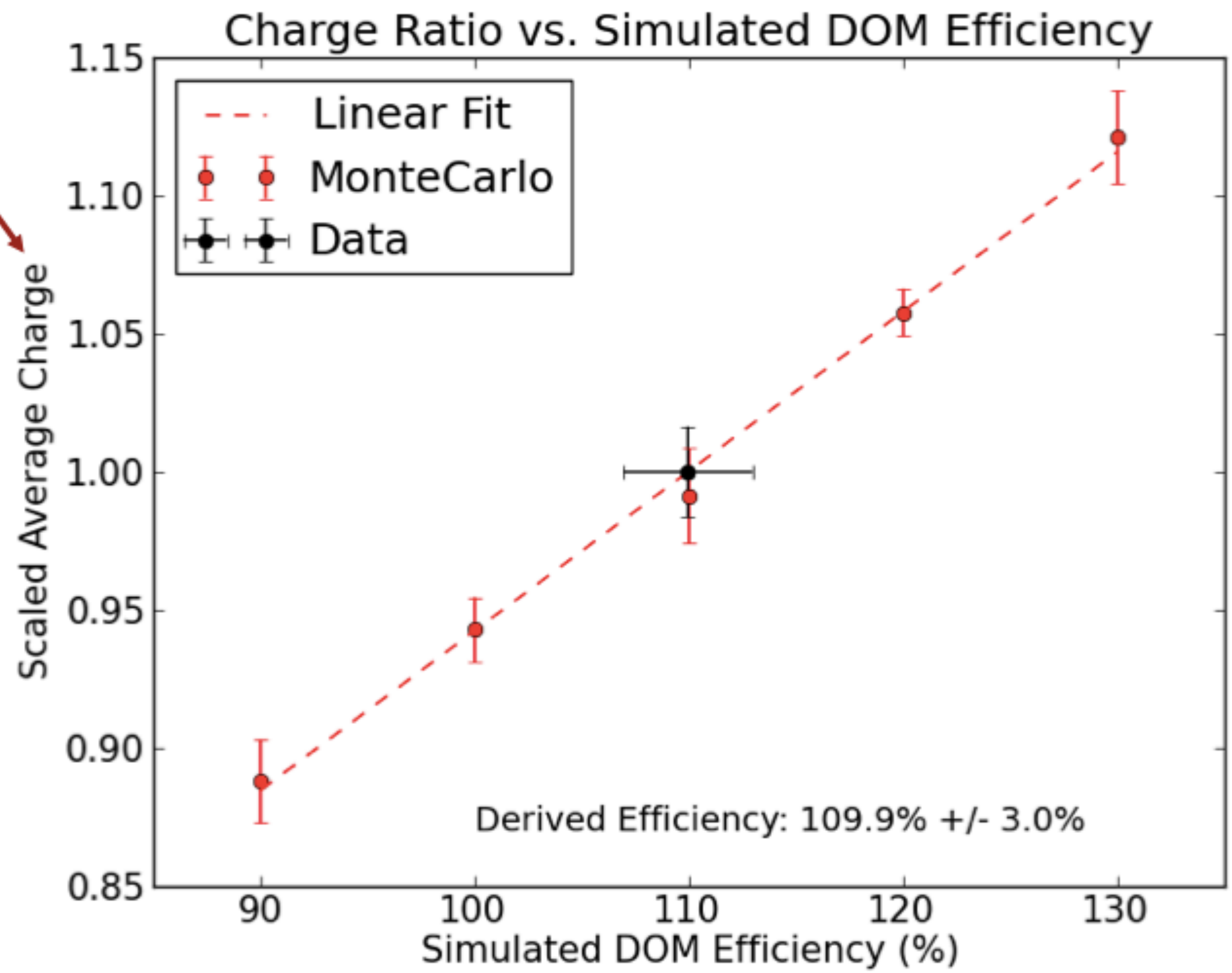
Reconstruction errors, questionable simulation, bigger fluctuations

Ice properties play a bigger role

Deriving the DOM module efficiency:

Average charge of 20-80 m bins

- Analysis response is linear over DOM efficiencies of 90% to 130%
- Derived efficiency is 109.9%
- 3% uncertainty includes statistics and systematics



Summary

- Minimum-ionizing muons provide a robust calibration source for measuring the DOM efficiency
- Systematic analysis derives a **DOM efficiency of 109.1% +/- 3.0%**, with ice model correlation coefficients:

Systematic MC dataset	DOM efficiency
Absorption +10%	99.4%
Scattering +10%	98.0%
Scat. And Abs. -7.1%	101.0%

DOM

Thanks for listening!

Tania R. Wood CAP Congress 2014

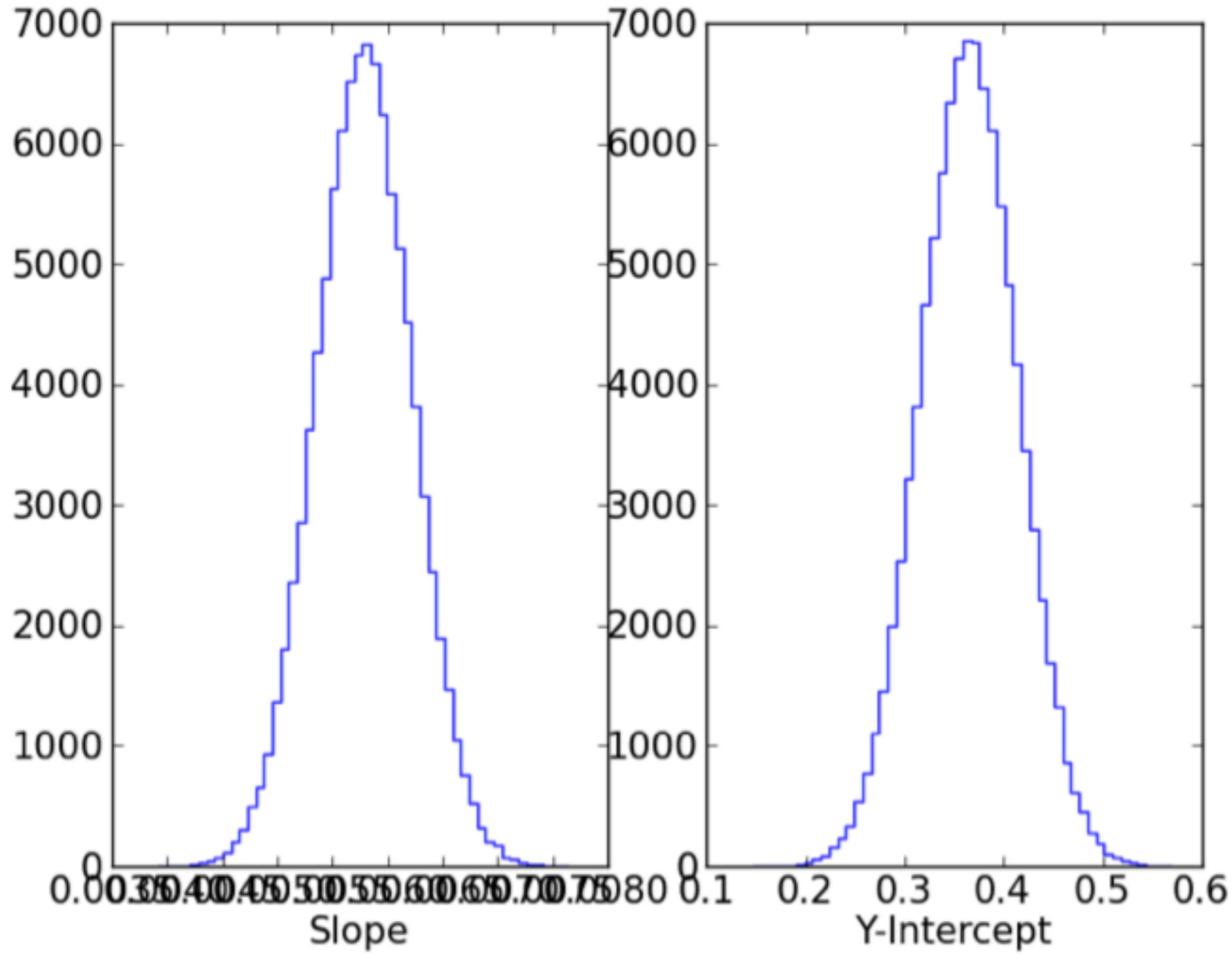

BACK UP SLIDES:

Uncertainty on Dom Efficiency is **3.0** %

Source of Error	Uncertainty in charge ratio	Uncertainty in derived sensitivity
Hole ice	1.6%	2.8%
Linear Fit (Data and MC statistics)	---------	0.94%
Bundle Uncertainty	0.3%	0.5%
Afterpulses	0.05%	0.09%
Noise Rate	0.02%	0.03%
Total		**3.0%**

- Statistical uncertainty on data propagated into linear fit

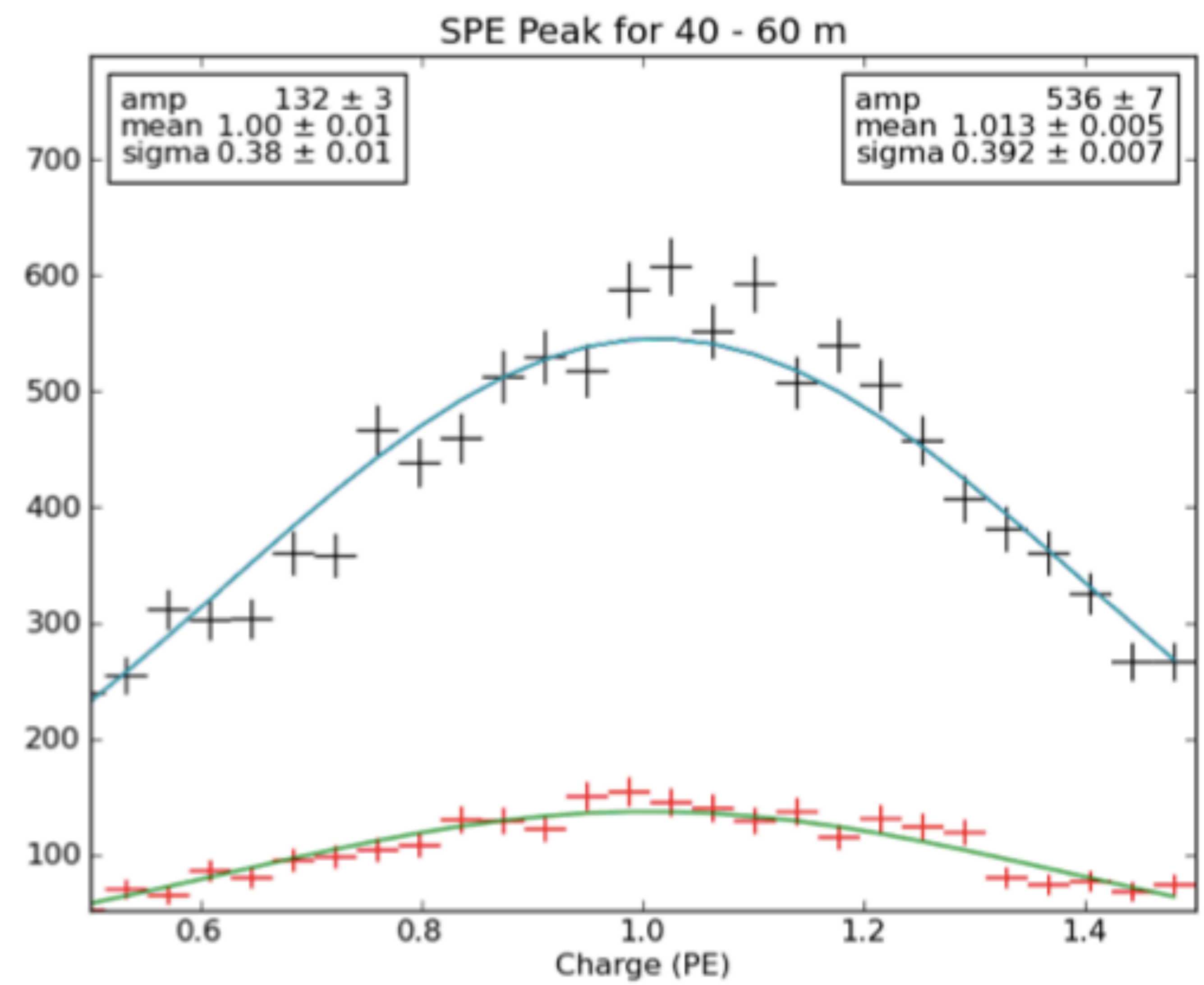
Linear fit uncertainty calculated via 10^5 resamplings of the MC points



- MC points resampled
- Covariance matrix of distributions for slope, y-intercept gives errors on linear fit

What about the SPE Peak?

- 1 photoelectron in data is not the same as 1 photoelectron in MonteCarlo
- Previously, we corrected for this effect to get the actual efficiency of the DOM
- 106.2% +/- 3.2% → actual DOM efficiency, given ideal charge calibration
- **109.9% +/- 3.0%** → effective DOM efficiency, recommended for every-day use in current simulation and physics analyses
- Investigation of this effect is ongoing



What about the bulk ice?

- In most physics analyses, errors on DOM efficiency and ice properties are assumed to be uncorrelated

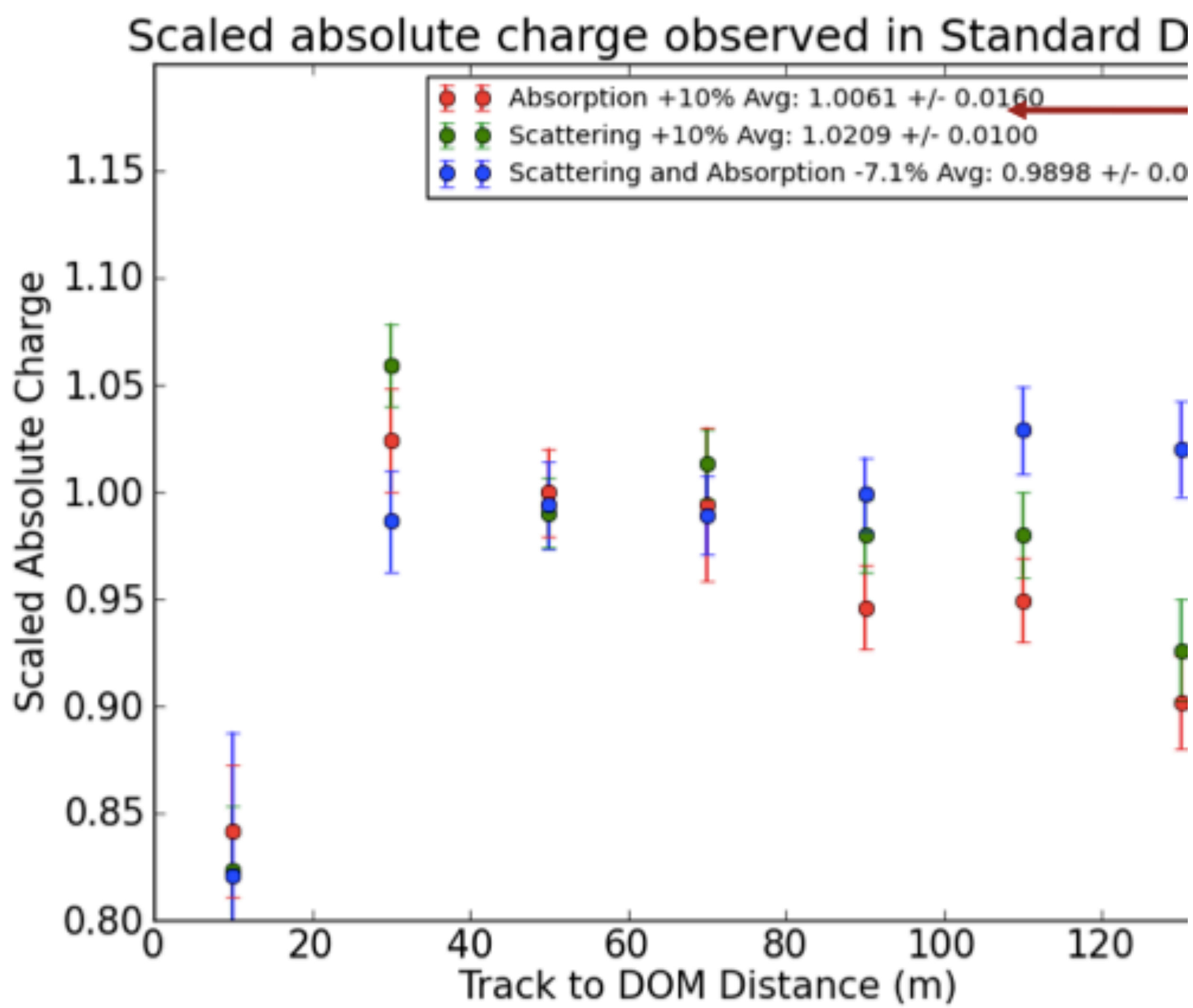
With DOM efficiency from muons, they are correlated

Solution:

Run different ice models through analysis to get degree of correlation

Ice systematics MC should be generated with these different DOM efficiencies

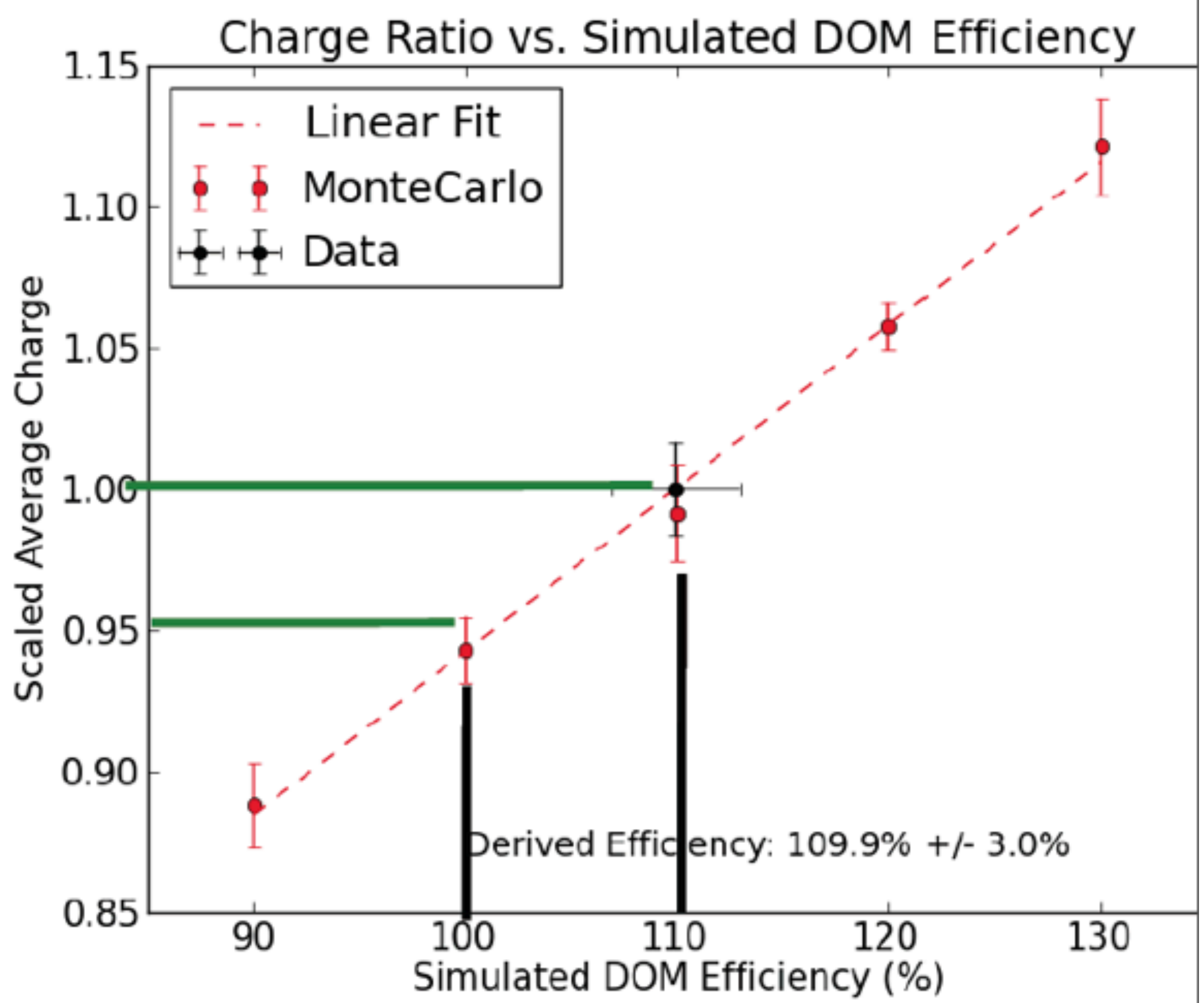
Uncertainties on these correlations are relatively large



Systematic MC dataset	DOM efficiency
Absorption +10%	99.4%
Scattering +10%	98.0%
Scat. And Abs. -7.1%	101.0%

Finishing touches: why do we think there is a bias in the analysis?

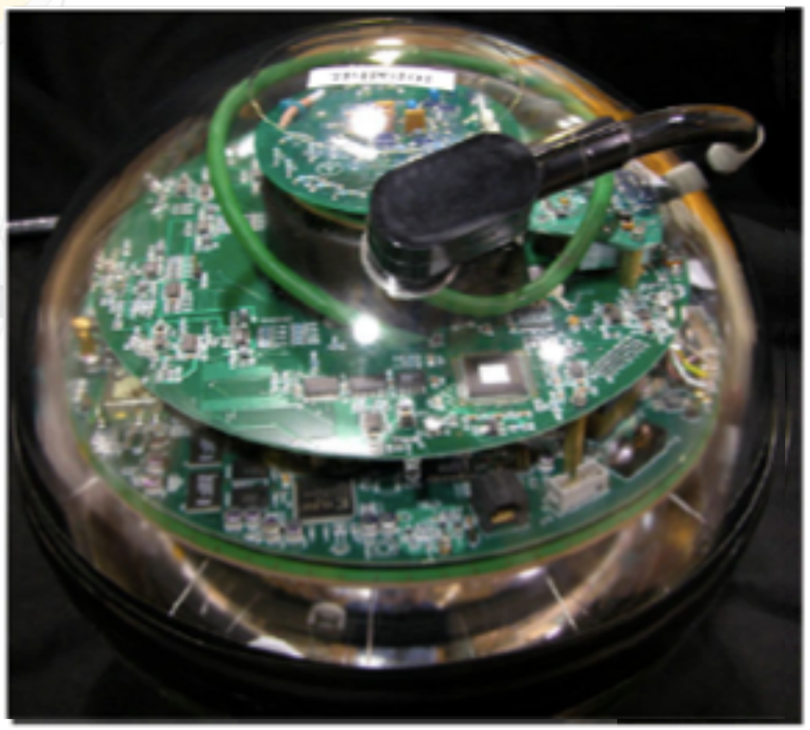
- Slope of this plot should be 1.. but it is 0.5
- ie. When you simulate 110% DOM efficiency you get ~5% increase in average charge (not 10%).
- This issue (systematic bias), is handled by making this very plot, one can extract the DOM efficiency without knowing the cause of this bias
- We would however, like to know where this comes from and if the source is a concern
- Investigation of this effect is ongoing



IceCube Performance Parameters

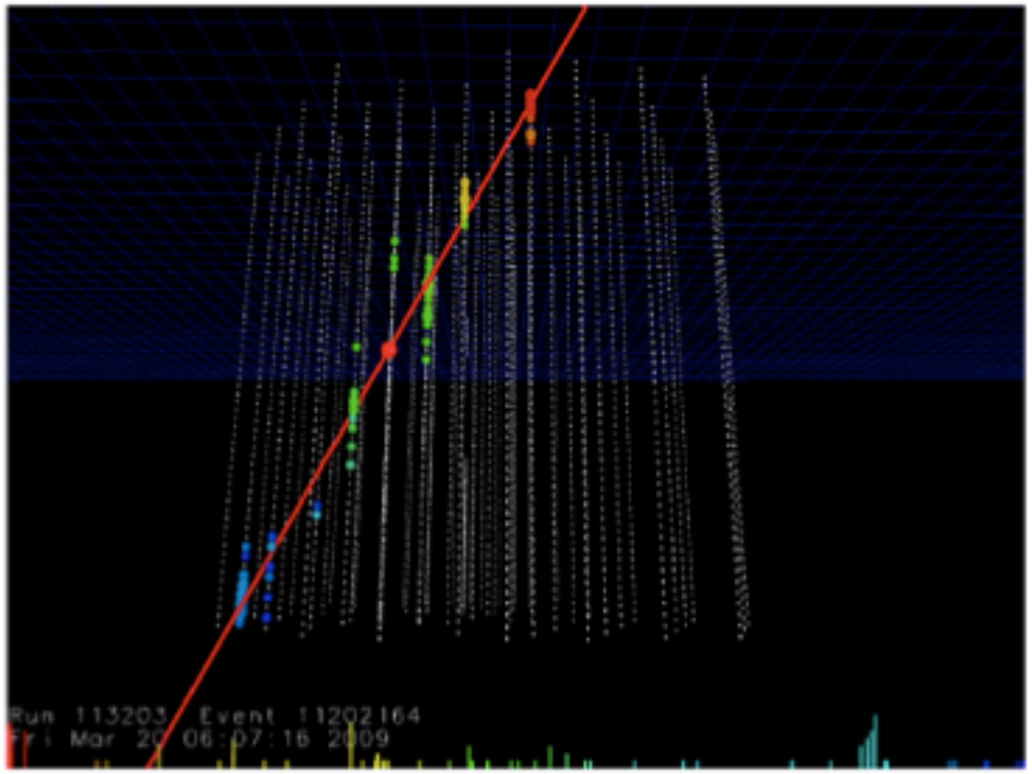
DOM Level

- time resolution
- charge response
- noise behavior
- reliability



Detector level

- angular resolution
- energy resolution
- final sensitivity



Noise Noise Noise ..

- Average dark noise rate $\approx$ 540Hz (atmospheric muons, radioactivity (~ppb.)). Artificial deadtime of 250µs -> 285 $\pm$ 28Hz
- Very Stable in time and only slightly with depth (slightly elevated correlated dark noise rate at the bottom of the detector where the ice is warmer (~-10 degC)

The Digital Optical Module (DOM)