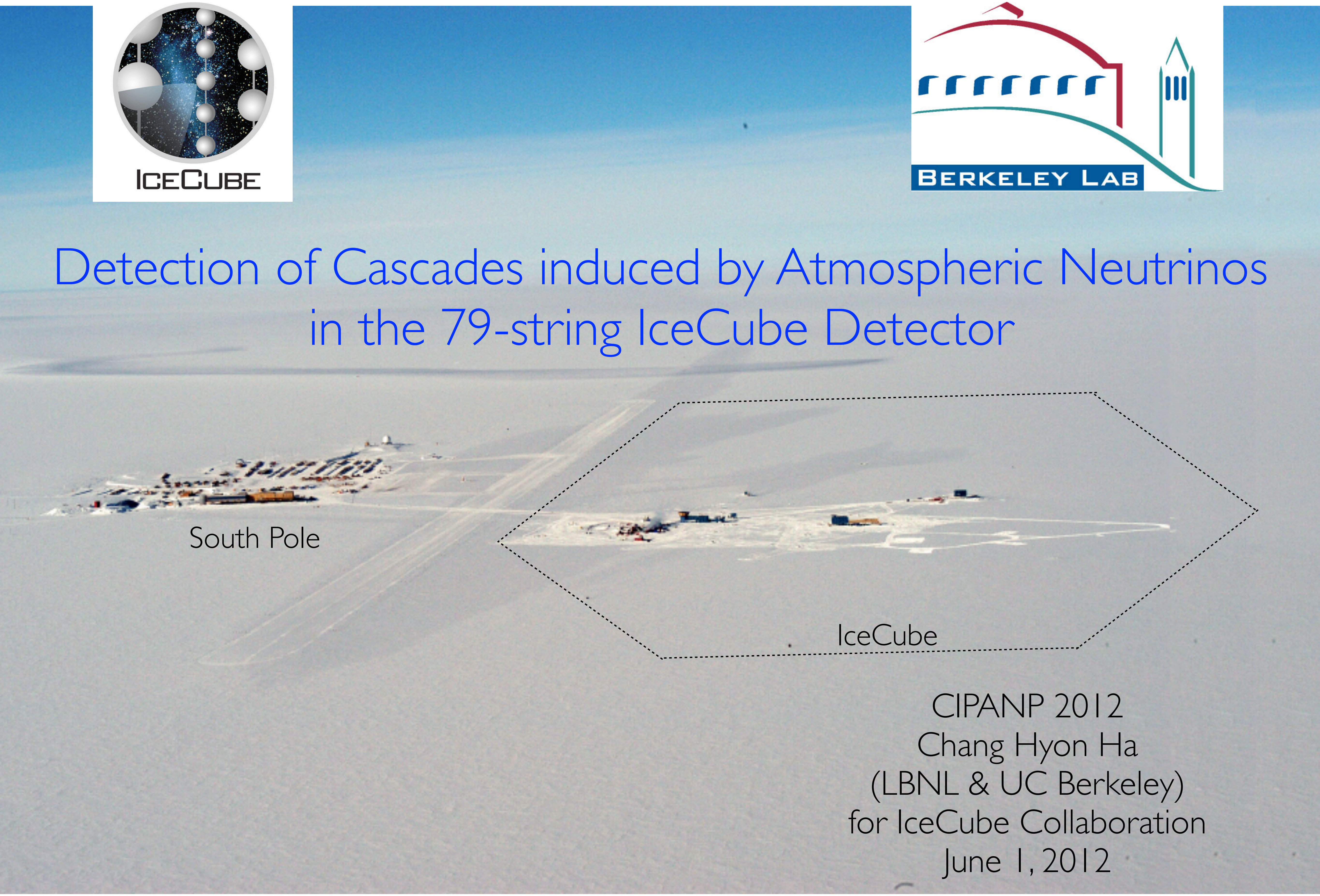
Detection of Cascades induced by Atmospheric Neutrinos in the 79-string IceCube Detector



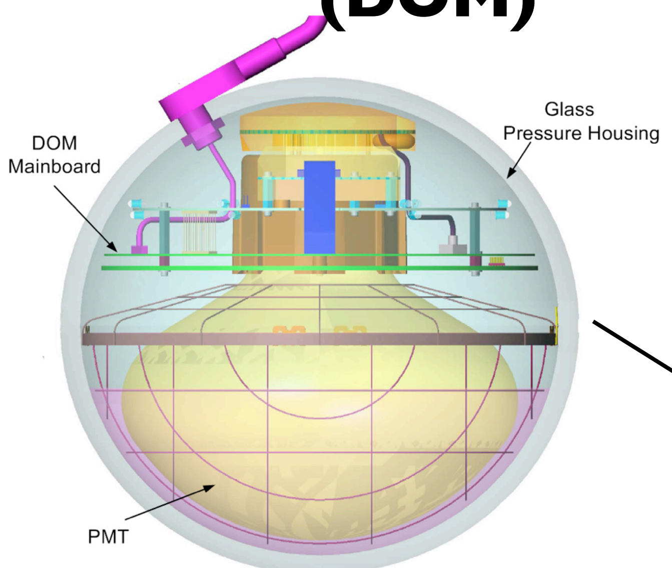
CIPANP 2012
Chang Hyon Ha
(LBNL & UC Berkeley)
for IceCube Collaboration
June 1, 2012

Outline

- The IceCube Neutrino Observatory
- High Energy Atmospheric Neutrino Production
- IceCube Low Energy Extension : DeepCore
- Cascade Analysis
  - E.-M. and Hadronic Showers produced by ν_e and neutral current of all flavors
- Conclusion

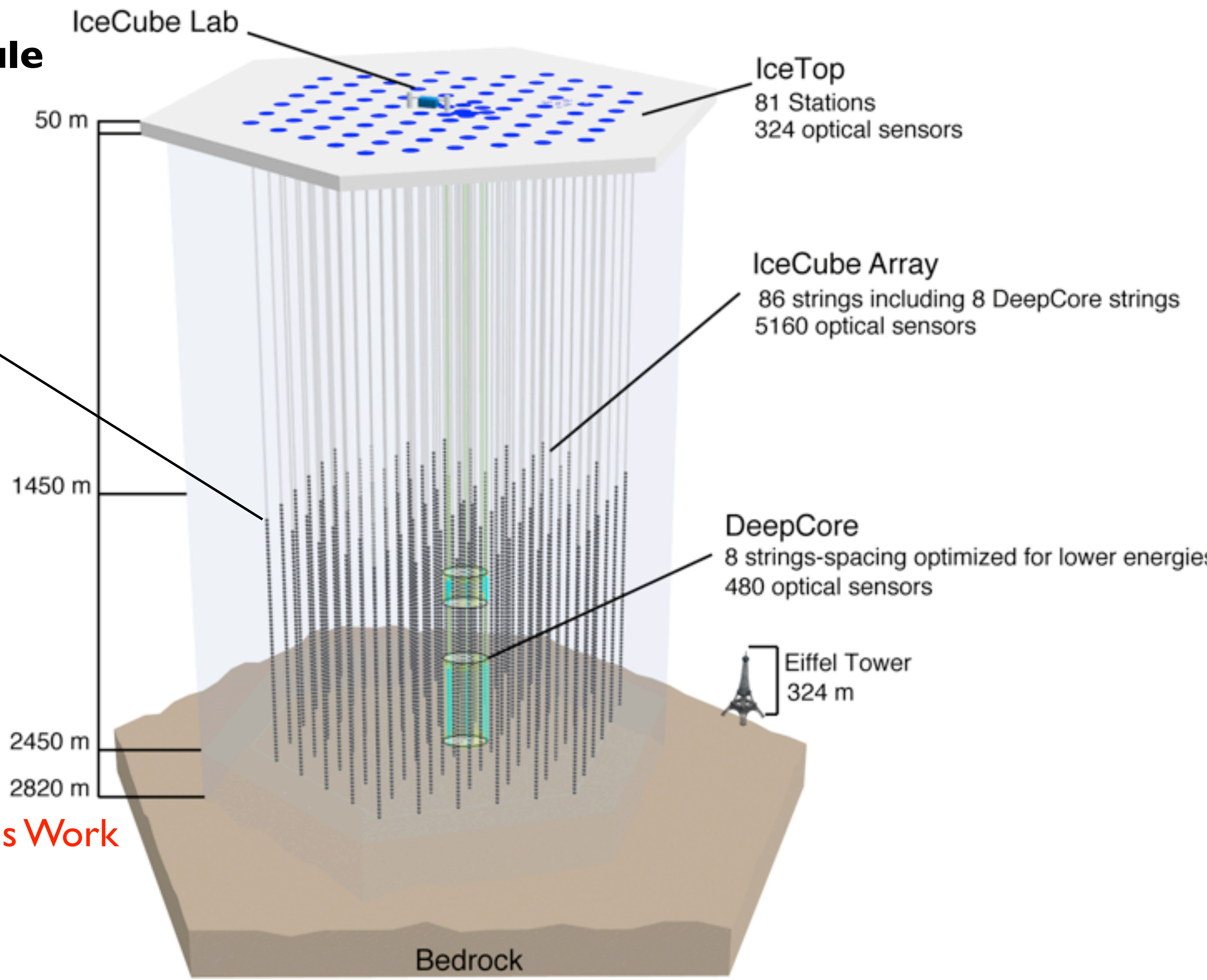
IceCube Observatory at South Pole

Digital Optical Module (DOM)

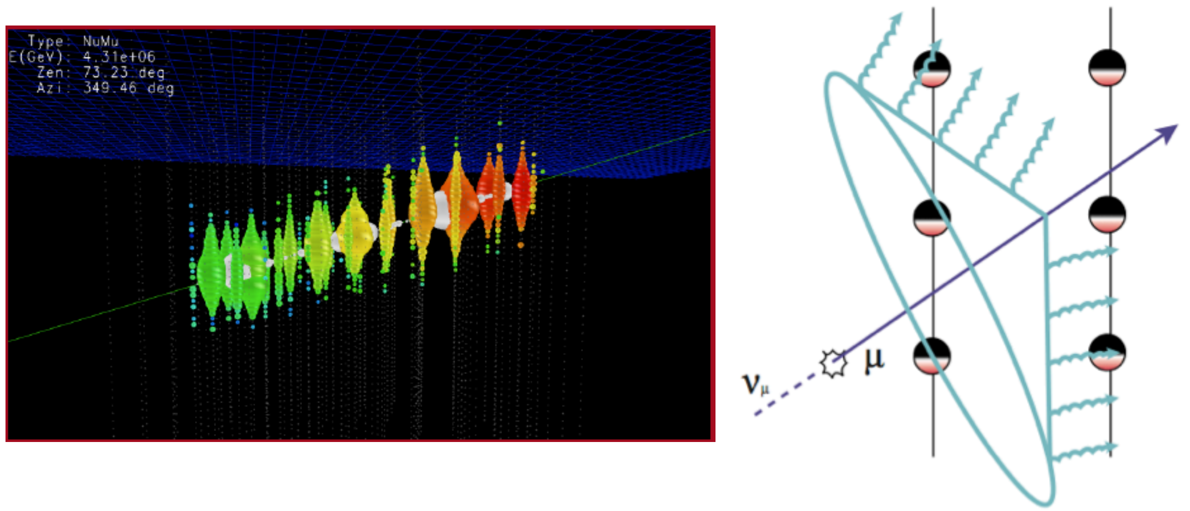


Project History

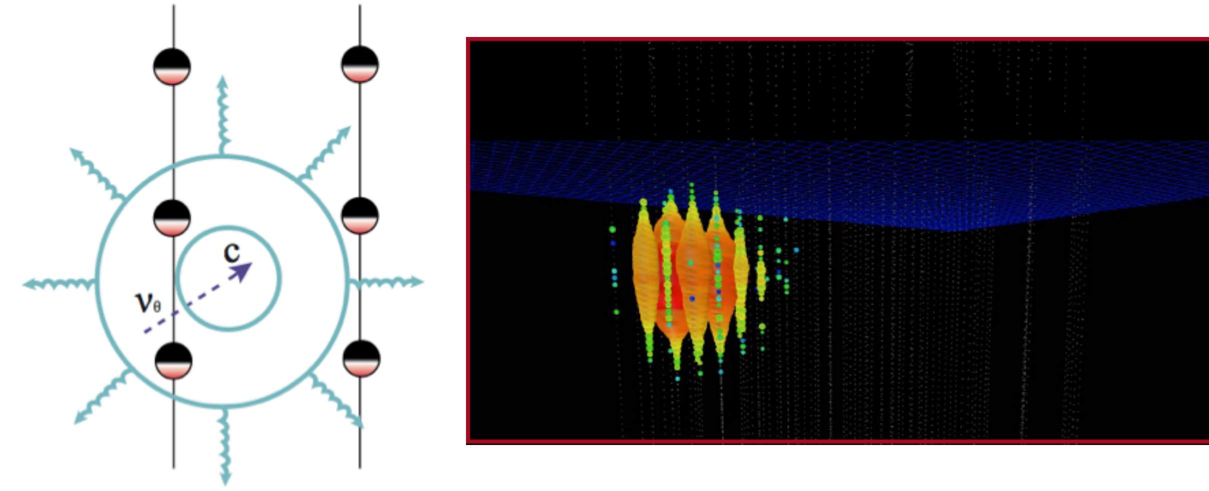
IC-1 (2005)
IC-9 (2006)
IC-22 (2007)
IC-40 (2008)
IC-59 (2009)
IC-79 (2010) ← This Work
IC-86 (2011)



Event Signatures
- Cherenkov Radiation



track



cascade

symbols	process	signature	note
ν_μ^{CC}	$\nu_\mu + N \rightarrow \mu + X$	track	Hybrid Event (track+cascade) if contained
ν_e^{CC}	$\nu_e + N \rightarrow e + X$	cascade	E.M. shower and Hadronic shower indistinguishable
ν_τ^{CC}	$\nu_\tau + N \rightarrow \tau + X$	cascade	1 PeV tau track length is ~50m
ν_α^{NC}	$\nu_\alpha + N \rightarrow \nu_\alpha + X$	cascade	$\alpha = \mu, e, \tau$

N= Target Nucleon and X = Hadronic Shower

High Energy Atmospheric Electron Neutrinos

Sources of ν_e in the atmosphere

$\pi^+ \rightarrow \nu_\mu \mu^+$

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$

$K^+ \rightarrow \pi^0 e^+ \nu_e (K^+_{e3})$

5% decay mode

$E_\nu < 100\ GeV$ | $E_\nu > 100\ GeV$

Kaon is a dominant source
for high energy neutrinos

decay length

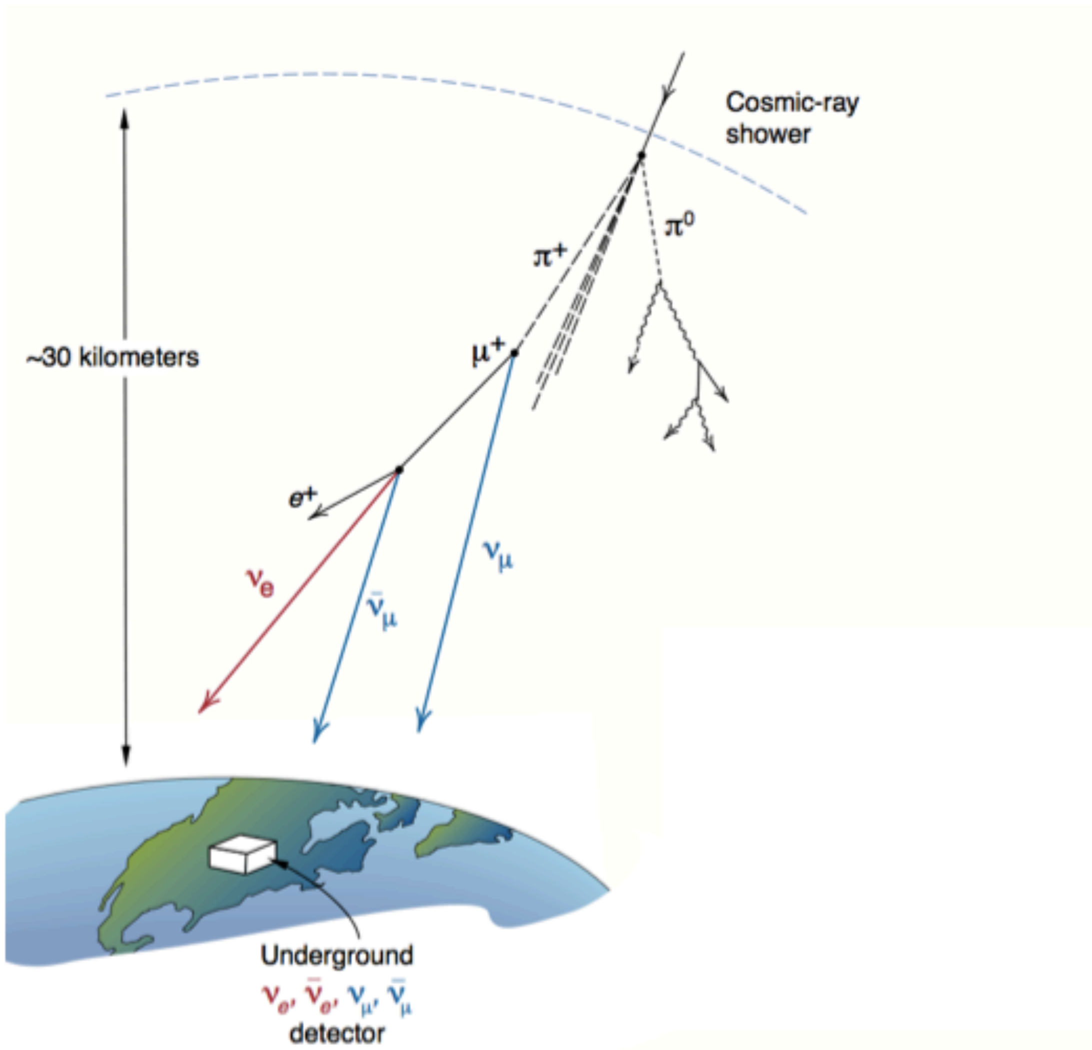
$c\tau(\mu) = 658.7m$

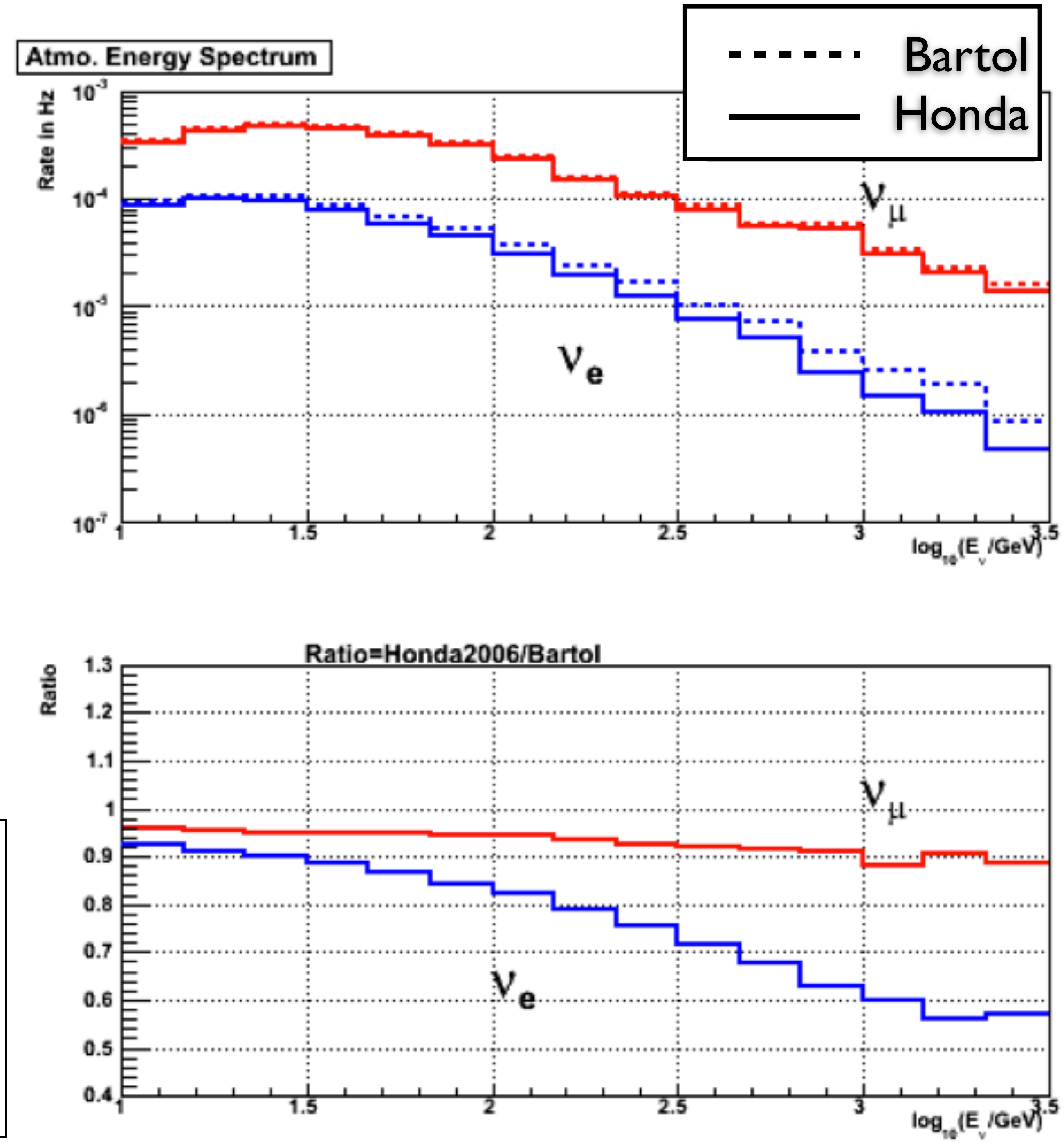
$c\tau(K) = 3.7m$

Flux Model Uncertainties

Below 10 GeV : pion production
Above 10 GeV : kaon production (7~15%)
At 1 TeV : kaon production (~35%)

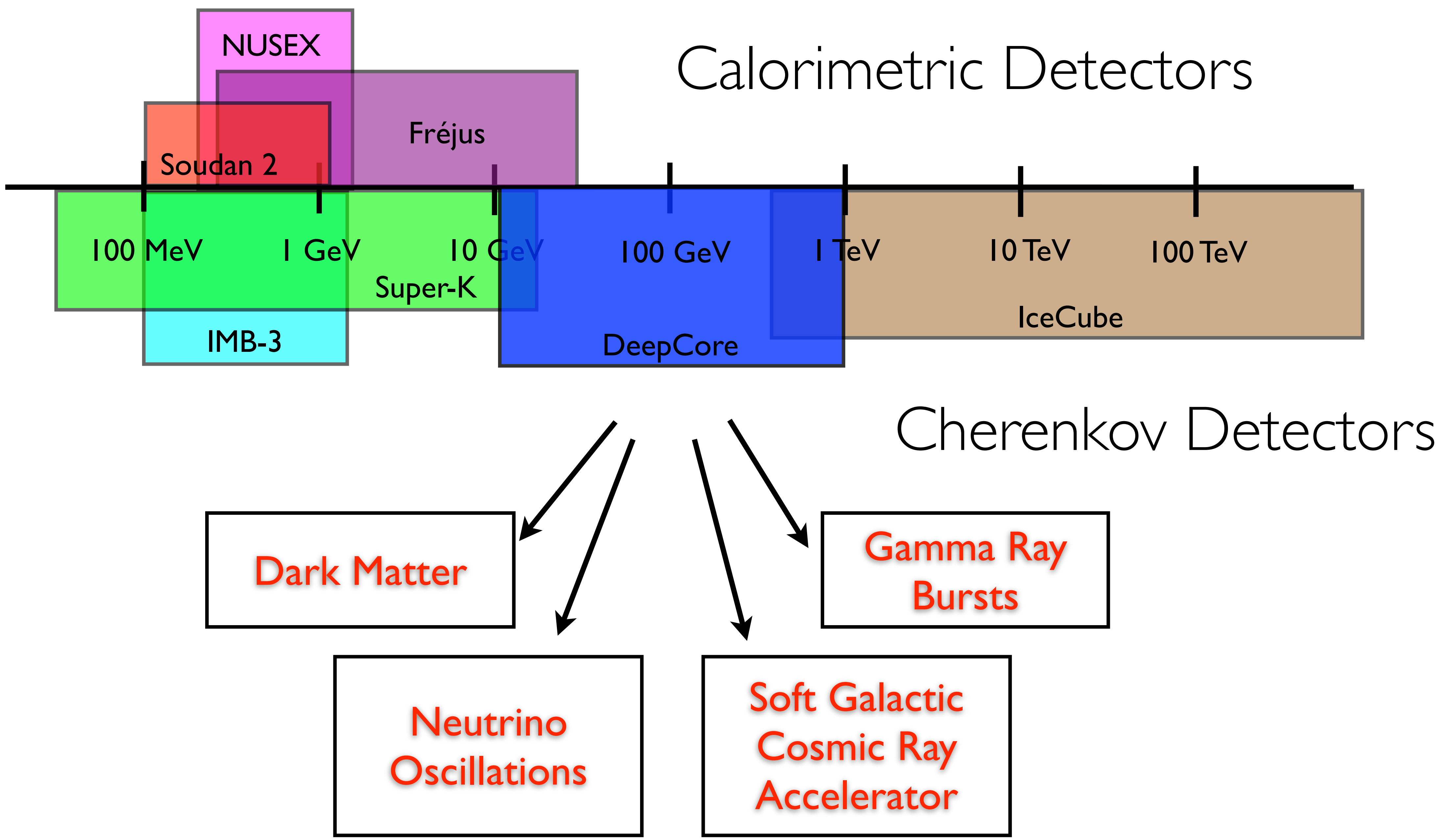
Atmospheric Neutrino Production



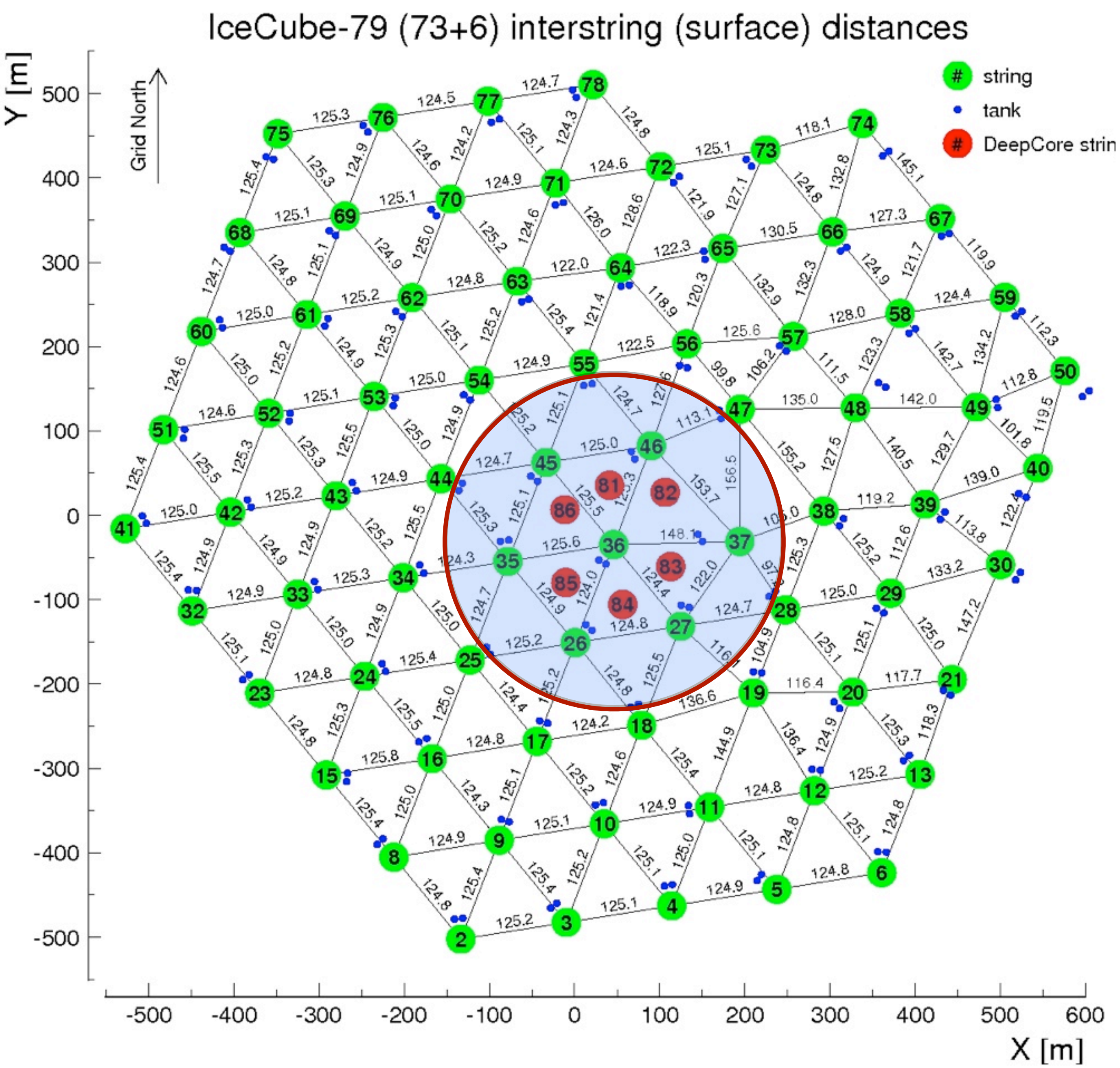


- ν_μ are better understood than ν_e.
- Higher energy muons interact predominantly than decay.
- Atmospheric ν_e flux not well known at high energies.

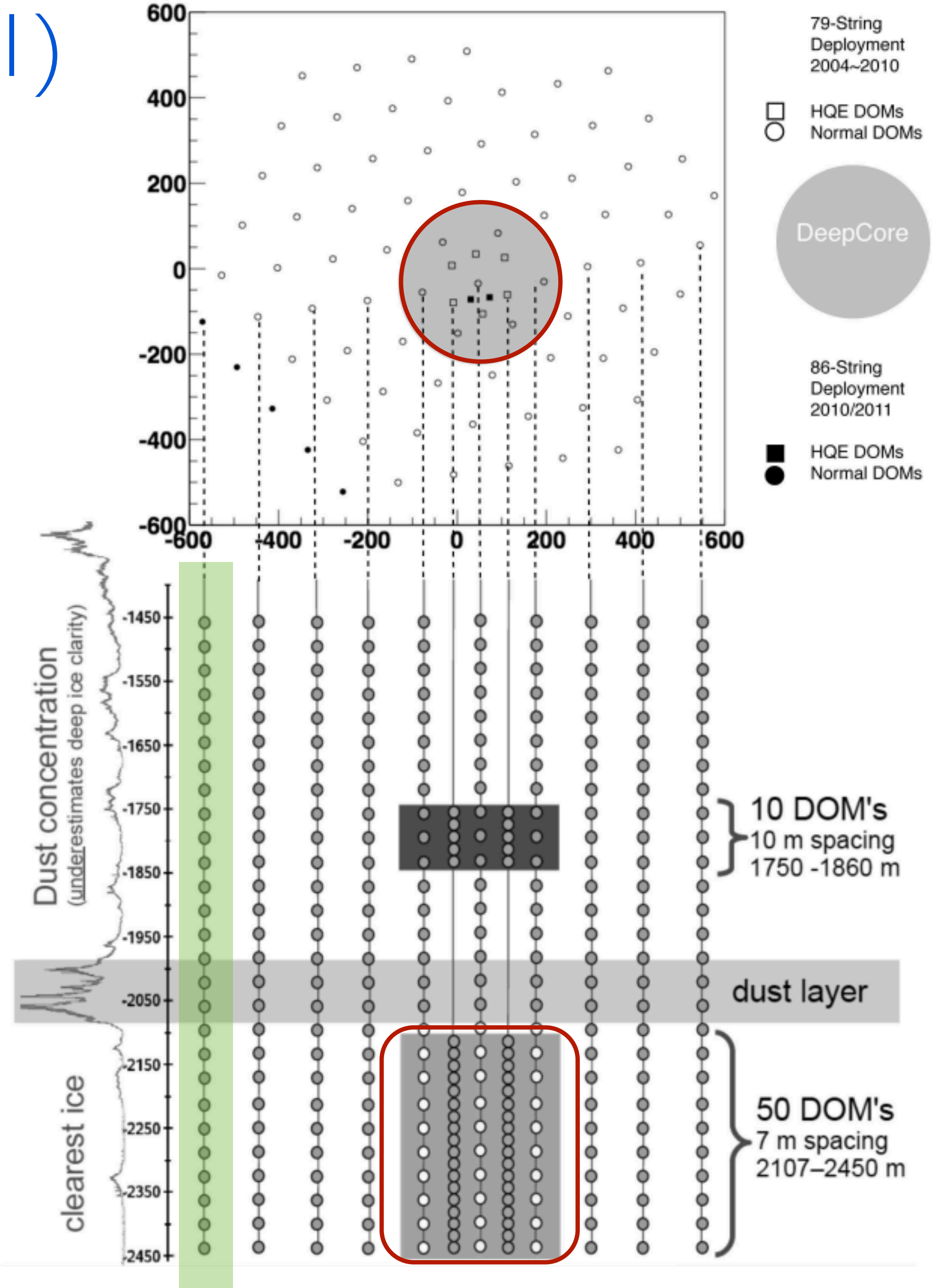
The Atmospheric Electron Neutrino Experiments



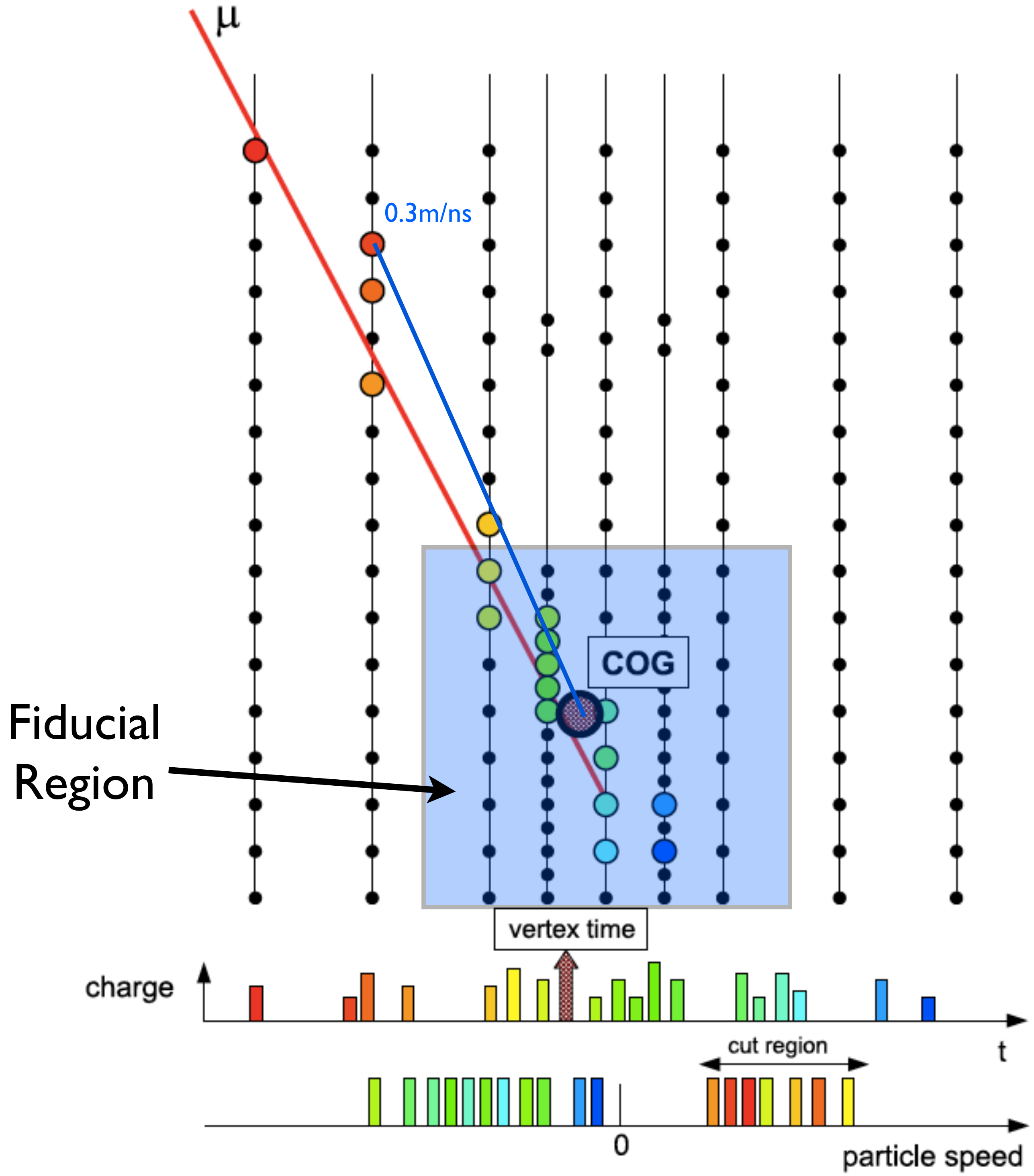
IceCube-79 Detector :This Work (May 31, 2010 ~ May13, 2011)



Fiducial Volume



South Pole Trigger & Filter



< Trigger >

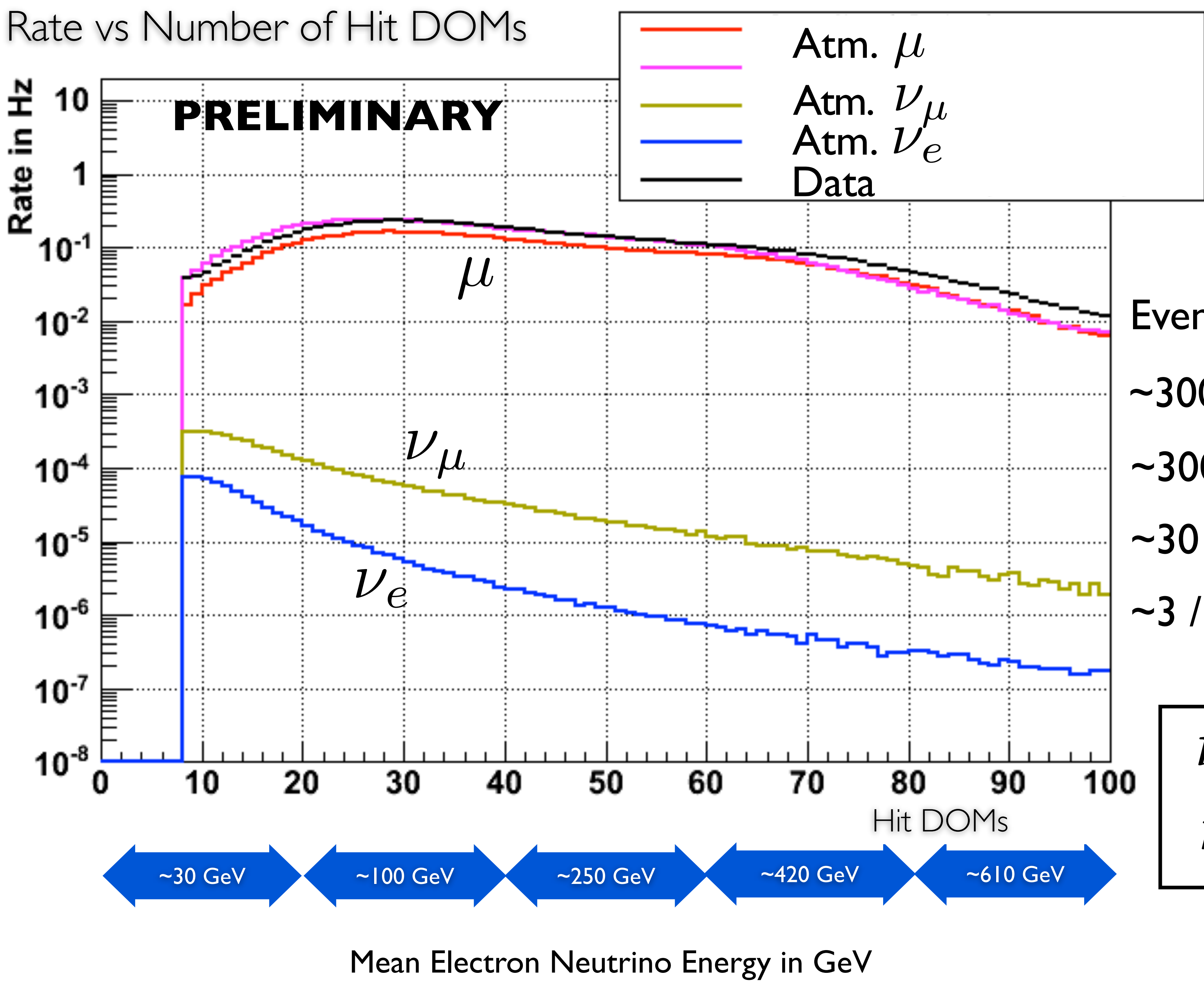
3 Coincident hits in 2500 ns.

< Filter >

COG (x,y,z,t) is calculated for fiducial hits. An event is rejected if one hit falls in speed window [0.25m/ns, 0.4m/ns]

8×10^{-3} BG rejection ~99% atm. neutrino SIG retention

Rate vs Number of Events at Filter



Events /bin/ yr

~3000 /bin/ yr

~300 /bin/ yr

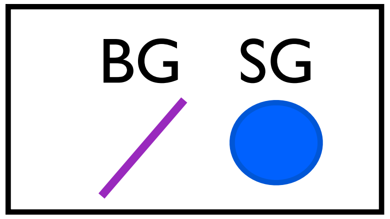
~30 /bin/ yr

~3 /bin/ yr

ν_μ ~ 150,000 / 365d

ν_e ~ 20,000 / 365d

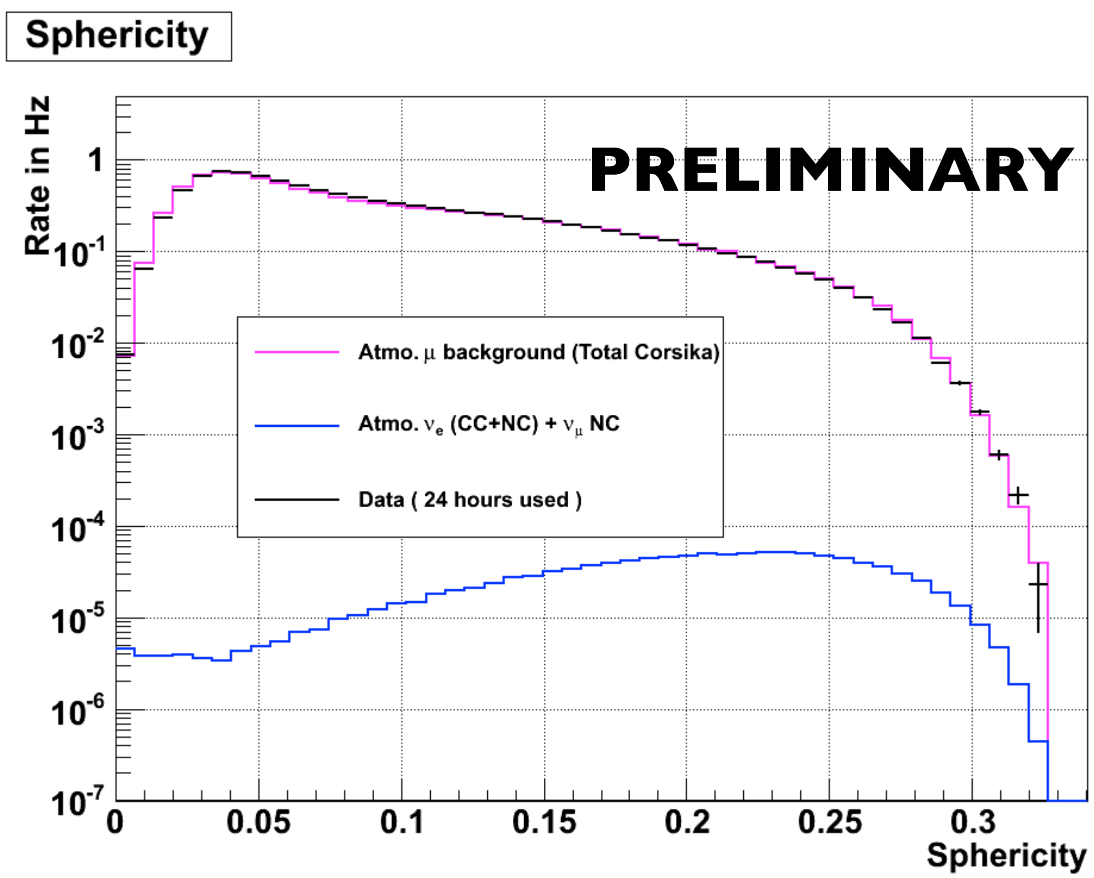
Event Topology



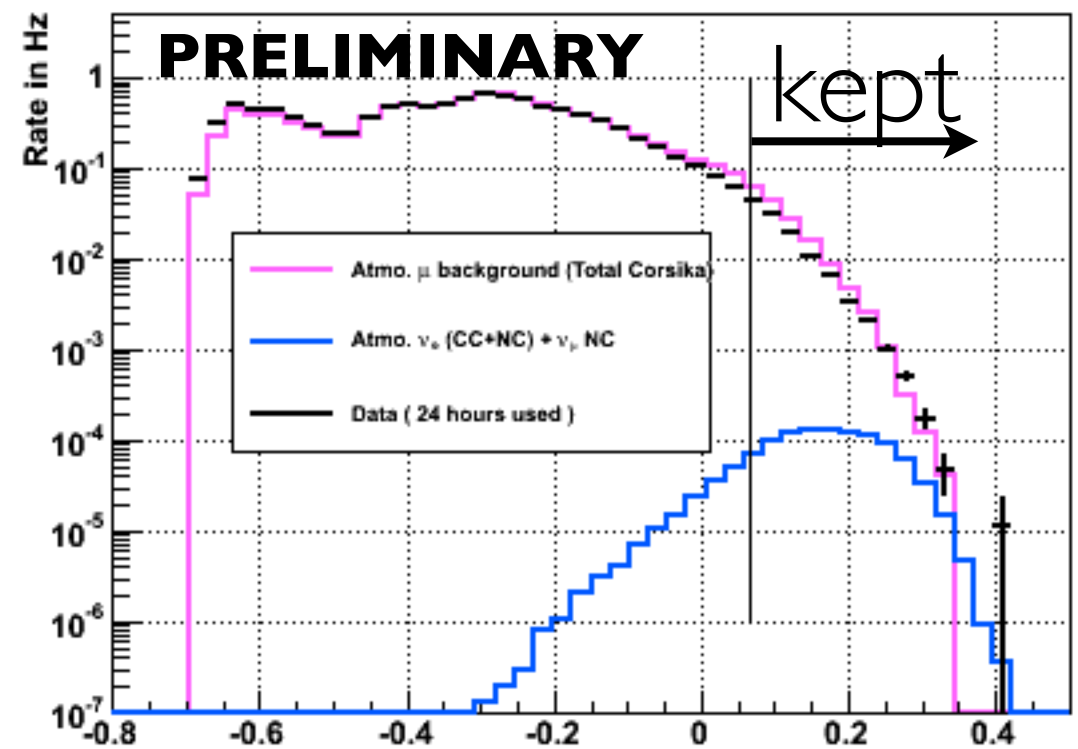
Data Reduction Cut

5 Input parameters to BDT training
For example, Sphericity variable

Use simple variables (fast calculations)
to reject 98.6% atmospheric muon BG



5-parameter BDT



BDT Score

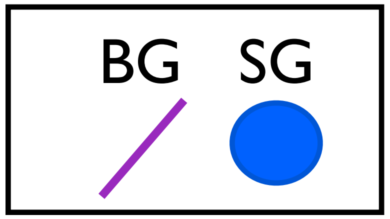
Track-like ⟷ Cascade-like

One of five input
parameters going into BDT

Data Reduction Cut at
BDT Score>0.067

85% ν_e Signal Efficiency w.r.t. Filter

Event Topology

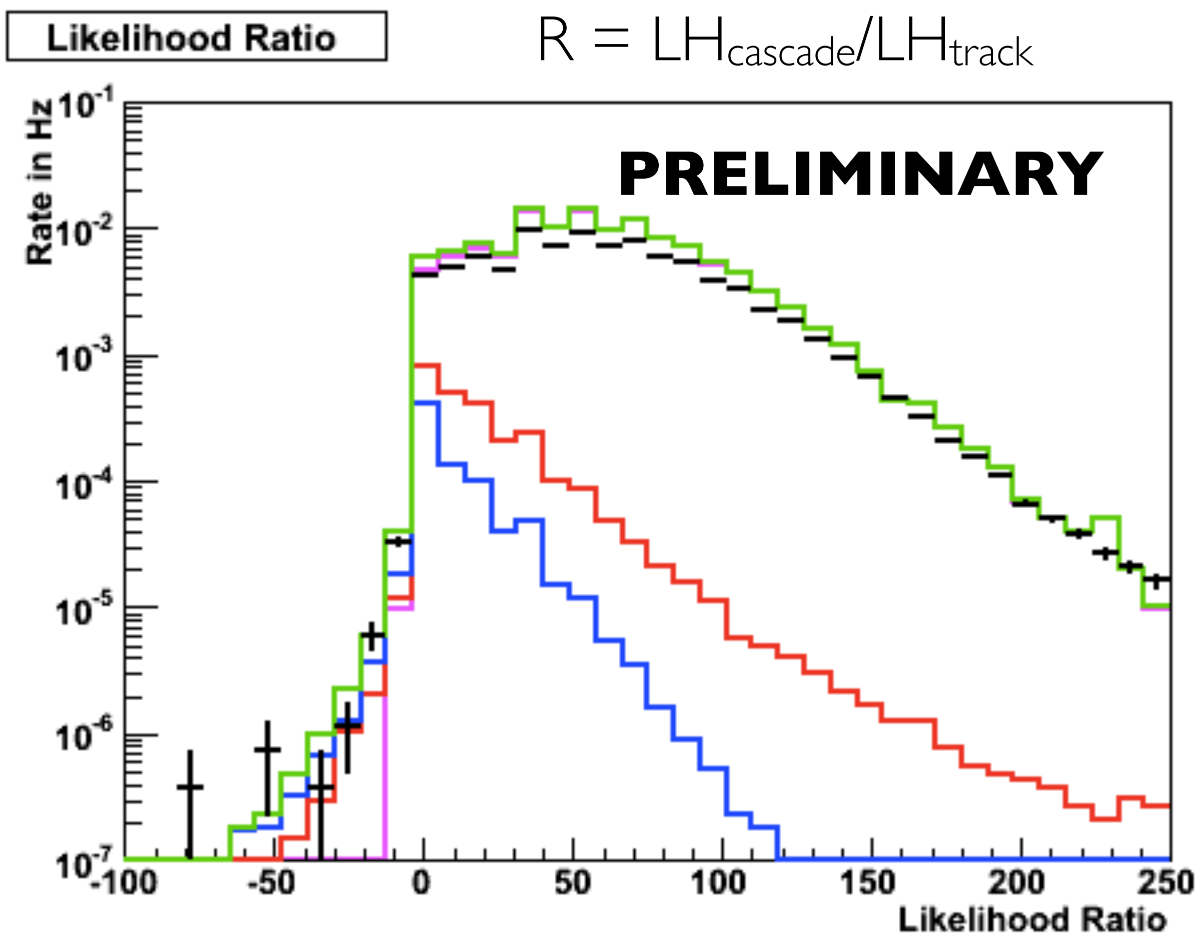


Neutrino Level Cut

7 Input parameters to BDT training
For example, Likelihood Ratio variable

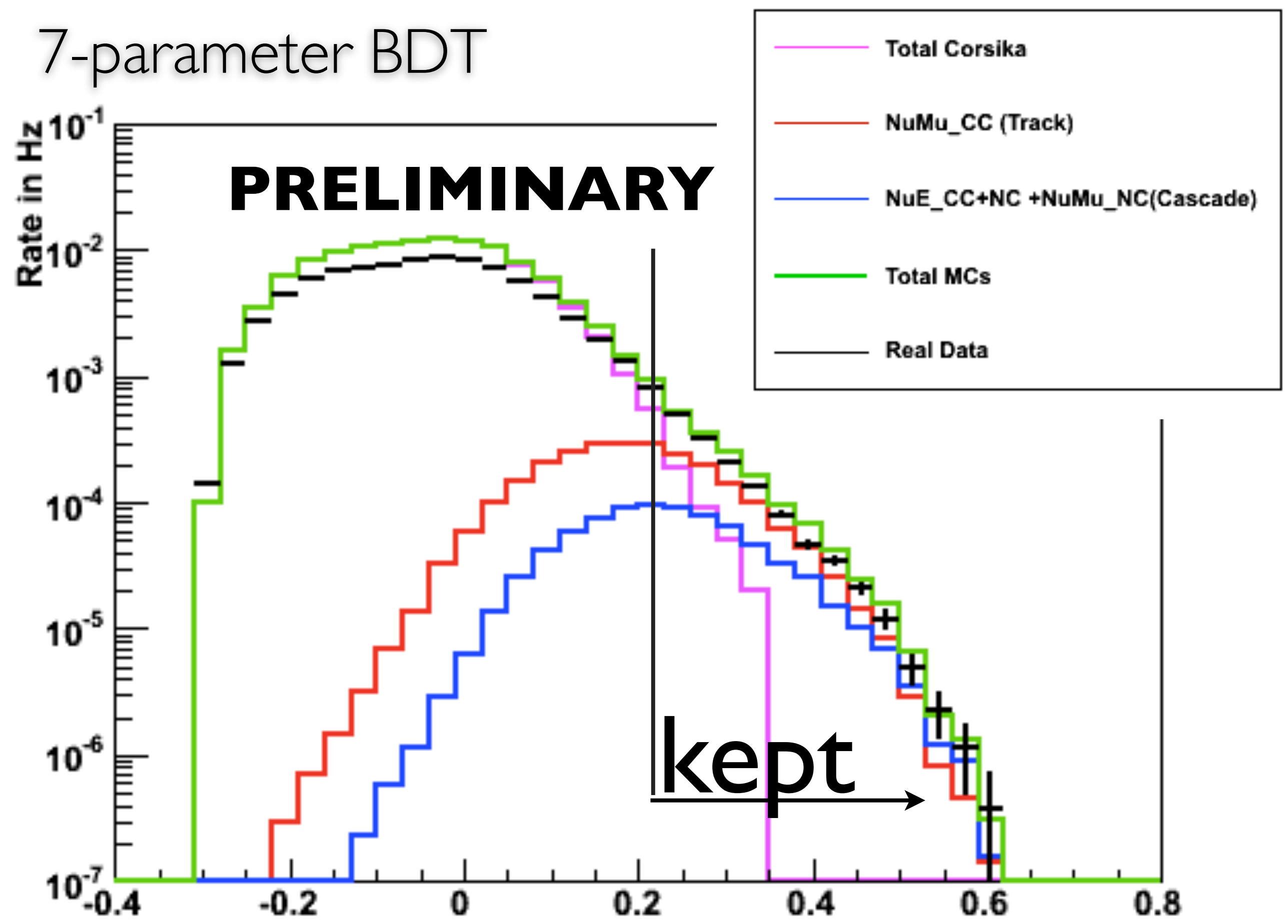
Use time-consuming max. likelihood reconstructions to reject 99.7% of atmospheric muon BG

$R = LH_{cascade}/LH_{track}$



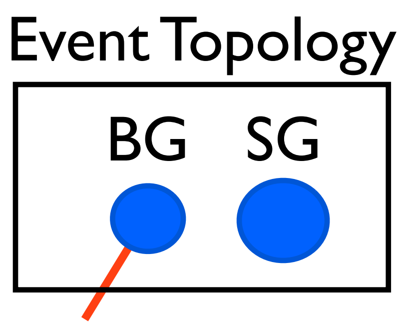
Cascade-like ⟷ Track-like

7-parameter BDT

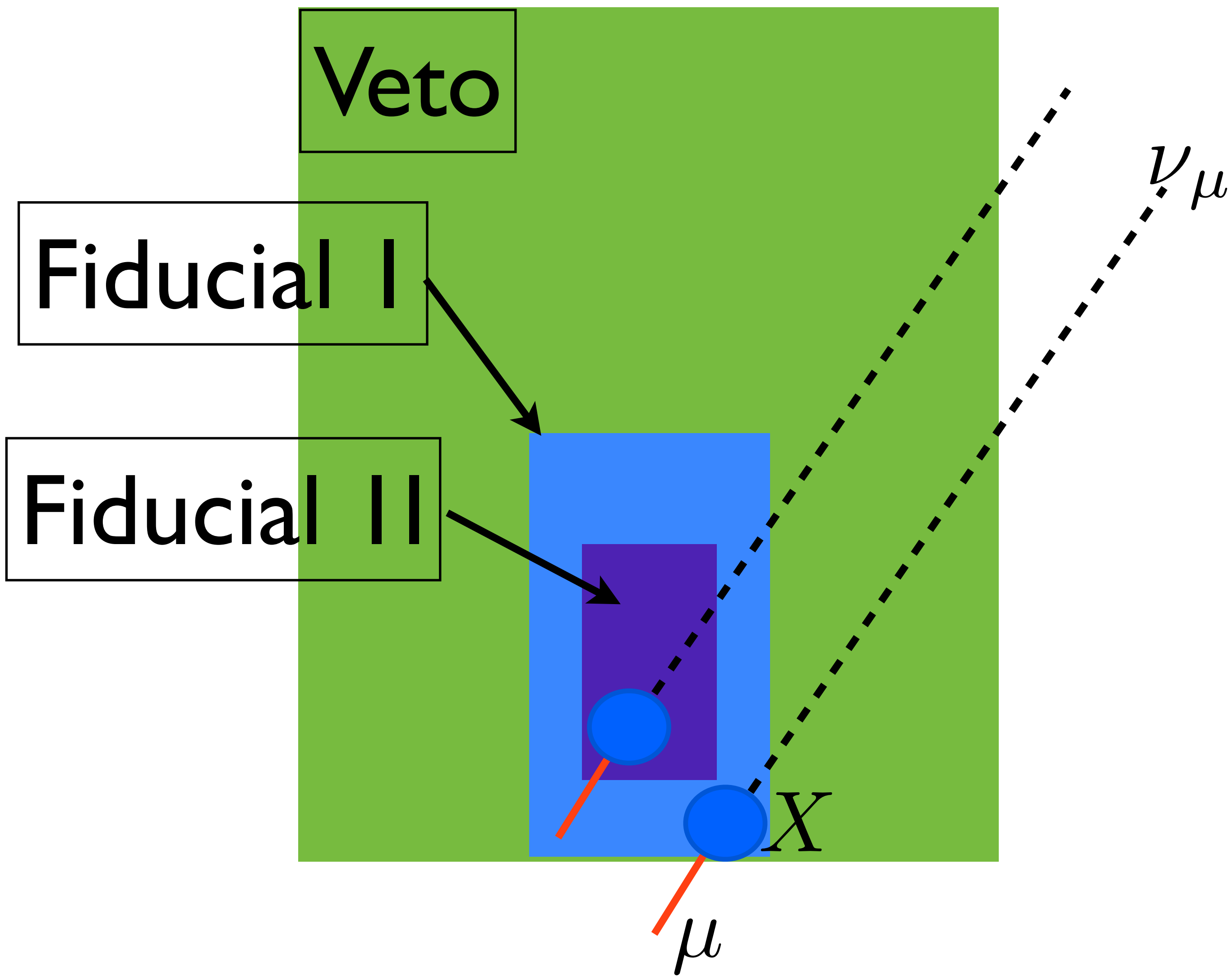


BDT Score

30% ν_e signal efficiency with ~7 orders of magnitude BG rejection w.r.t. the trigger



Cascade Detection Cut- Veto Principle
(to remove further track events ν_μ^{CC})

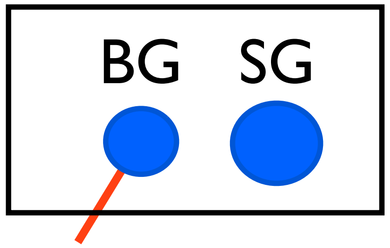


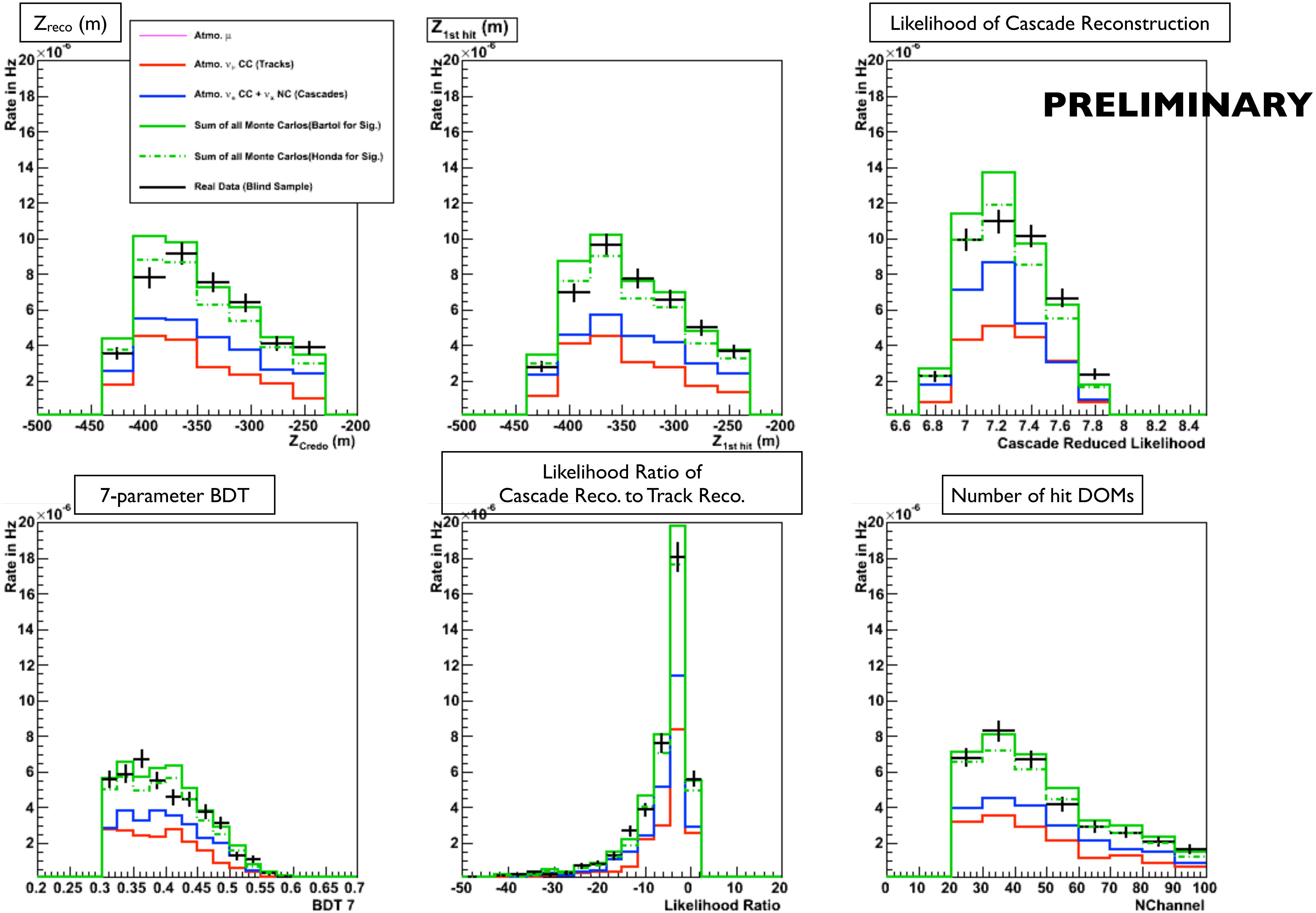
Tighten Fiducial Volume by requiring the reconstructed vertex to be inner most region.

Then, demand better spherical light distribution pattern using quality parameters

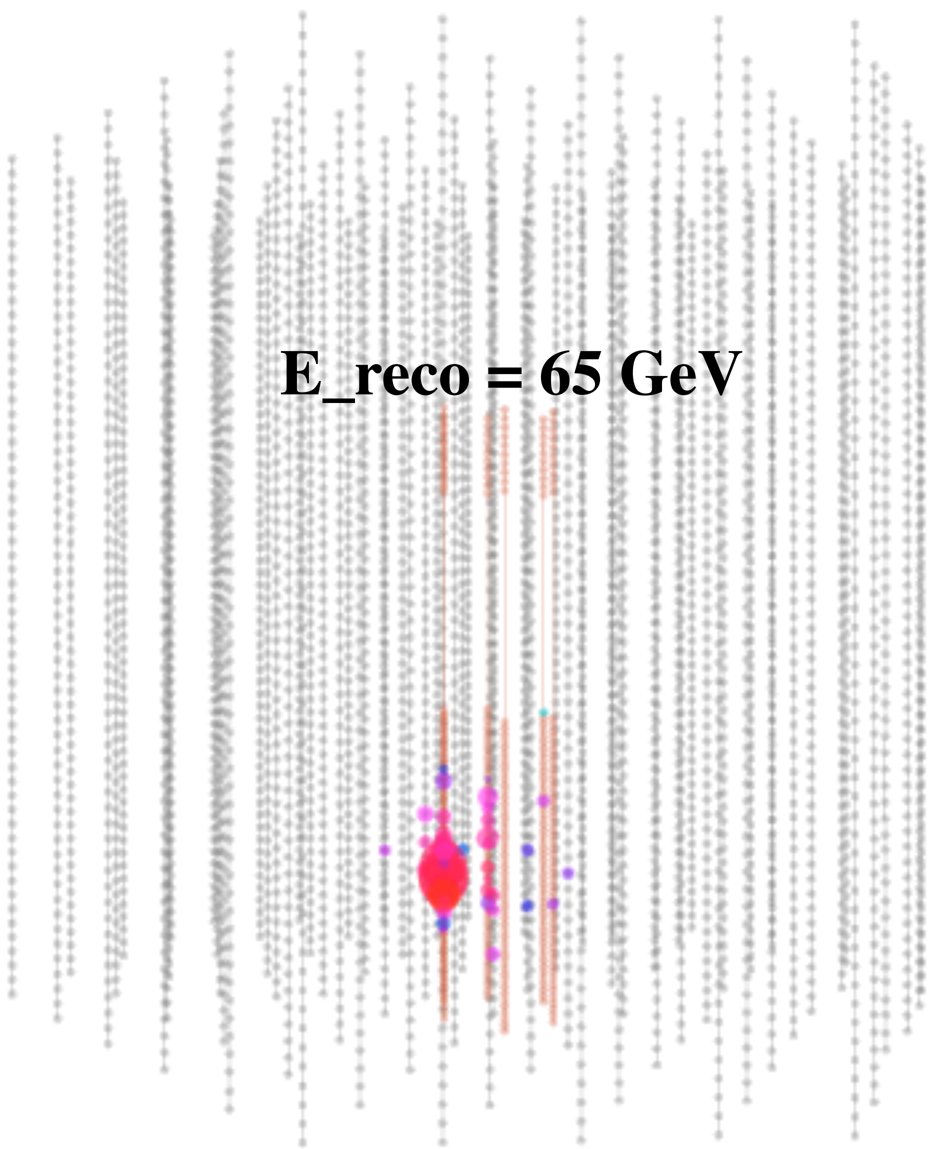
Cascade Detection Cut
(to remove further track events ν_μ^{CC})

Event Topology

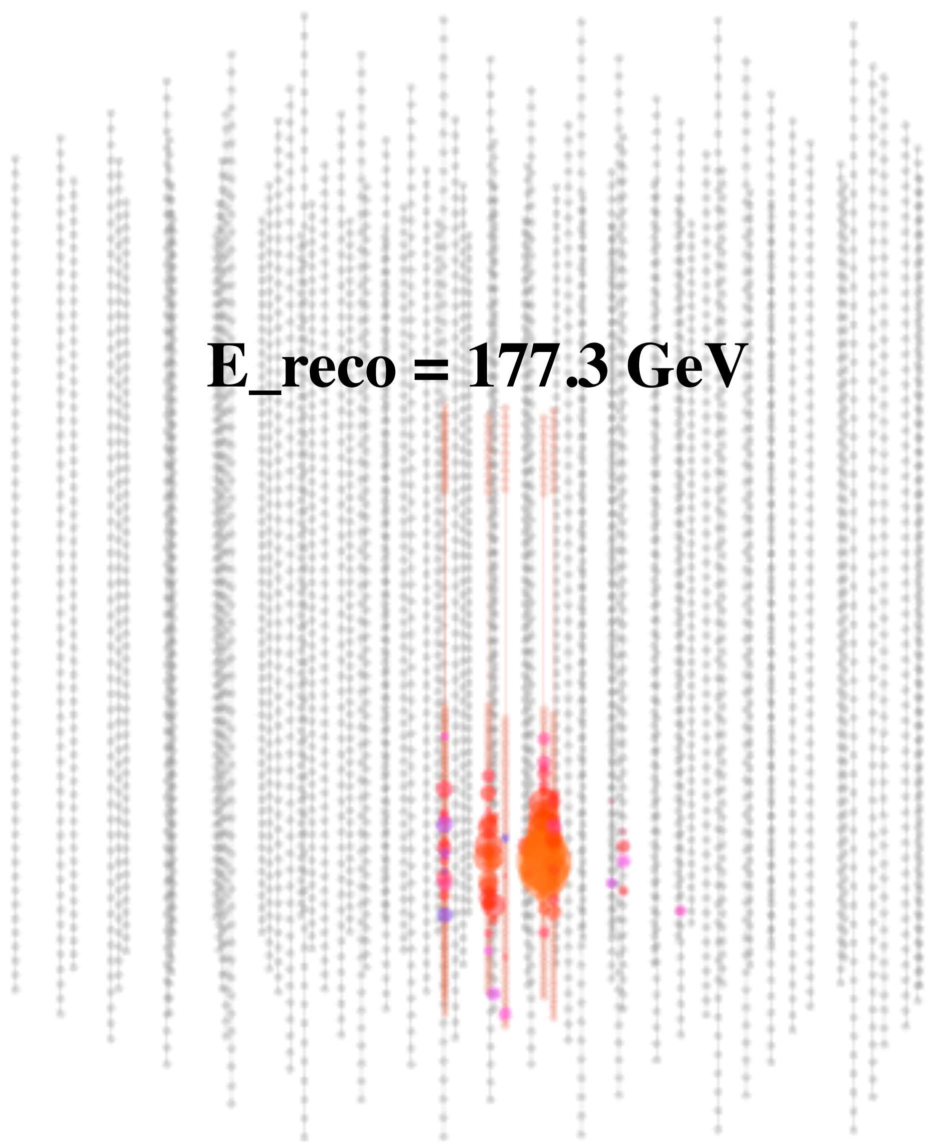




Candidate Events



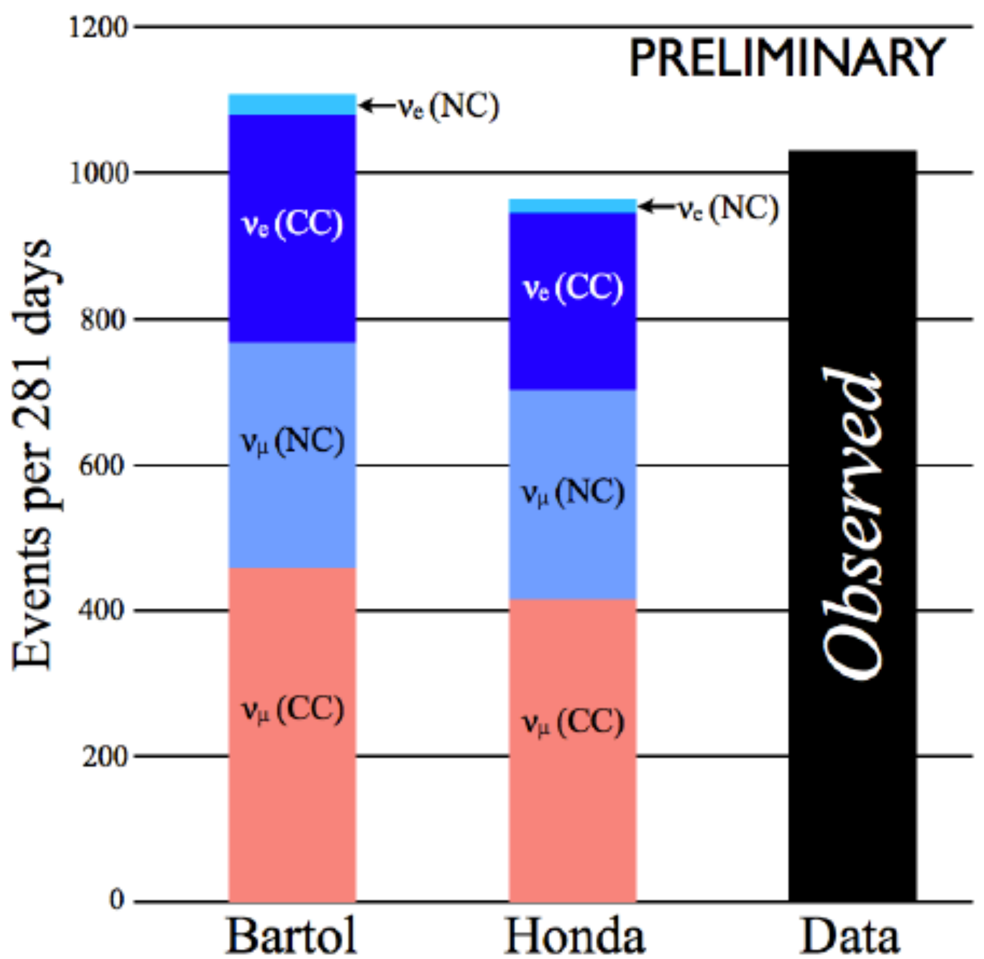
Run = 116090
Event ID = 16645709
2010/06/25



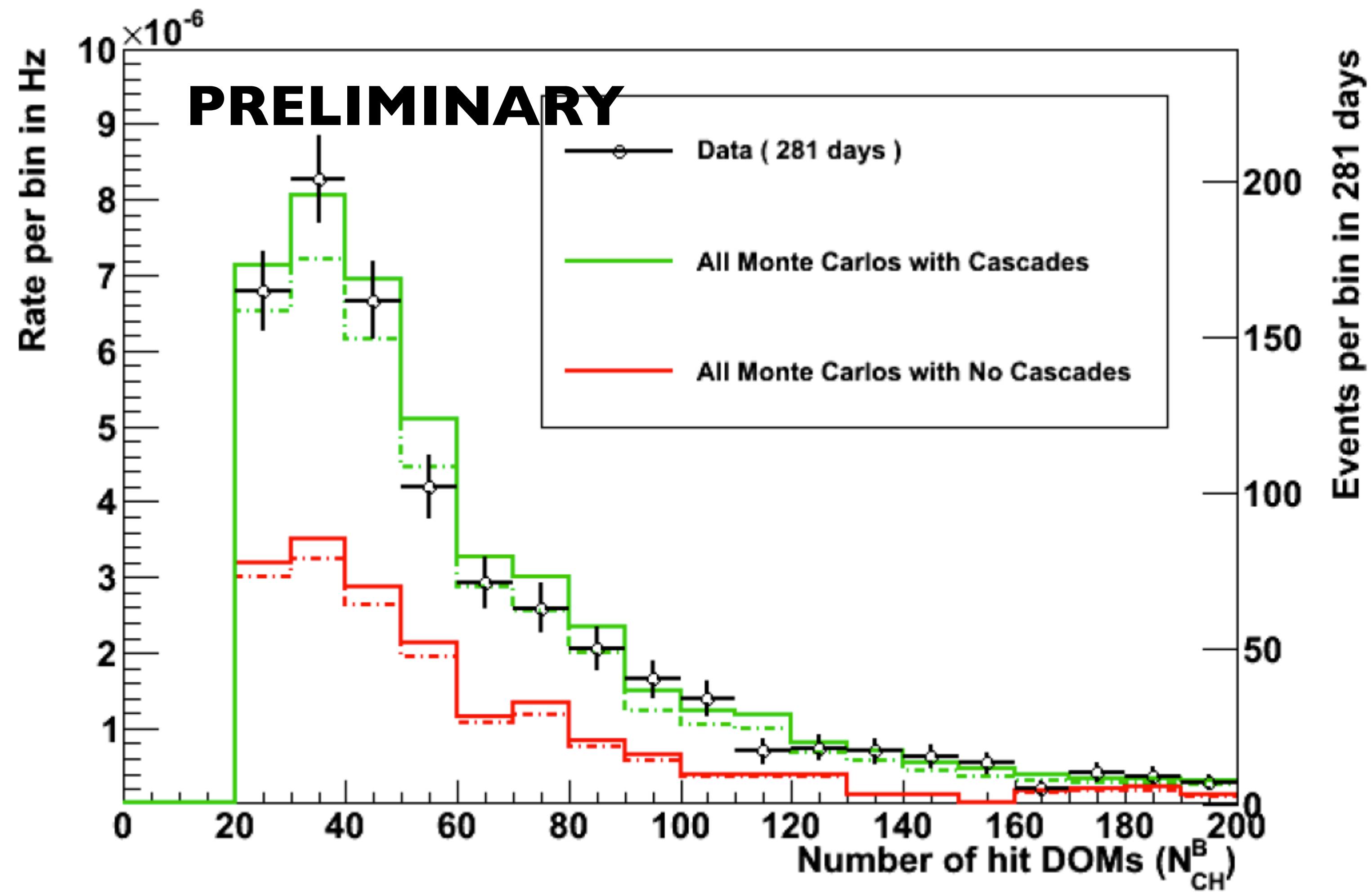
Run = 116090
Event ID = 48118343
2010/06/25

Cascade Detection Cut-Results

Channel contributions



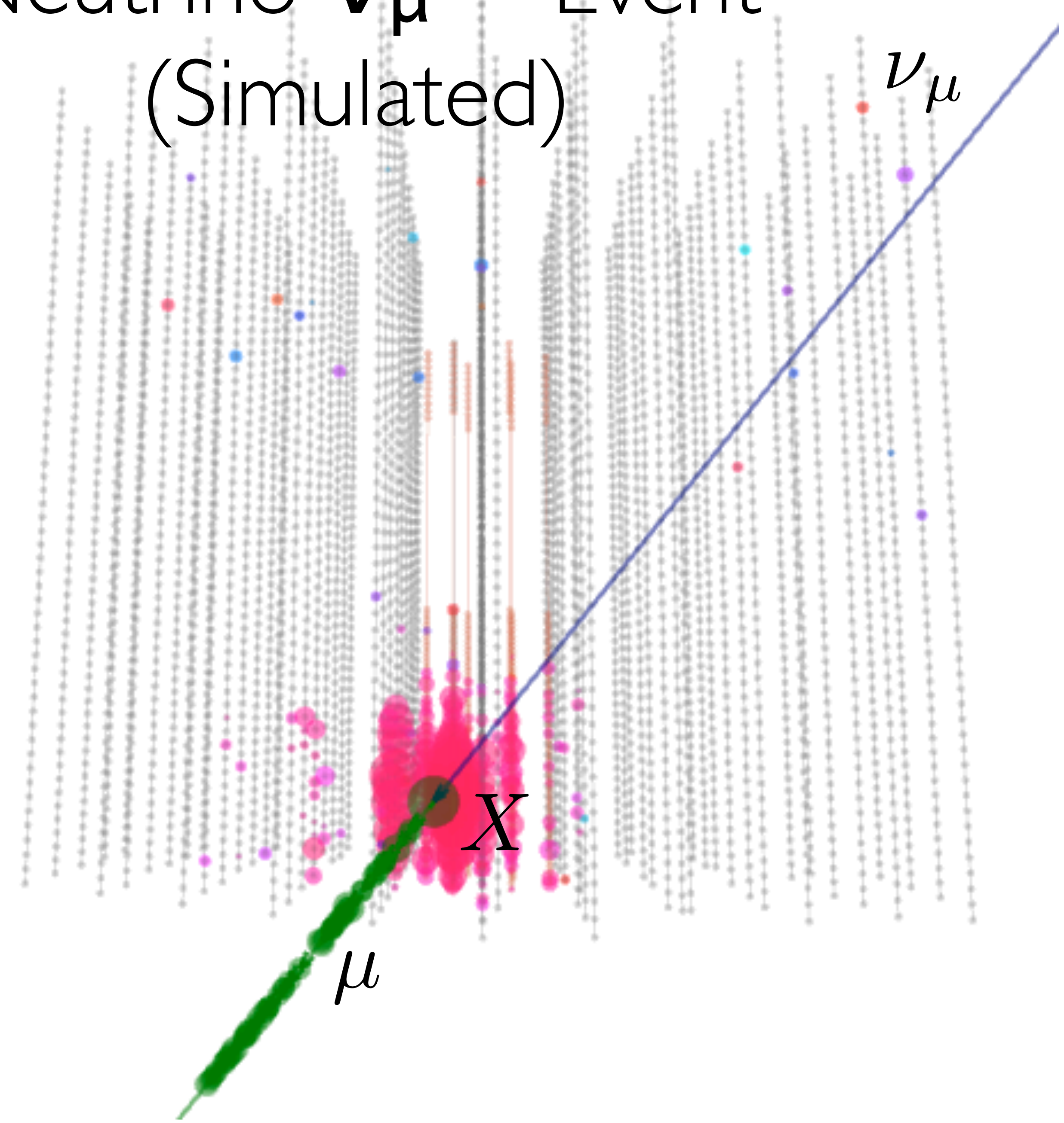
Rate vs Hit DOMs Distribution

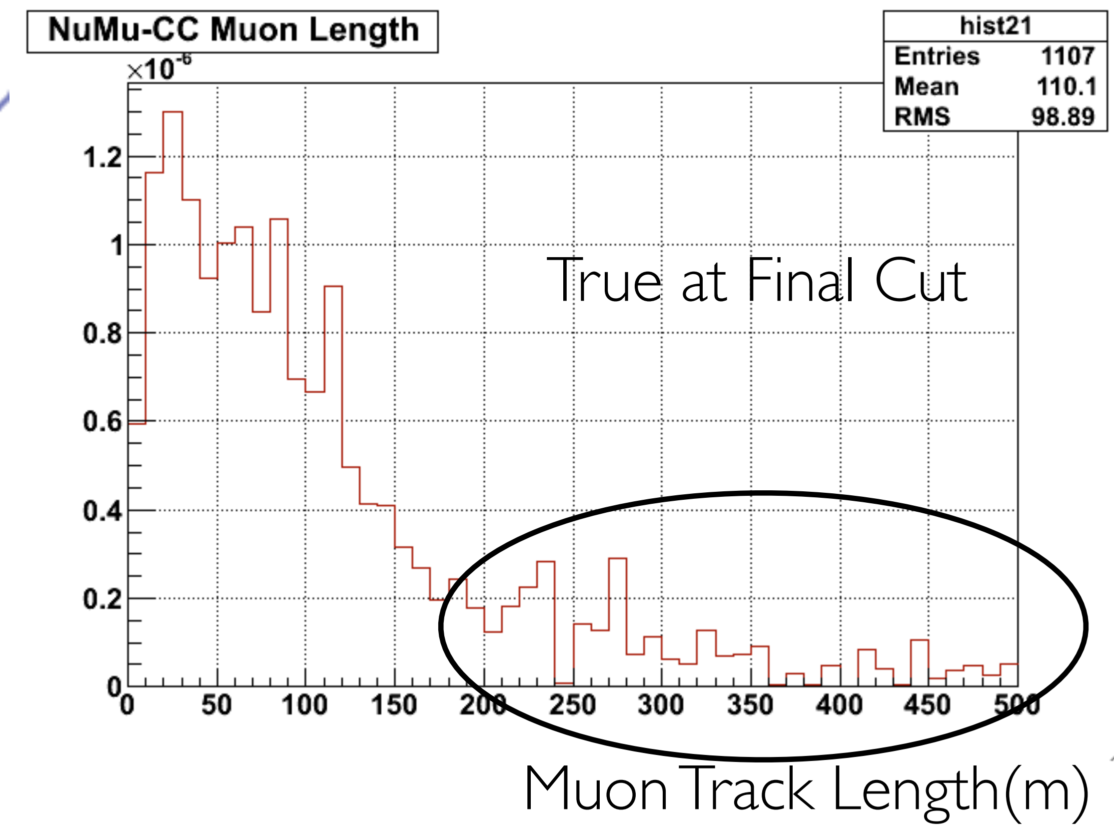


-To remove μ-BG and reduce ν_μ^{CC}-BG , we placed a set of tight cuts.
-After the cut, 1029 events remained in 281 days of full data sample.
-Predicted 59% neutrino-induced cascades, 41% ν_μ^{CC}
-Contamination of μ-BG and systematic uncertainties still being evaluated.

Atmospheric ν_μCC Background

Neutrino ν_μCC Event (Simulated)





Remaining events have short muons plus muons that exit detector quickly (circle on above plot)

Conclusion

- First high energy atmospheric neutrinos detected ~15 years ago by AMANDA
  - Observing long muon tracks created by atmospheric ν_μ interactions
  - Detection of the atmospheric neutrino-induced cascades has been challenging -> many upper limits (Too many downgoing muon BG & No veto).
- For the first time, we have detection of atmospheric neutrino-induced cascade events in IceCube-DeepCore 79-string data with the veto technique
  - With final selections, 1029 events / 281 days are found with 59%-purity cascades prediction with <E>~100 GeV.
  - New Detection Channel with successful DeepCore design
  - Better understanding for high energy atmospheric ν_e flux (Kaon production)
- Systematic uncertainties (ice properties, cosmic ray muon contamination, DOM light collection efficiency, neutrino flux, and cross sections) are under evaluation
- More Analyses focusing on lower energies (~30 GeV) with DeepCore are forthcoming.
  - Neutrino Oscillation Analyses ($\nu_\mu \rightarrow \nu_\mu$ and $\nu_\mu \rightarrow \nu_\tau$)
  - Dark Matter Searches and Galactic neutrino source searches.