Vetoing Atmospheric Muons (and Neutrinos)

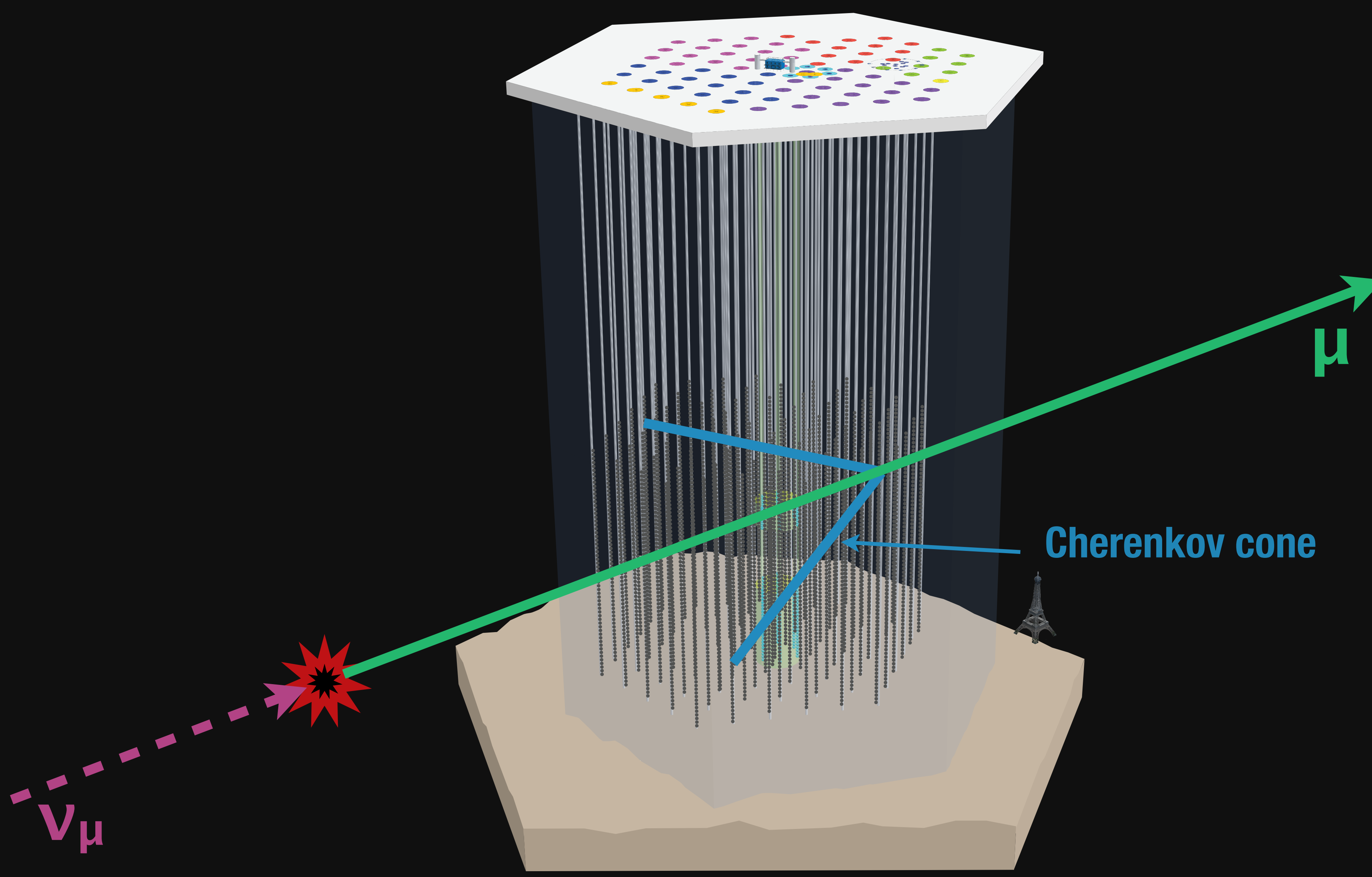
An analysis technique to look at neutrinos from the “other” hemisphere

Claudio Kopper, UW Madison - for the IceCube Collaboration

ckopper@icecube.wisc.edu

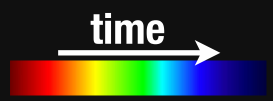
The IceCube Neutrino Observatory

Neutrinos are detected by looking for Cherenkov radiation from secondary particles (muons, particle showers)

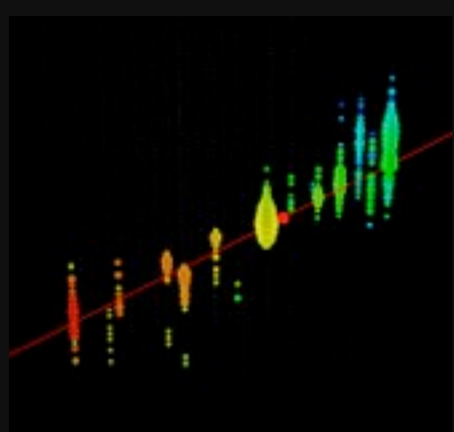


Neutrino Event Signatures

Signatures of signal events



CC Muon Neutrino

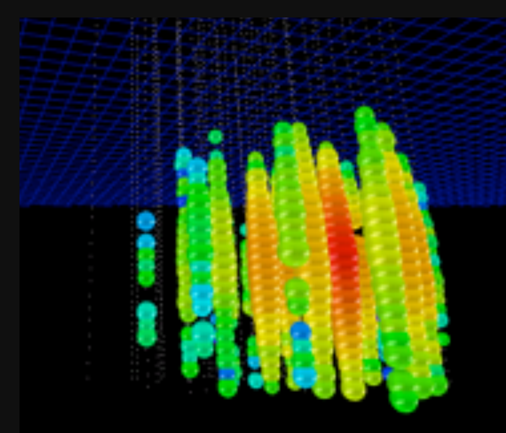


$$\nu_\mu + N \rightarrow \mu + X$$

track (data)

factor of ≈ 2 energy resolution
$< 1^\circ$ angular resolution

Neutral Current / Electron Neutrino



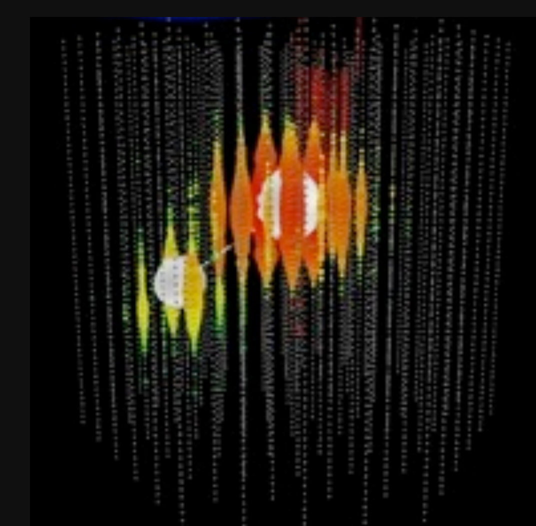
$$\nu_\mathrm{e} + N \rightarrow \mathrm{e} + X$$

$$\nu_\mathrm{x} + N \rightarrow \nu_\mathrm{x} + X$$

cascade (data)

$\approx \pm 15\%$ deposited energy resolution
$\approx 10^\circ$ angular resolution
(at energies ≈ 100 TeV)

CC Tau Neutrino



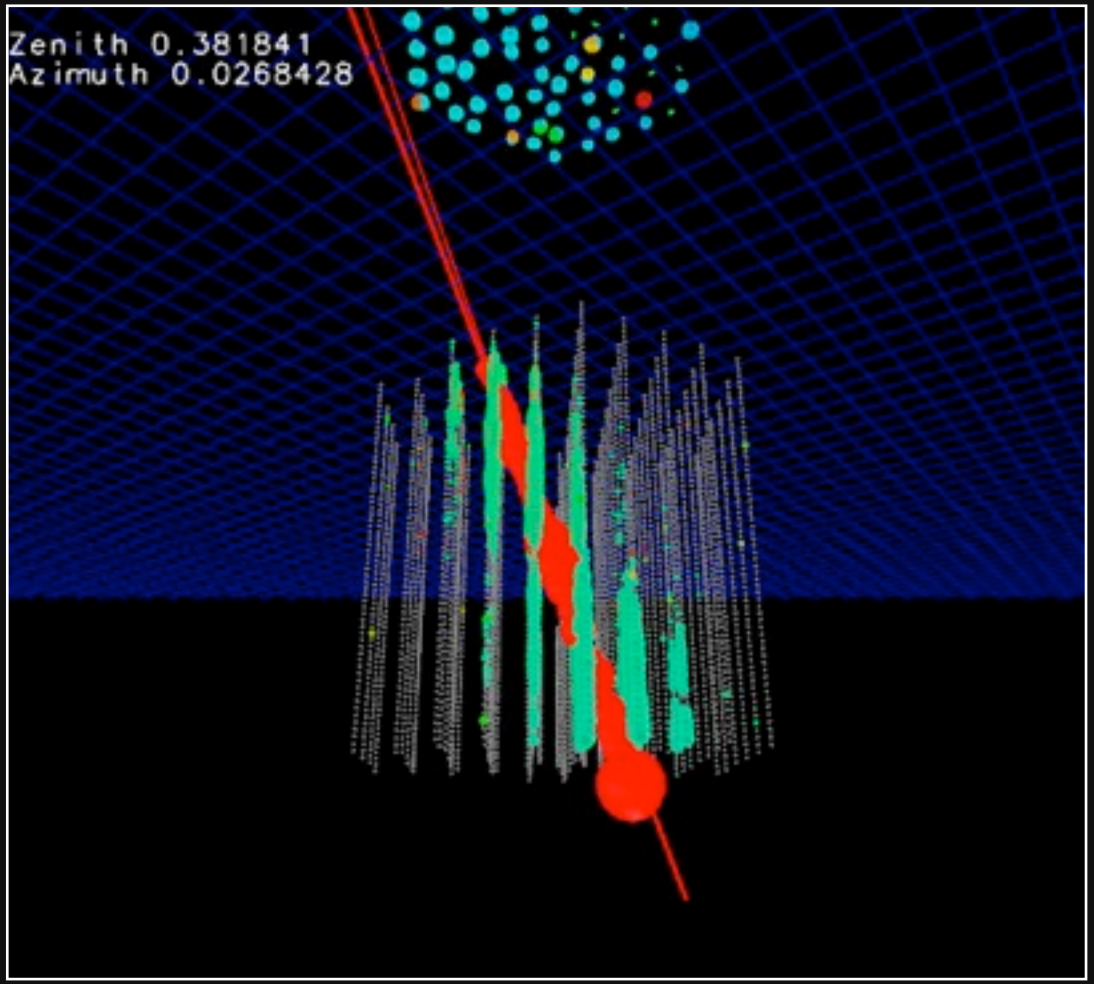
$$\nu_\tau + N \rightarrow \tau + X$$

"double-bang" and other signatures (simulation)

(not observed yet)

Backgrounds and Systematics

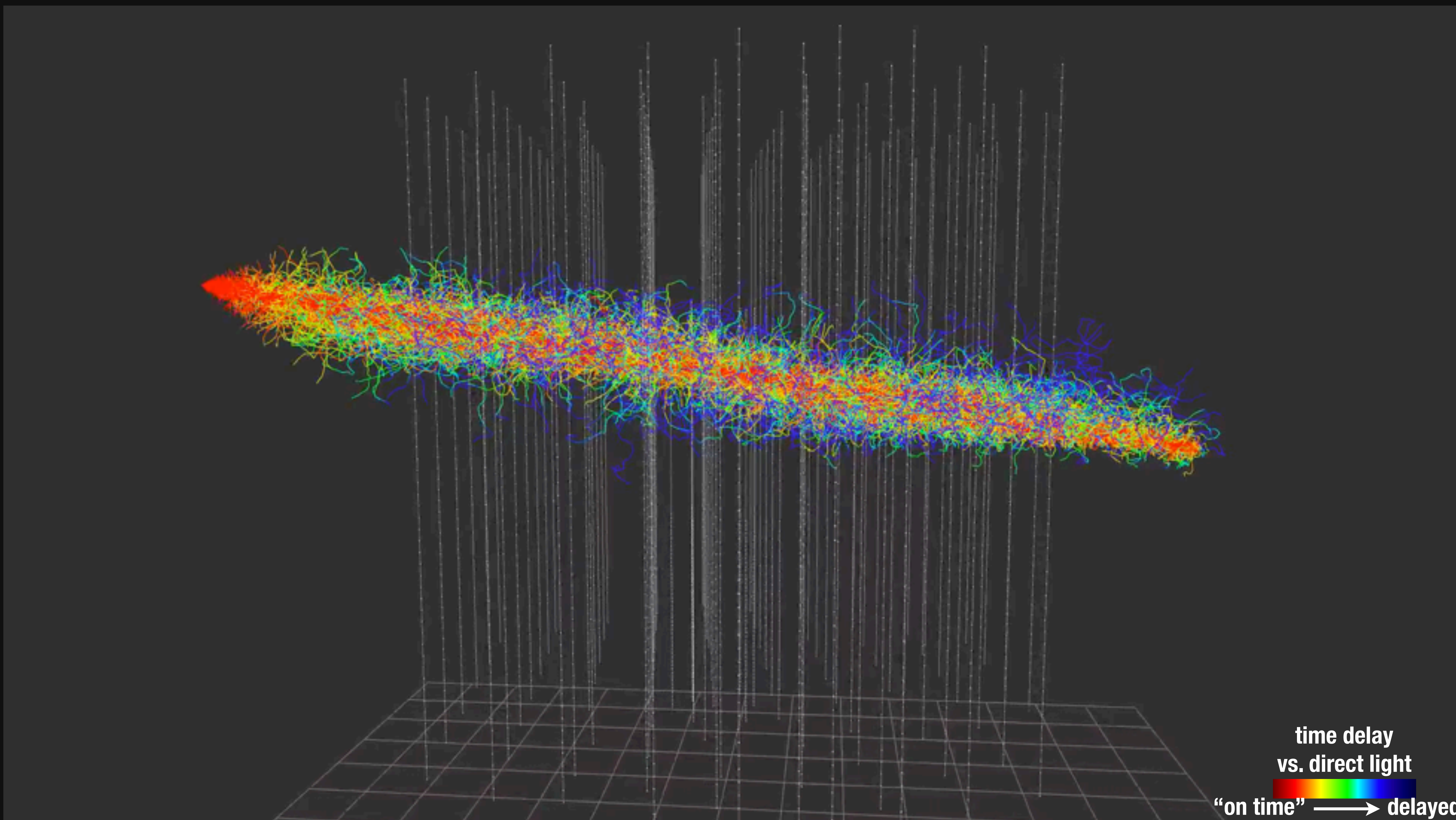
- **Backgrounds:**
  - Cosmic Ray Muons
  - Atmospheric Neutrinos
- **Largest Uncertainties:**
  - Optical Properties of Ice
  - Energy Scale Calibration
  - Neutral current / ν_e degeneracy



A bundle of muons from a CR interaction in the atmosphere (also observed in the "IceTop" surface array)

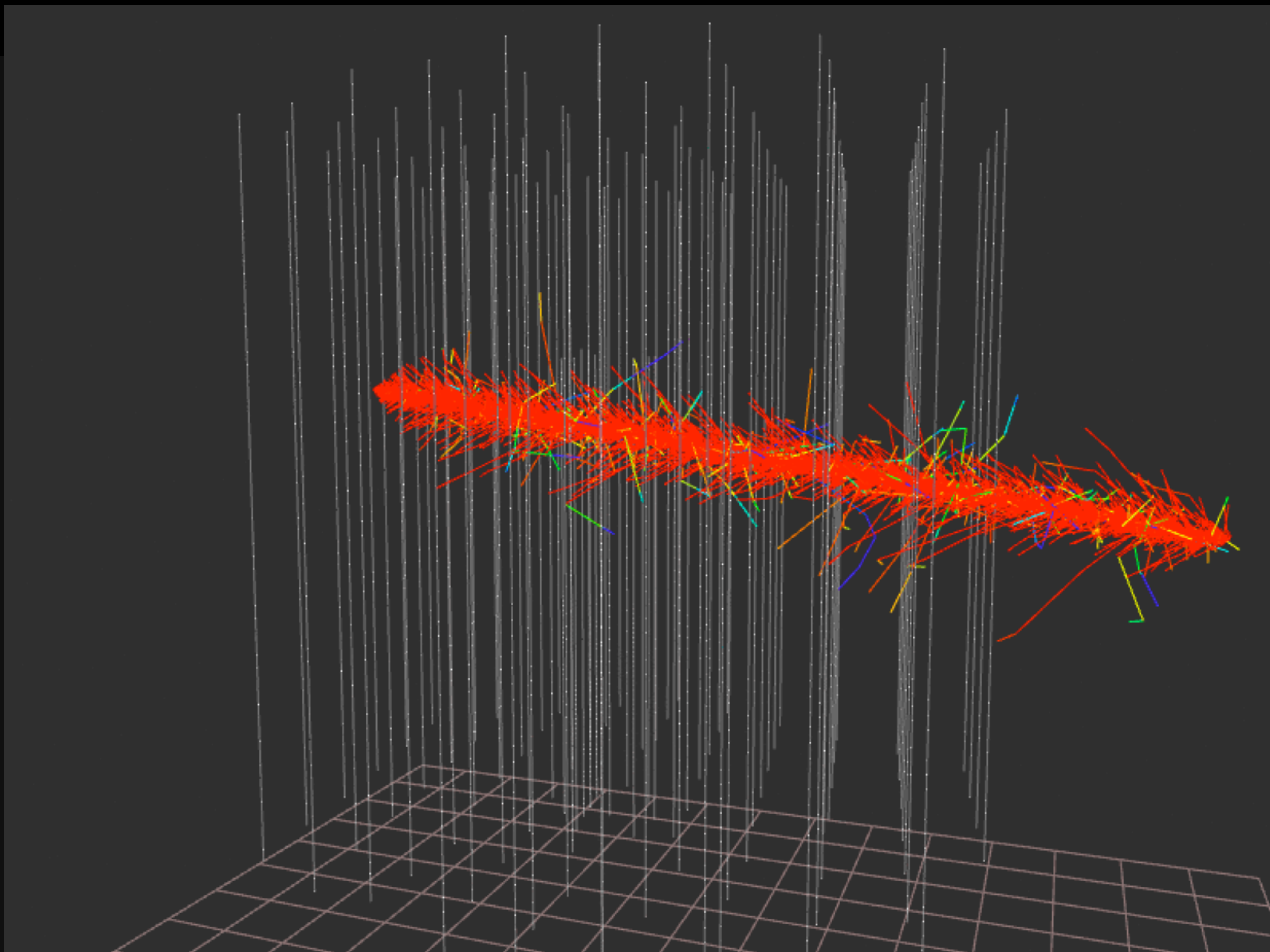
Muon Track in Ice

Light propagation is dominated by scattering



The Same Muon in Water

Replacing all the ice in IceCube with Mediterranean water

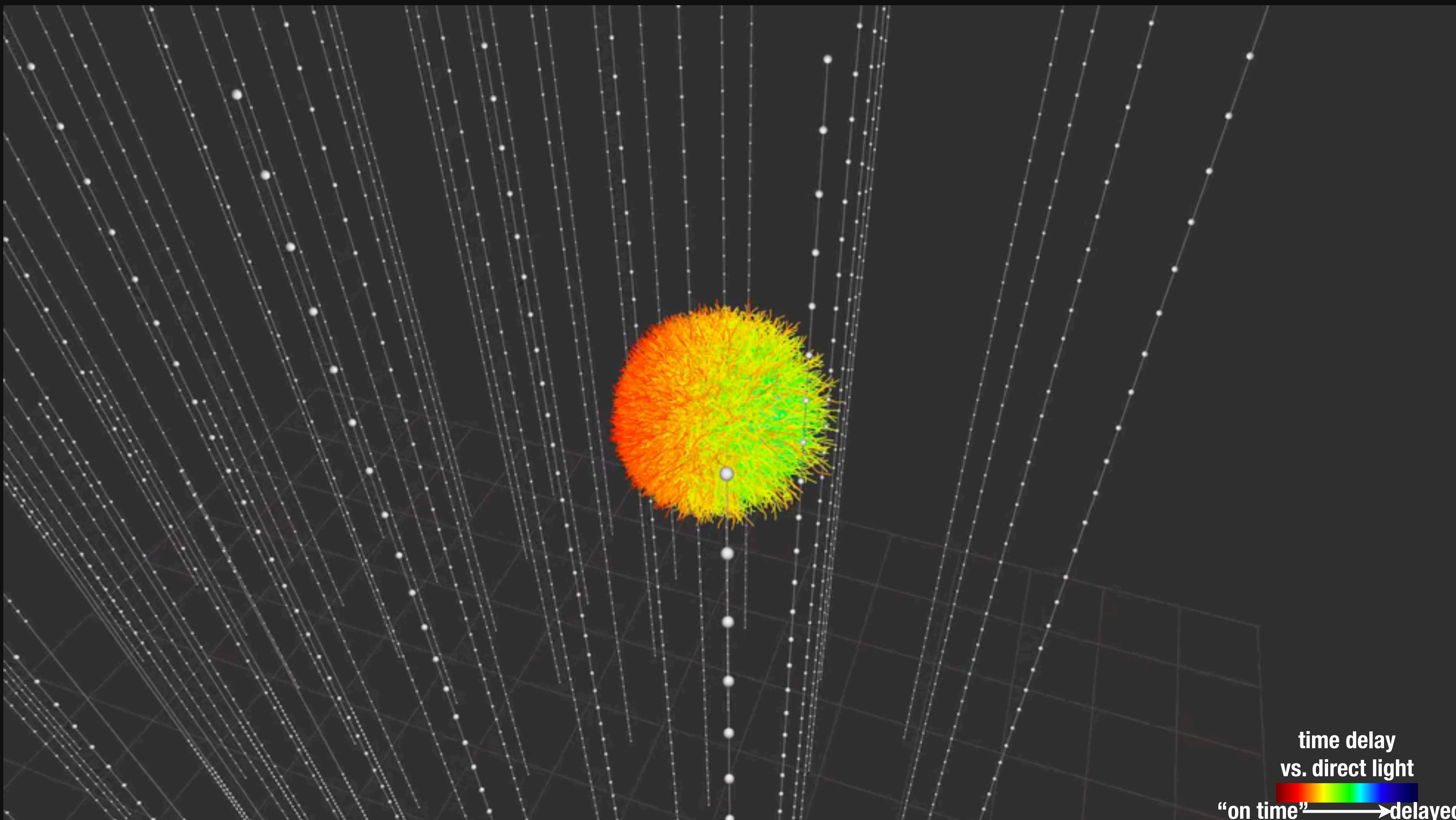


time delay
vs. direct light

"on time" → delayed

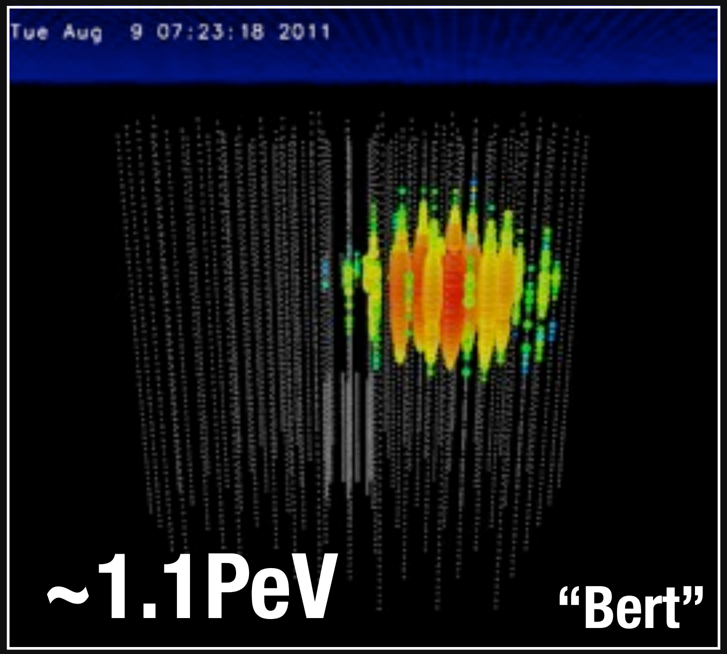
Shower in Ice

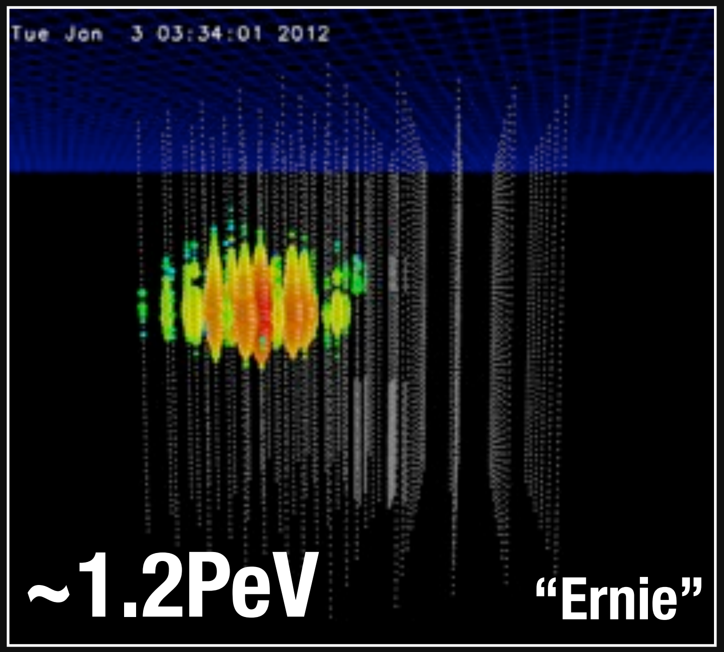
Shower directions reconstructed from timing profile



Results

We have 100TeV to 1PeV events

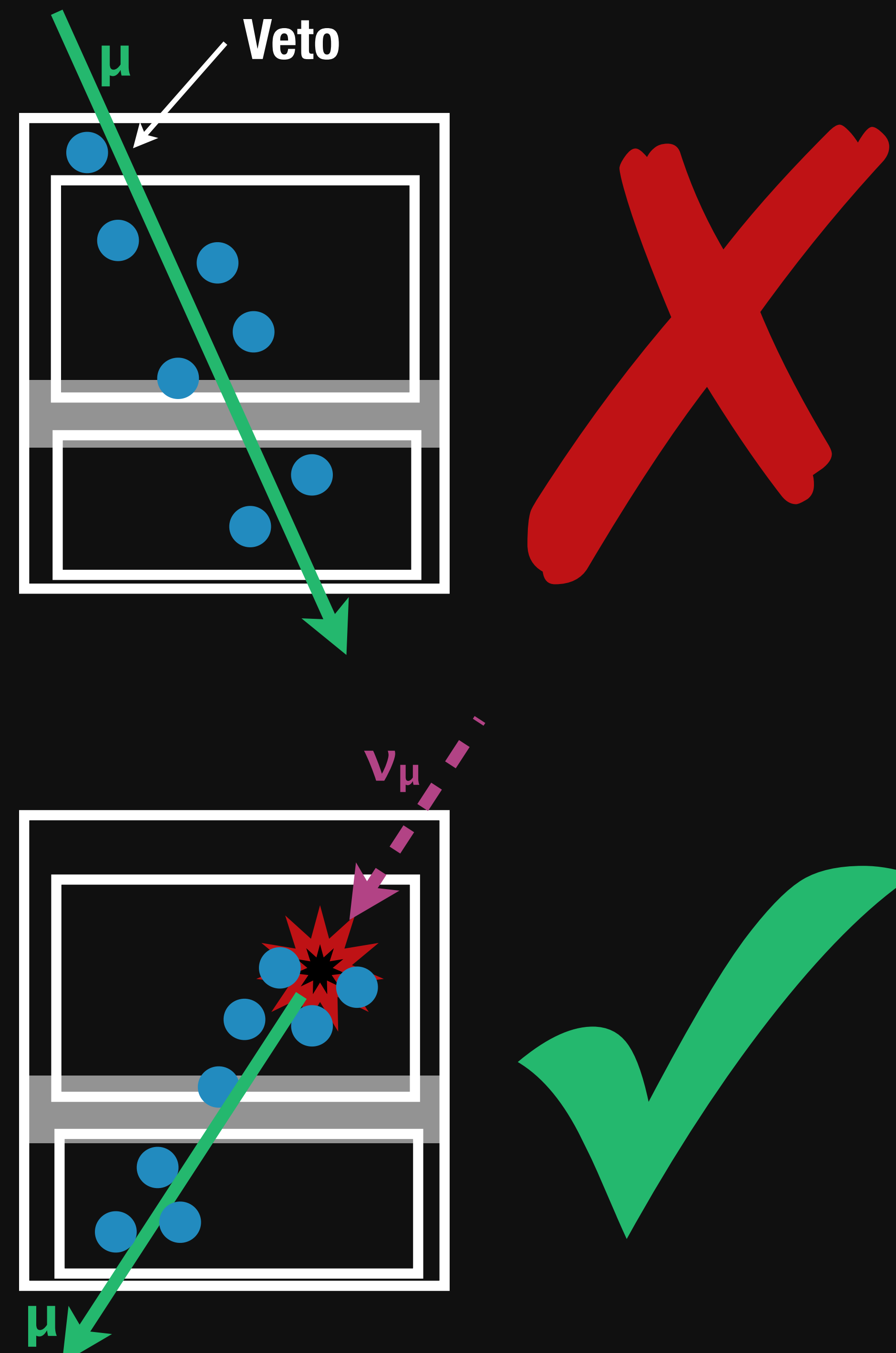




Contained Event Analysis

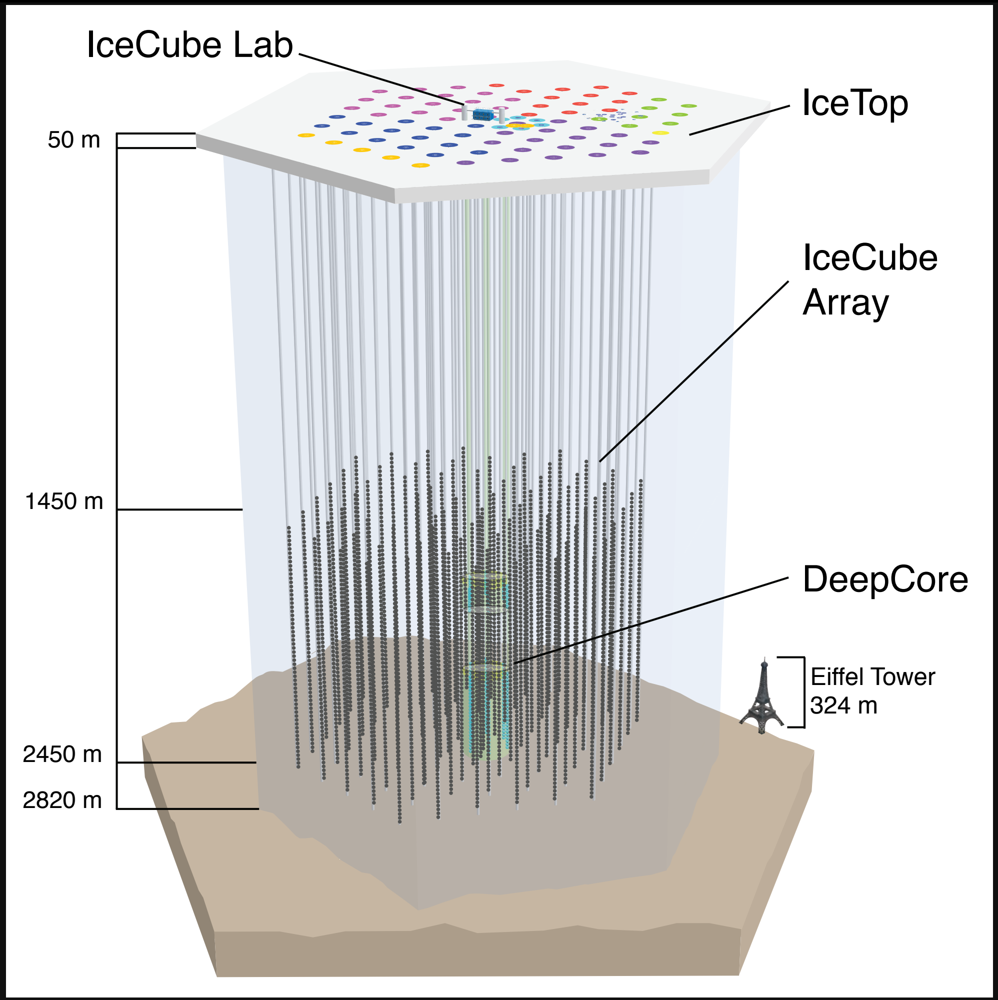
Specifically designed to find these contained events. Analysis of dataset taken from May 2010 to May 2012 (662 days of livetime)

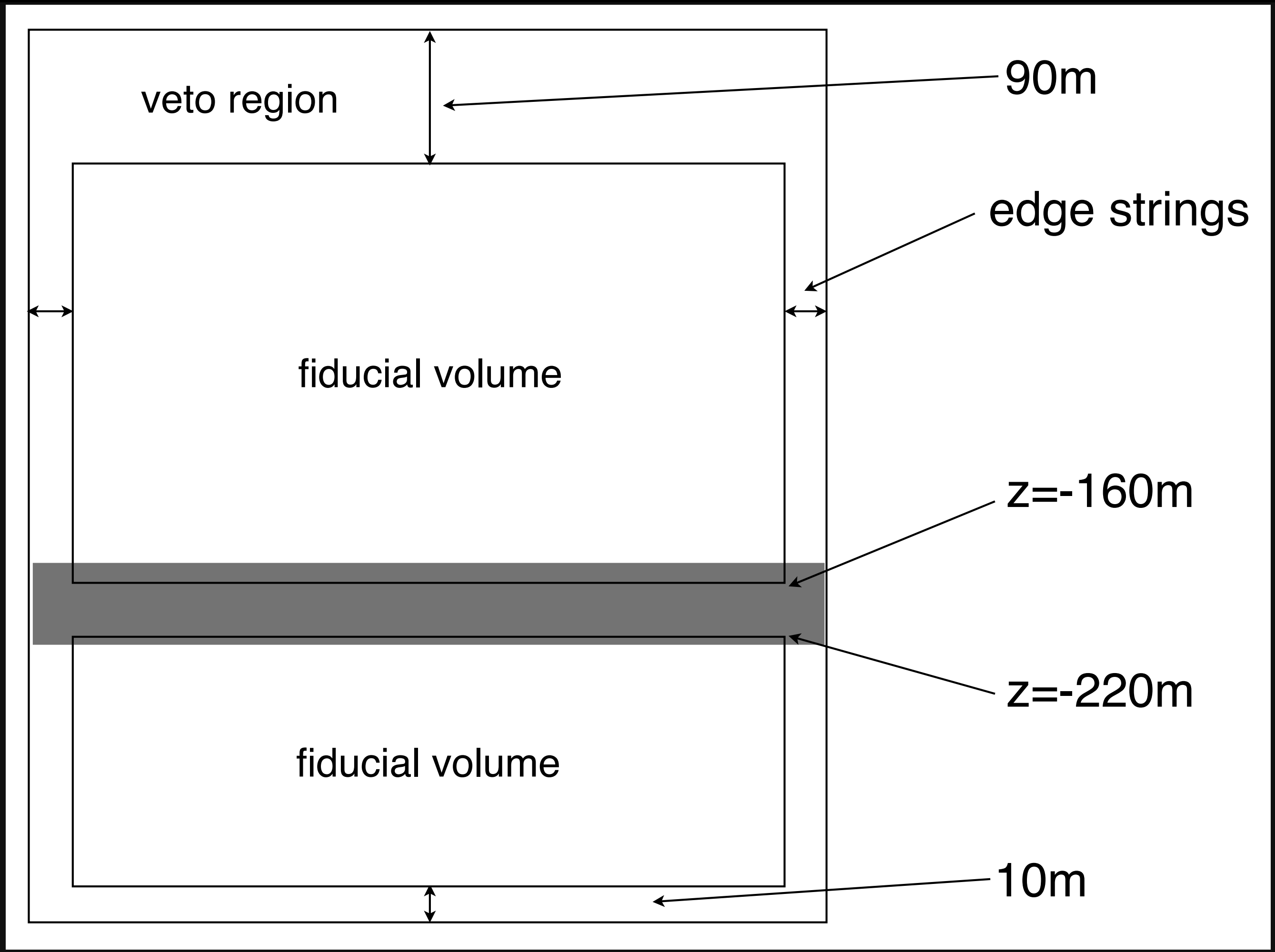
- Explicit contained search at **high energies** (cut: Q_{tot}>6000)
- 400 Mton effective fiducial mass
- Use atmospheric muon veto
- Sensitive to all flavors in region above 60TeV
- Three times as sensitive at 1 PeV
- Estimate background from data



Background 1 - Atmospheric Muons

Mostly incoming atmospheric muons sneaking in through the main dust layer





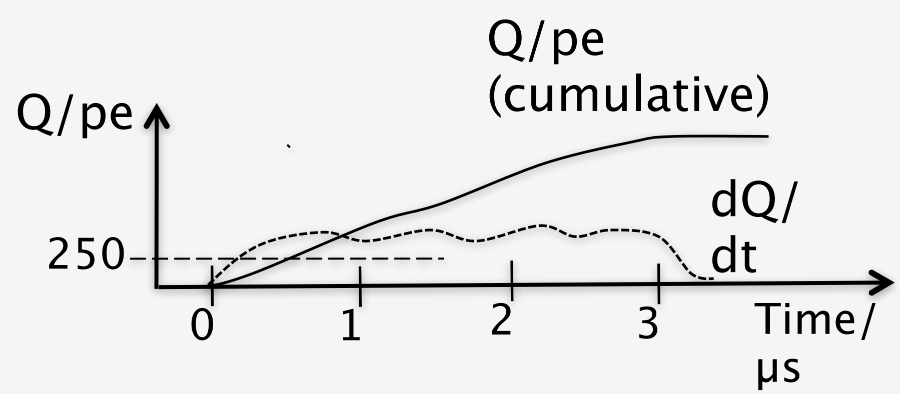
- Reject incoming muons when “early charge” in veto region
- Control sample available: tag muons with part of the detector - known bkg.
- 6±3.4 muons per 2 years (662 days)

Background 1 - Atmospheric Muons

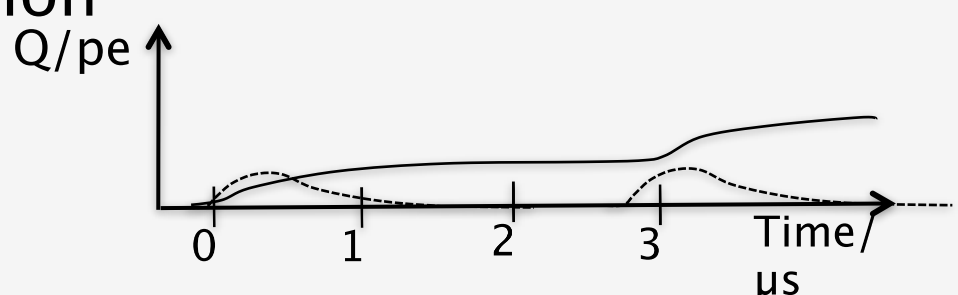
What's "early charge"?

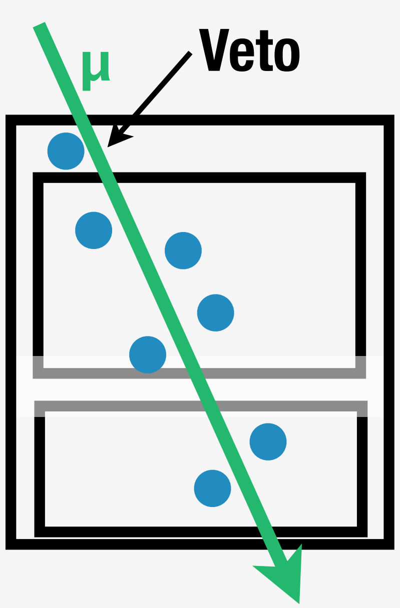
Throughgoing muon

Total detector



Veto region

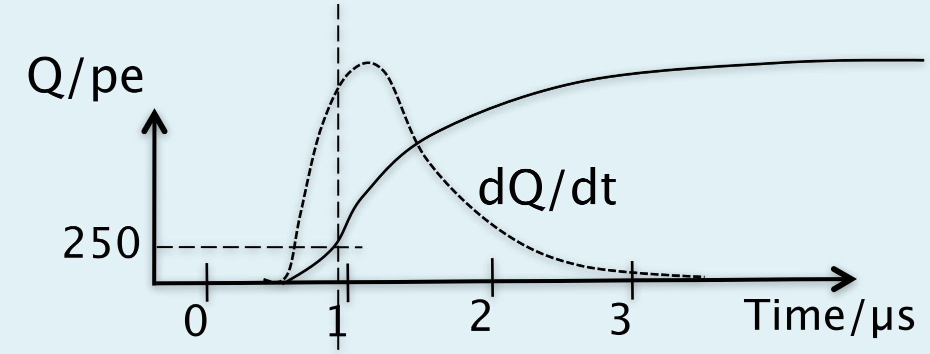


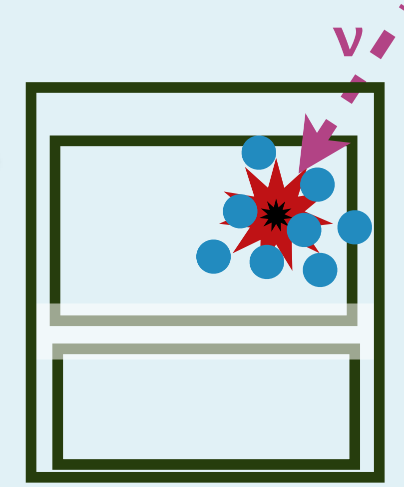


T_{250}= time at which Q= 250 pe

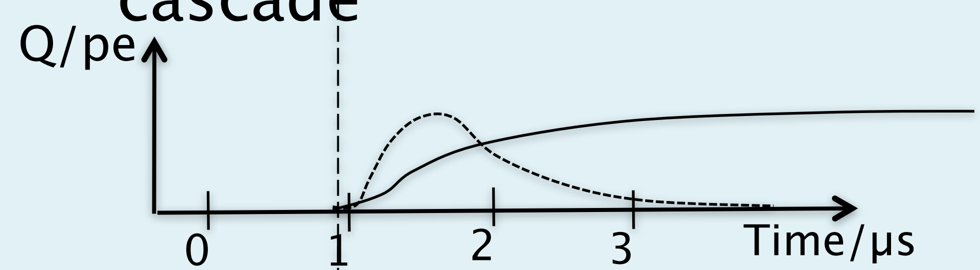
Contained cascade

Total detector

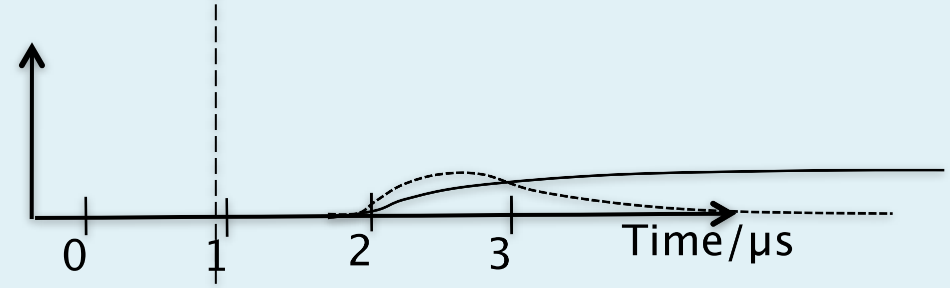




Veto region – barely contained cascade



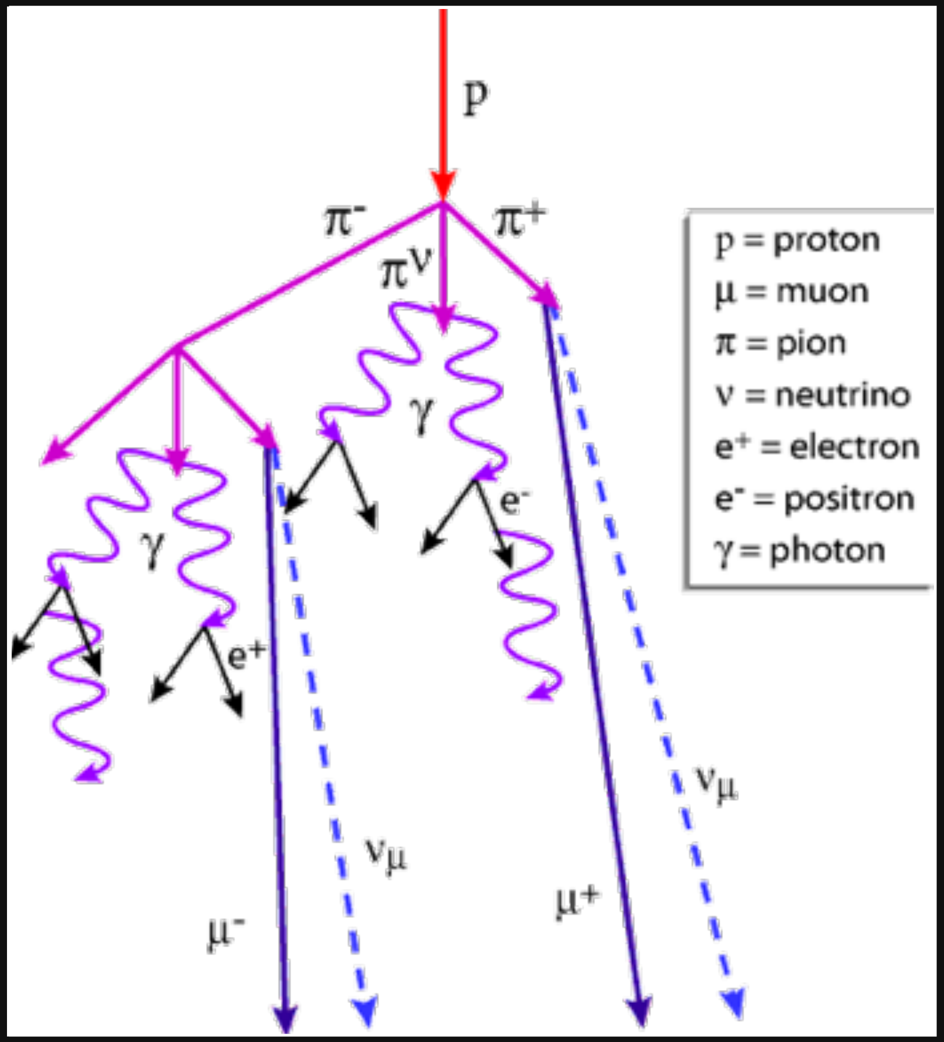
Veto region – well contained cascade



T_{250}= time at which Q= 250 pe

Vetoing Atmospheric Neutrinos

- Atmospheric neutrinos are made in air showers
- For downgoing neutrinos, the muons will likely not have ranged out at IceCube
- Downgoing events that start in the detector are extremely unlikely to be atmospheric



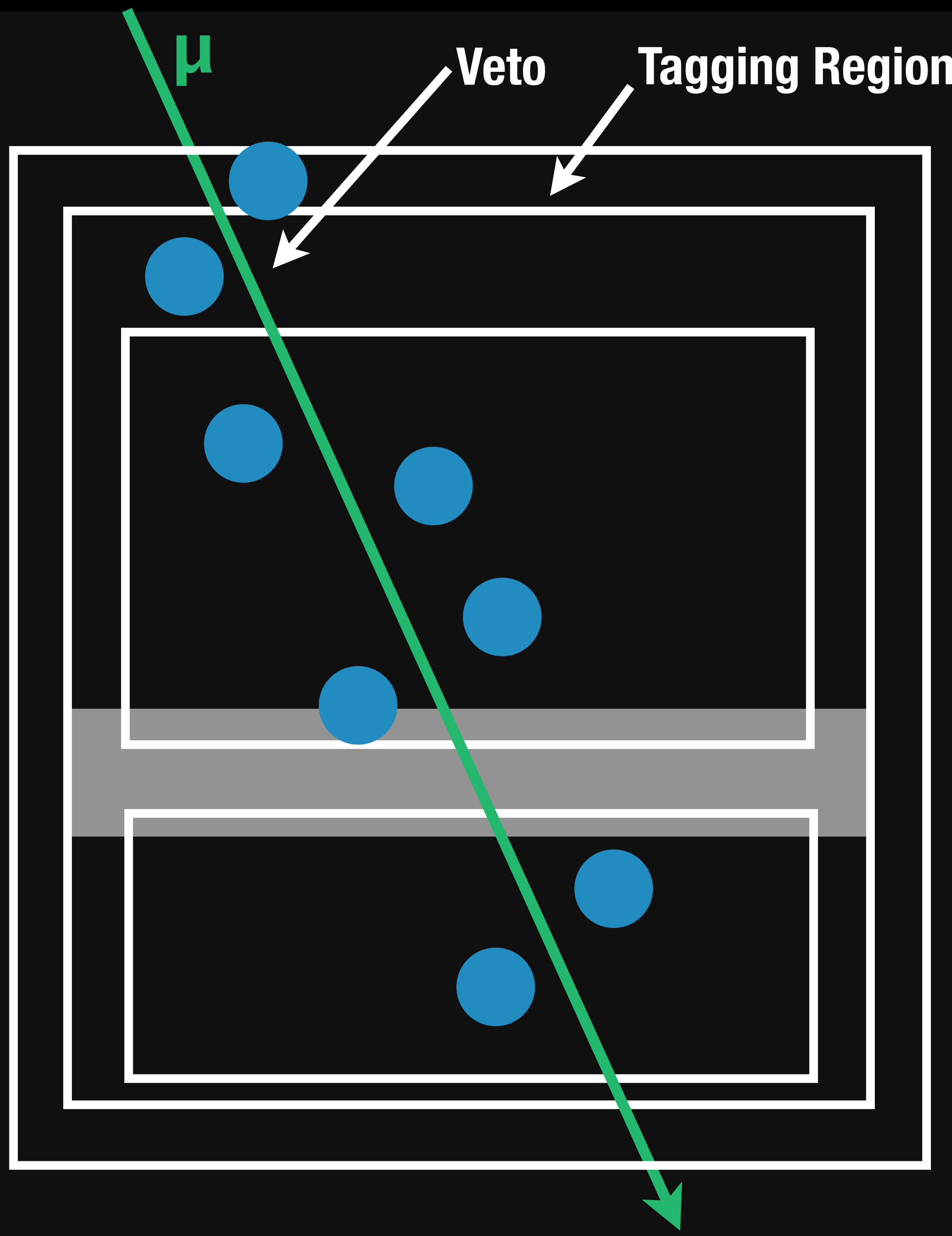
Schönert et al., arXiv:0812.4308

- Note: optimal use requires *minimal* overburden to have the highest possible rate of cosmic ray muons!

Estimating Muon Background From Data

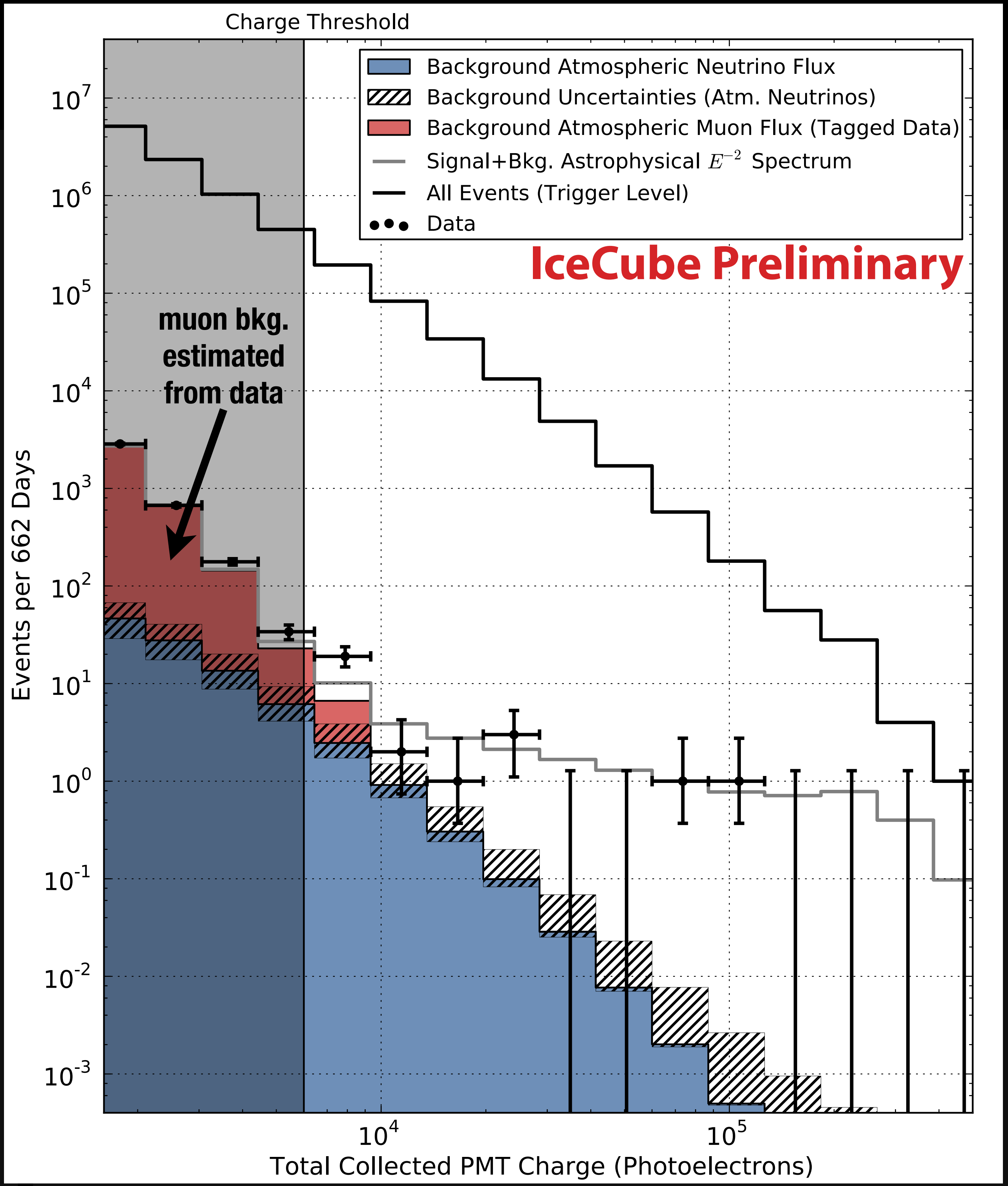
Use known background from atmospheric muons tagged in an outer layer to estimate the veto efficiency

- Add one layer of DOMs on the outside to tag known background events
  - Then use these events to evaluate the veto efficiency
- Avoids systematics from simulation assumptions/models!
- Can be validated at charges below a cut (6000 p.e.) where background dominates



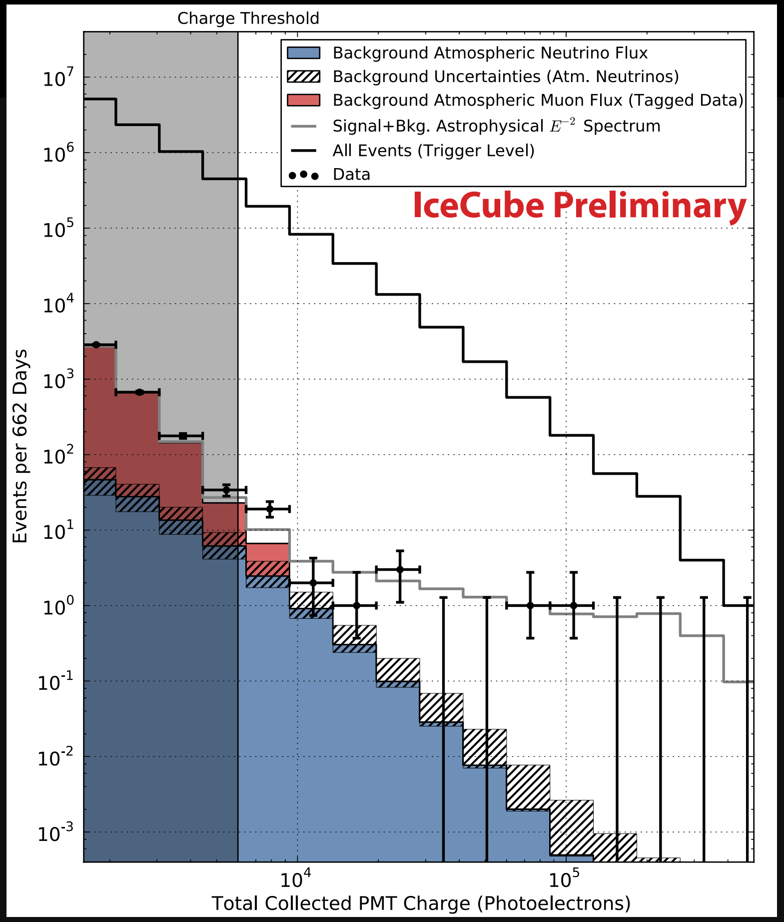
Charge Distribution with Muon Bkg.

- Fits well to tagged background estimate from atmospheric muon data (red) below charge threshold (Q_{tot}>6000)



Limits of the Current Method

- **Lower energy/charge region is dominated by background**
  - muons “sneaking” through the veto
  - coincident events: first one “triggers” veto, second one provides charge
- **Estimation of background only works in a straightforward way for “simple enough” cuts**
  - correlations between veto cuts and other selections might complicate things



The Future

- **Improvements of the method, like:**
  - dynamic veto "thickness" as a function of charge
  - enhancements of the detector (top veto, additional strings, ...)
- **Take more data with IceCube**
- **Is this an option / possibility for KM3NeT or is it better to focus on a detector optimized for point sources using muons?**