Particle Physics in Ice with IceCube DeepCore

PENNSTATE

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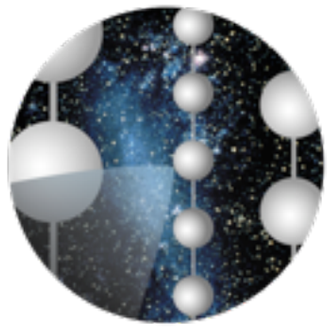
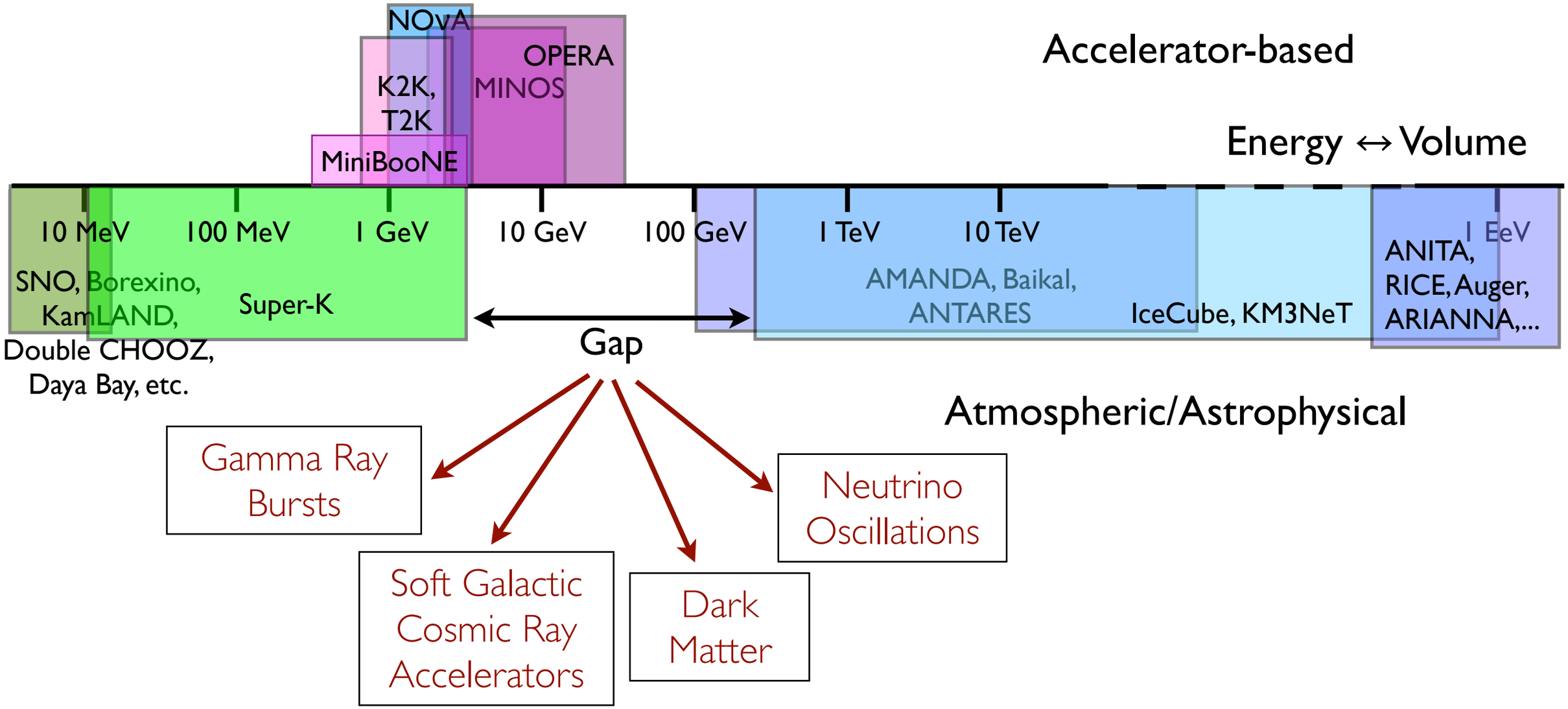


RICAP ’11
Rome, Italy
May 25, 2011

The Neutrino Detector Spectrum



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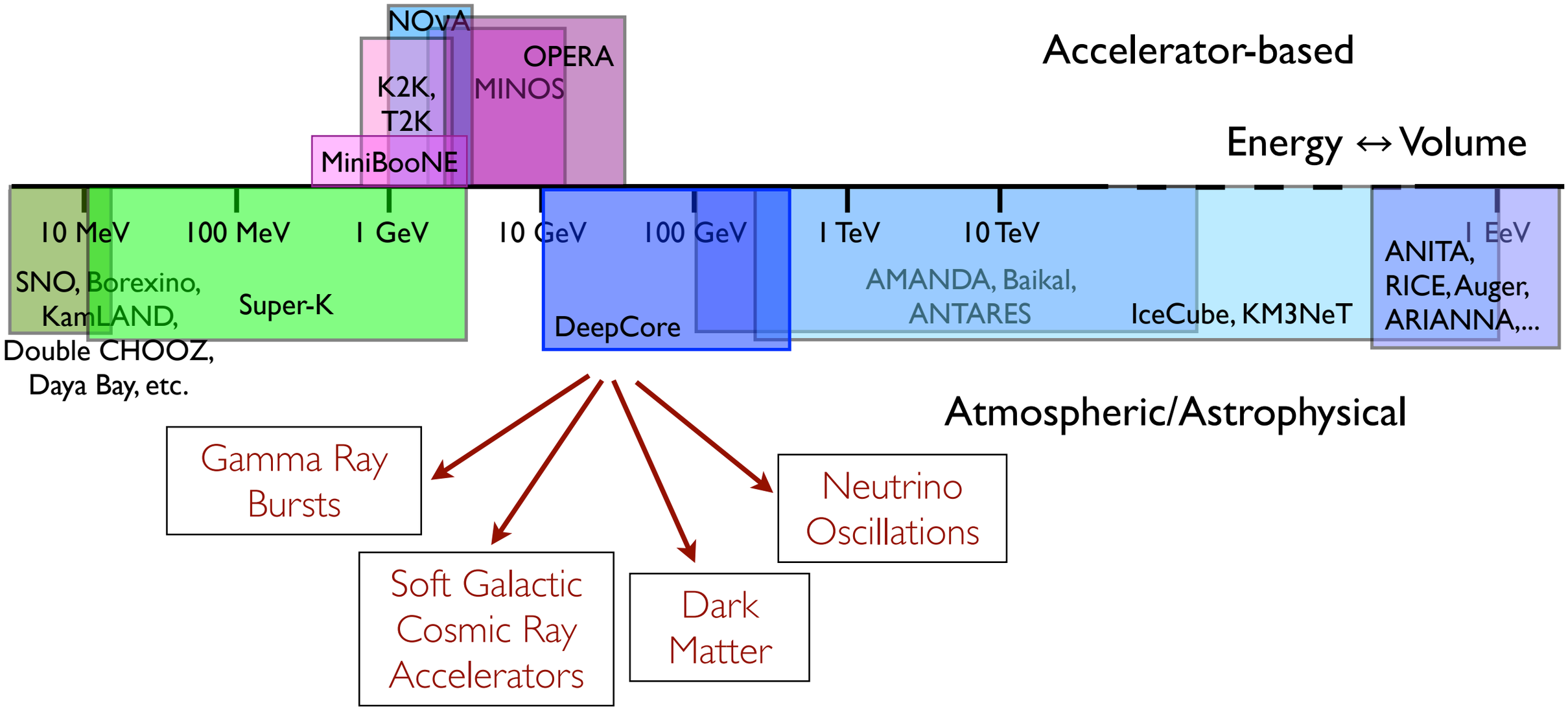
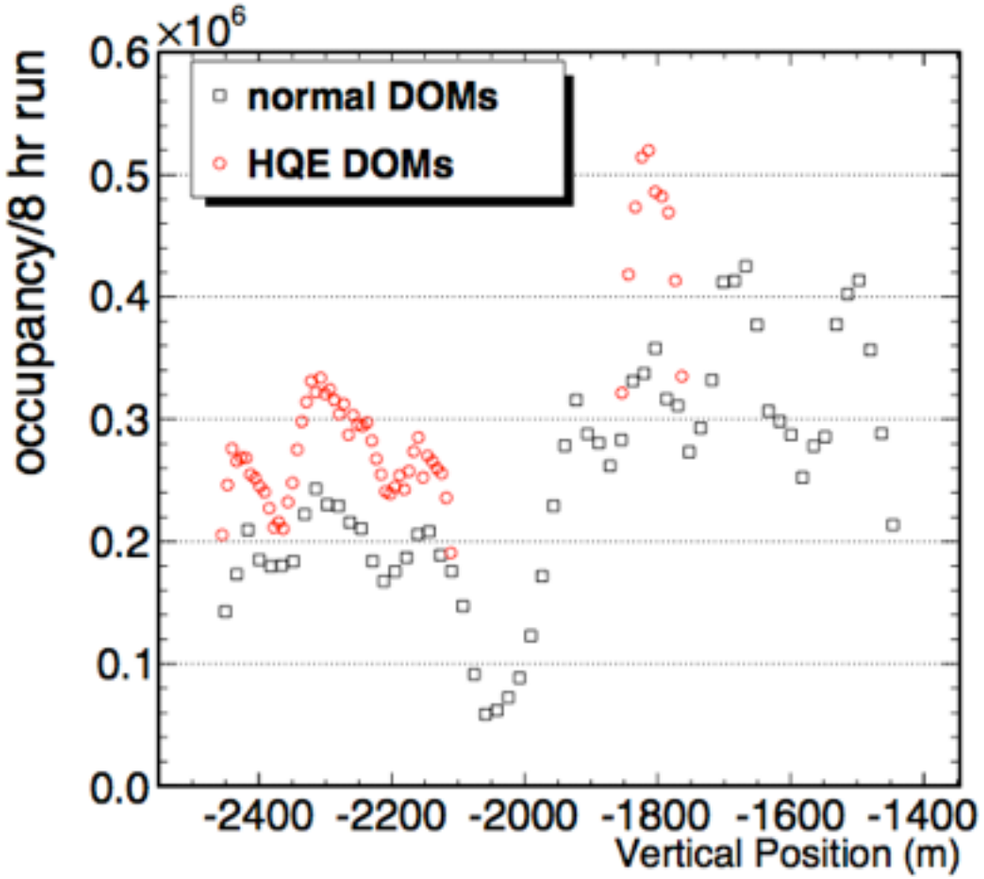


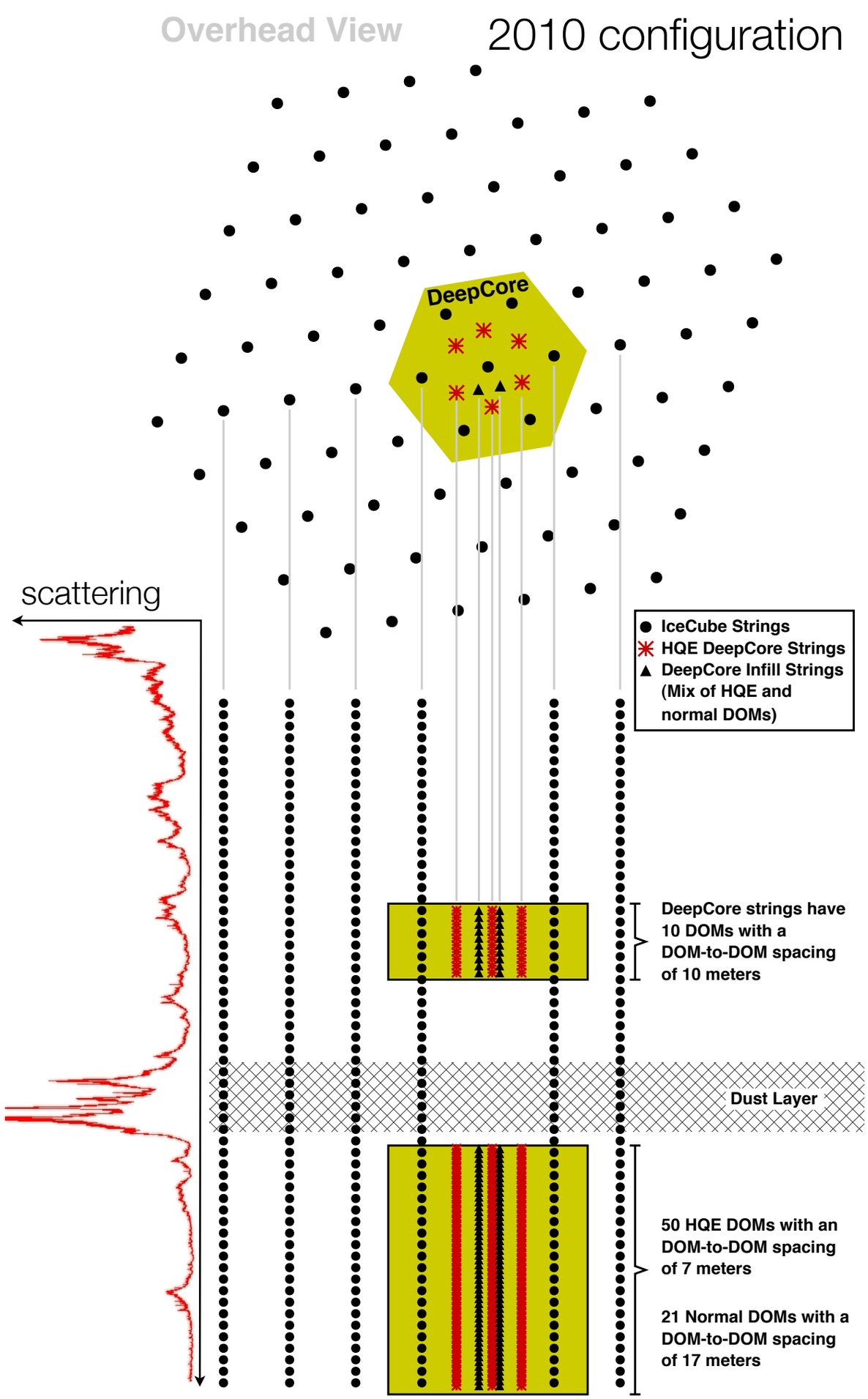
IceCube DeepCore

- IceCube collaboration decided to augment “low” energy response with a densely instrumented infill array: DeepCore
  - Significant improvement in capabilities from ~10 GeV to ~100 GeV (ν_μ)
- Primary scientific rationale is the indirect search for dark matter
- Particle physics using atmospheric neutrinos
  - Neutrino oscillations, including tau neutrino appearance
- Neutrino sources in Southern Hemisphere
  - Galactic cosmic ray accelerators, dark matter in the Galactic center
- Neutrino astronomy at low energies (e.g. GRBs)

IceCube DeepCore

- DeepCore extends the reach of IceCube to lower energies
  - Denser module spacing
  - Hamamatsu super-bialkali PMTs
  - Deployed in the clearest ice





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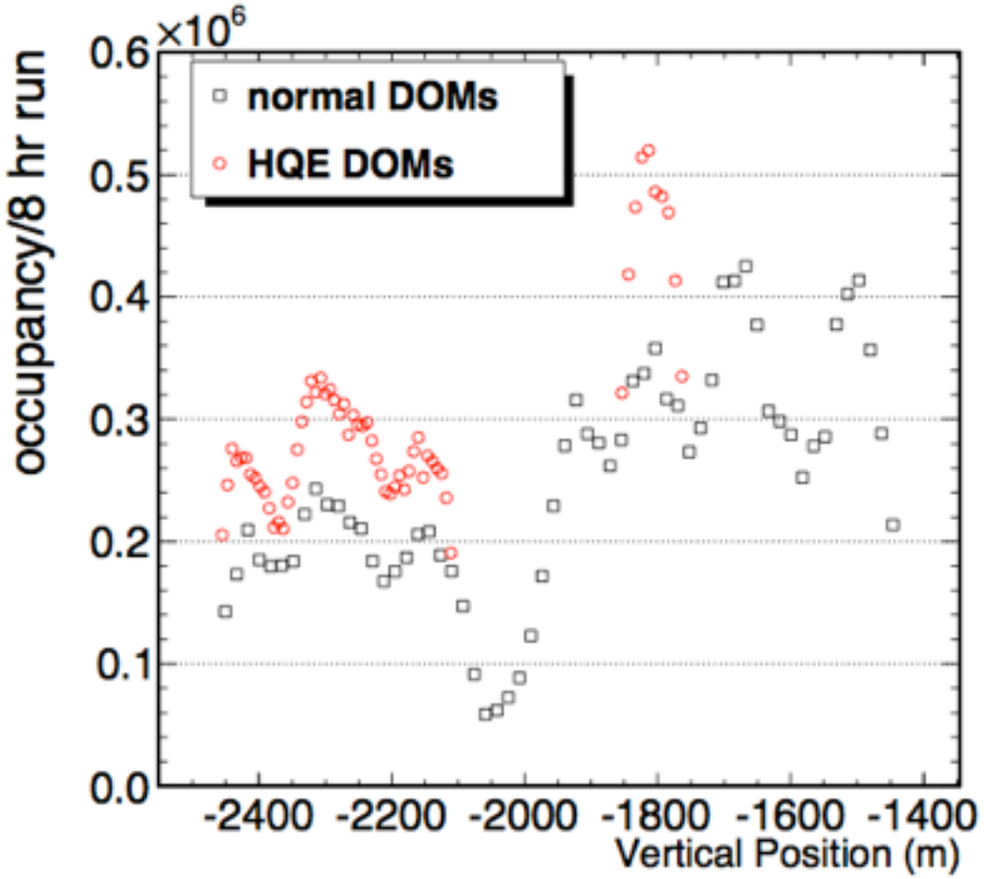
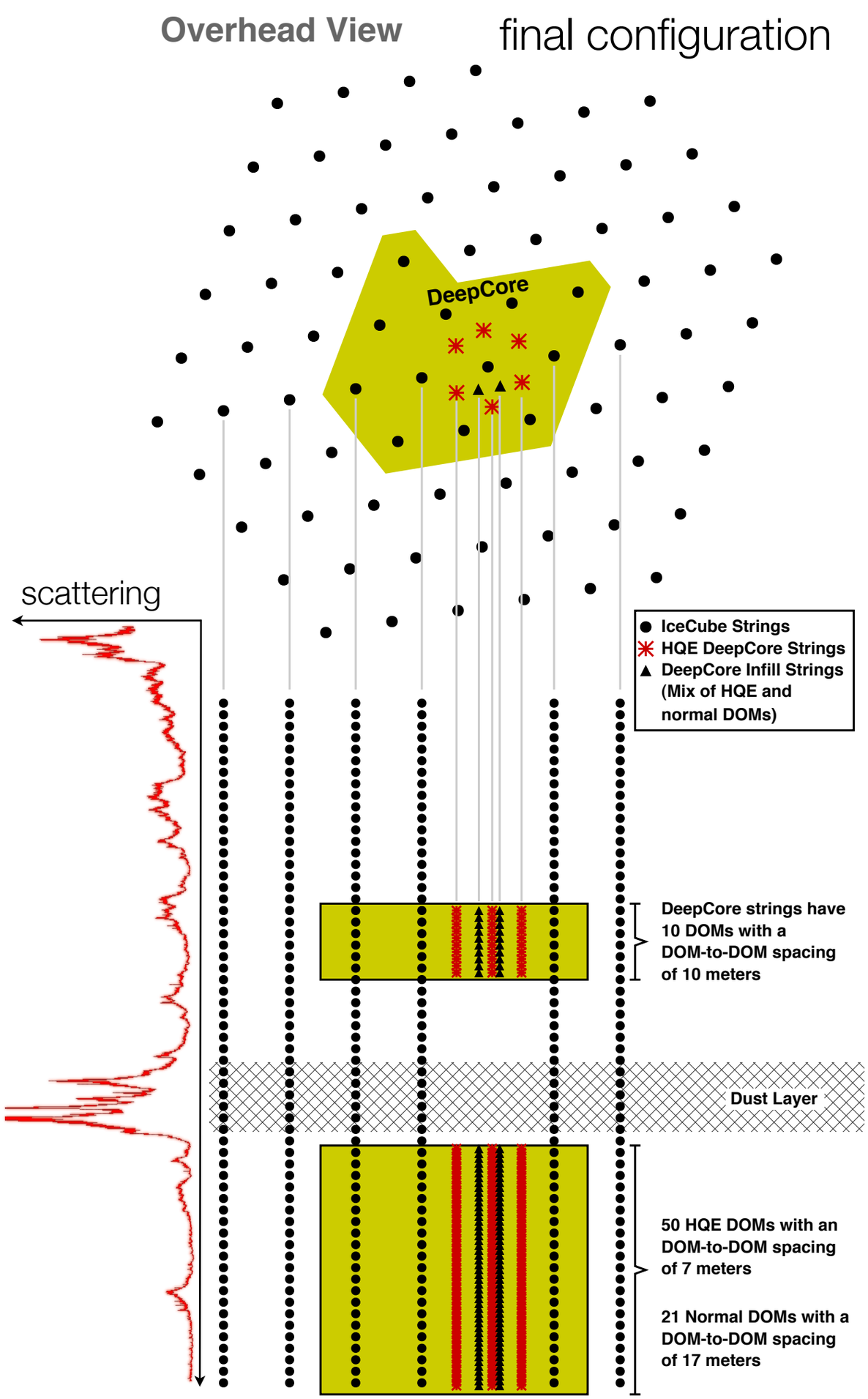
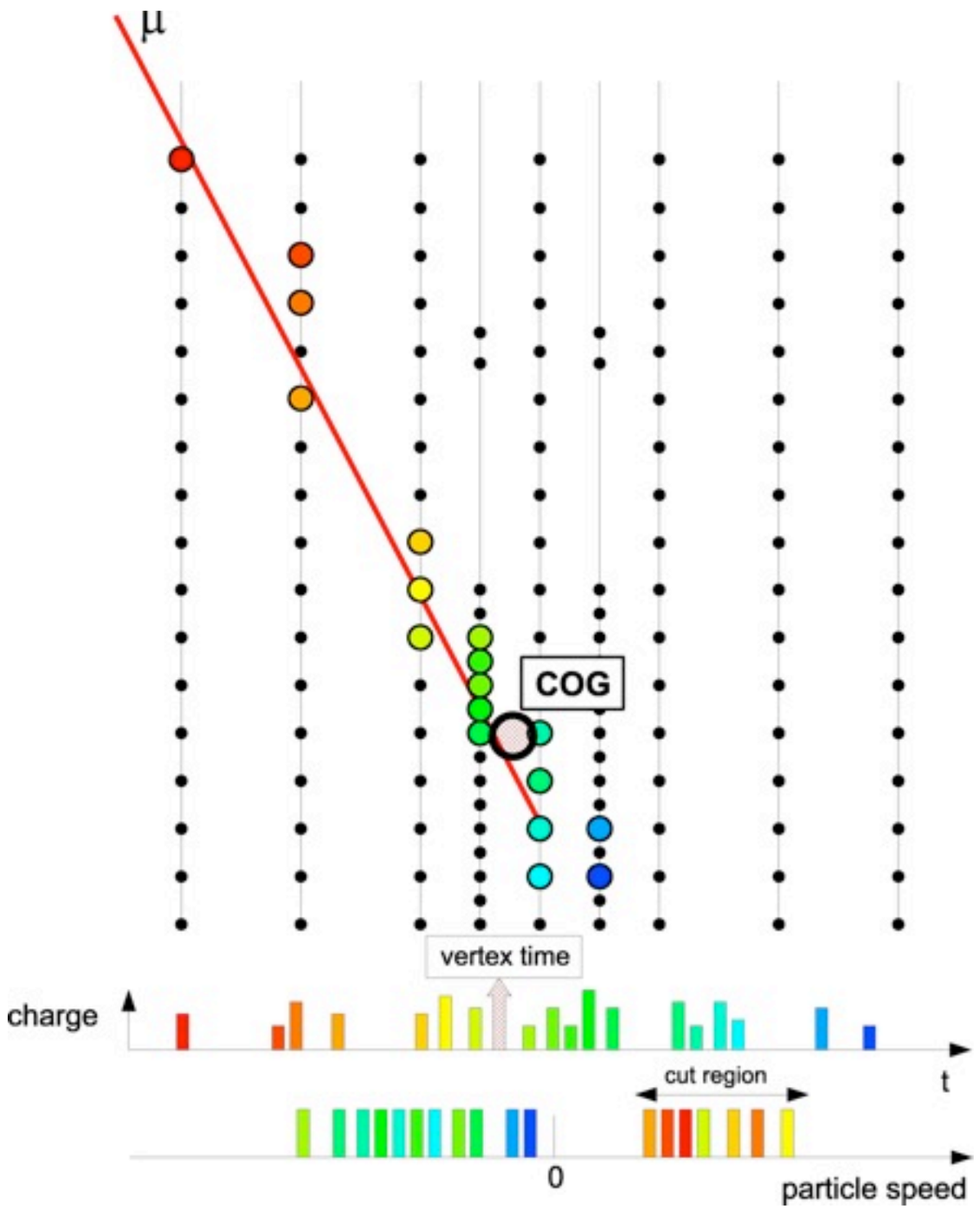
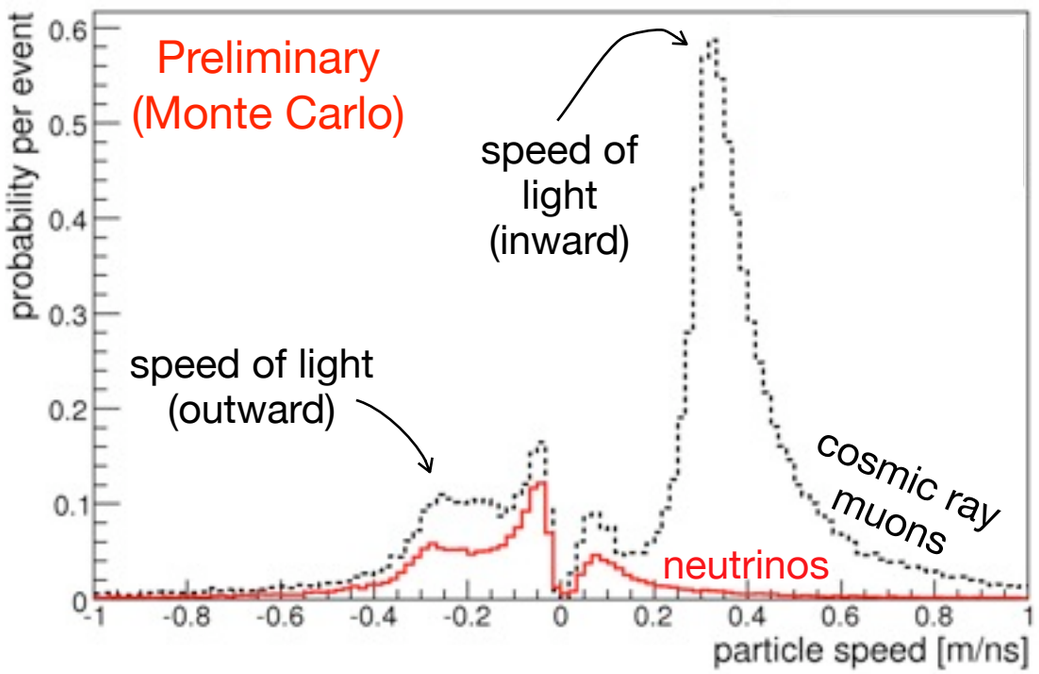




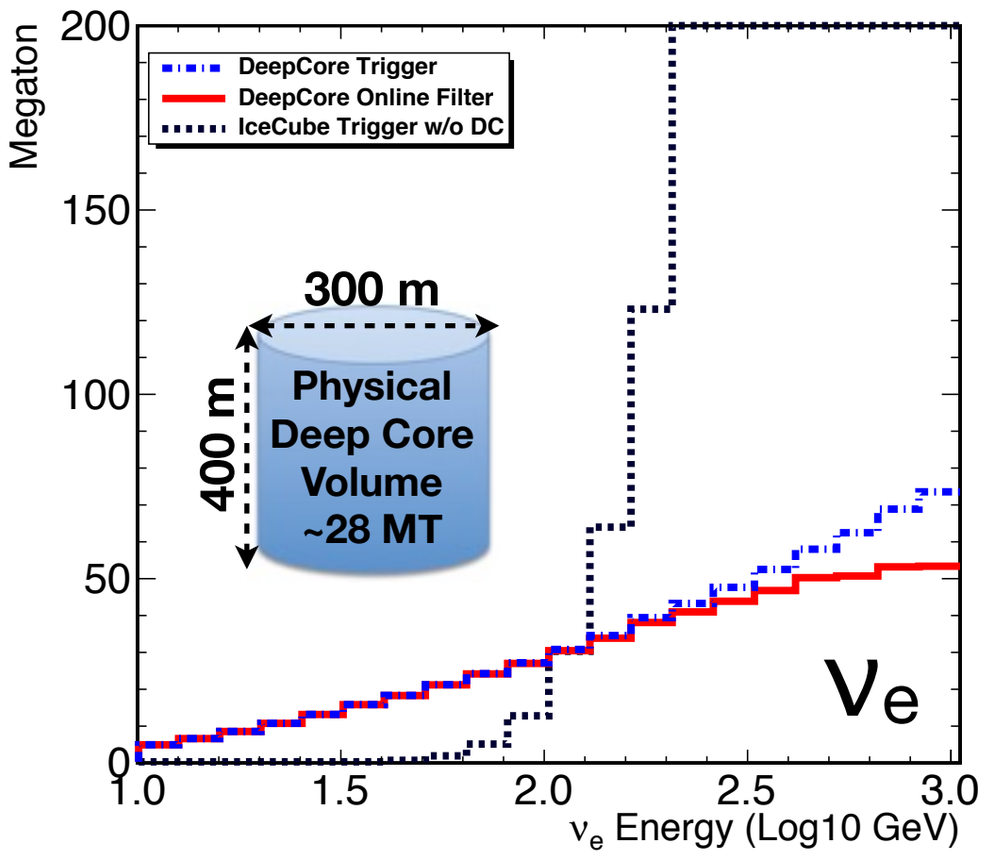
Online Atmospheric Muon Veto

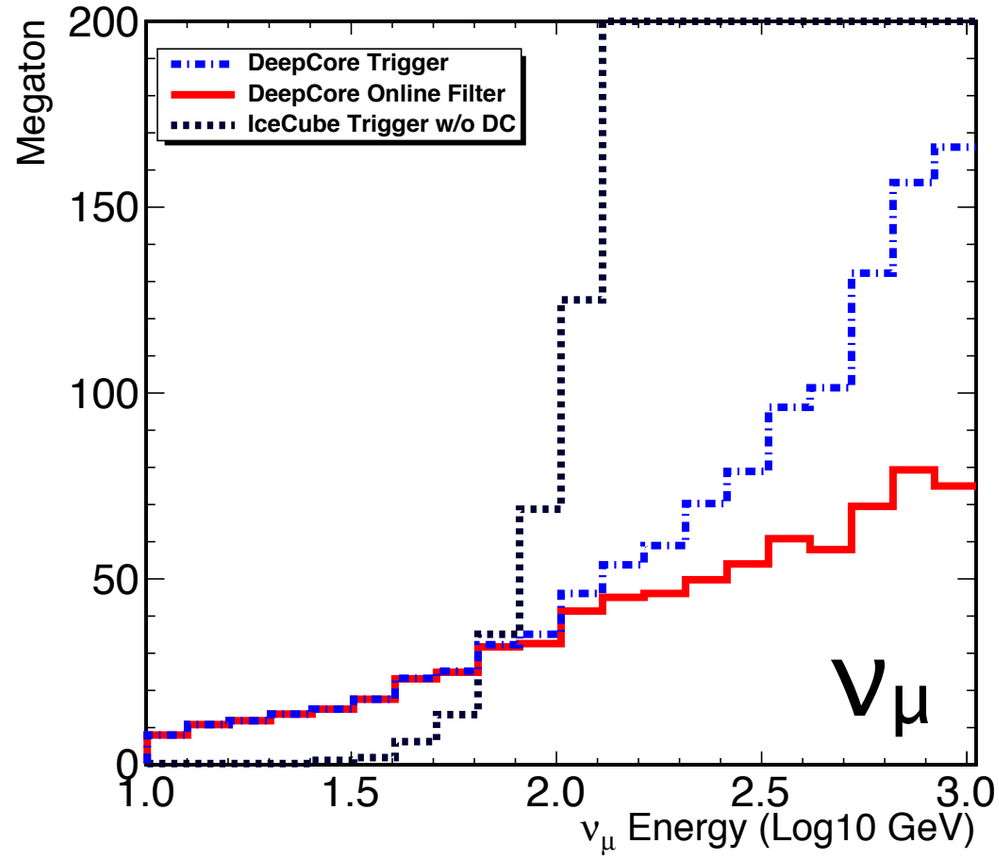


- Look for hits in veto region consistent with speed-of-light travel time to hits in DeepCore
  - Achieves 7 x 10^{-3} rejection of cosmic ray muon background
  - Loss of <2% of fiducial neutrinos



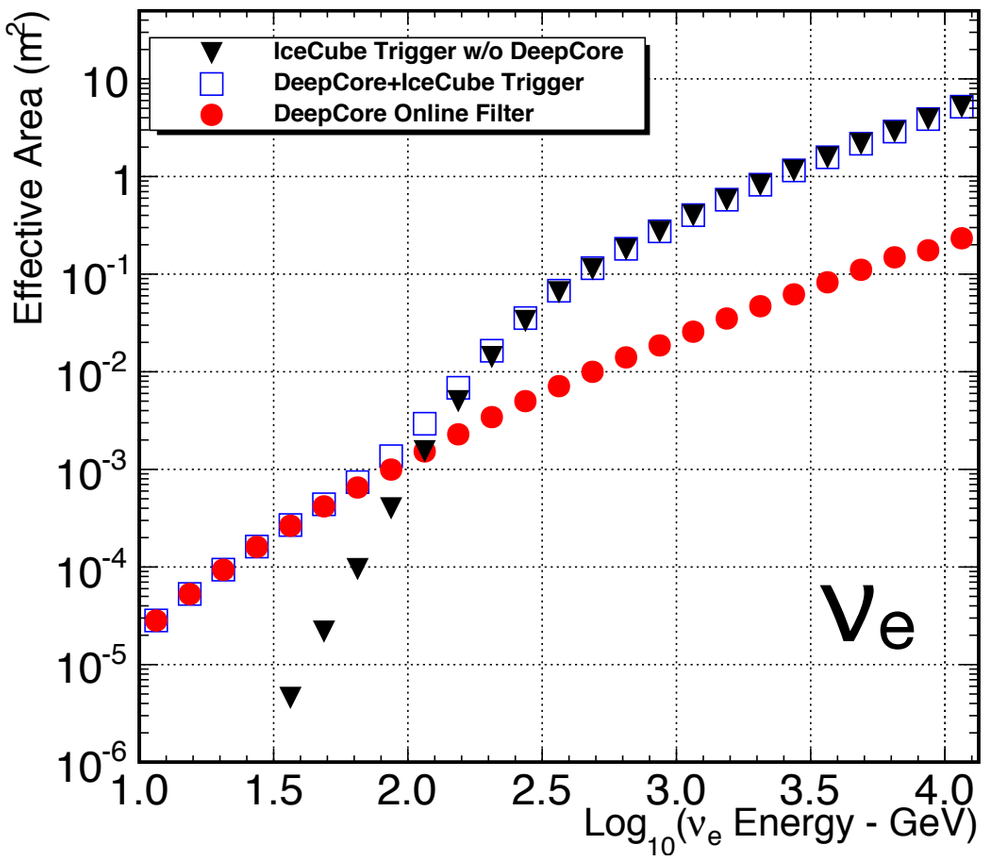
DeepCore Lepton Effective Volume

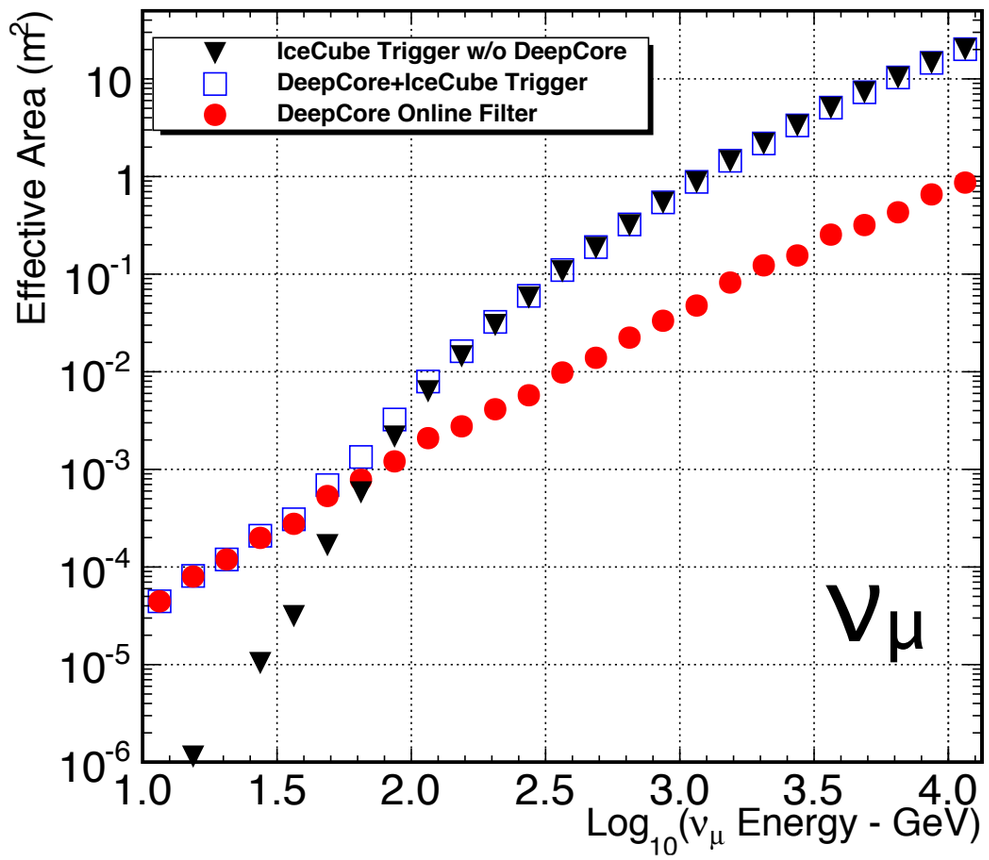




- Many DeepCore triggers are events occurring in the rest of IceCube
  - These events are rejected by the online veto algorithm
  - Online efficiency for neutrinos interacting in the DeepCore volume is >98%
  - Efficiency in final analysis will be significantly lower; losses to reconstruction efficiency, background rejection

DeepCore Neutrino Effective Area



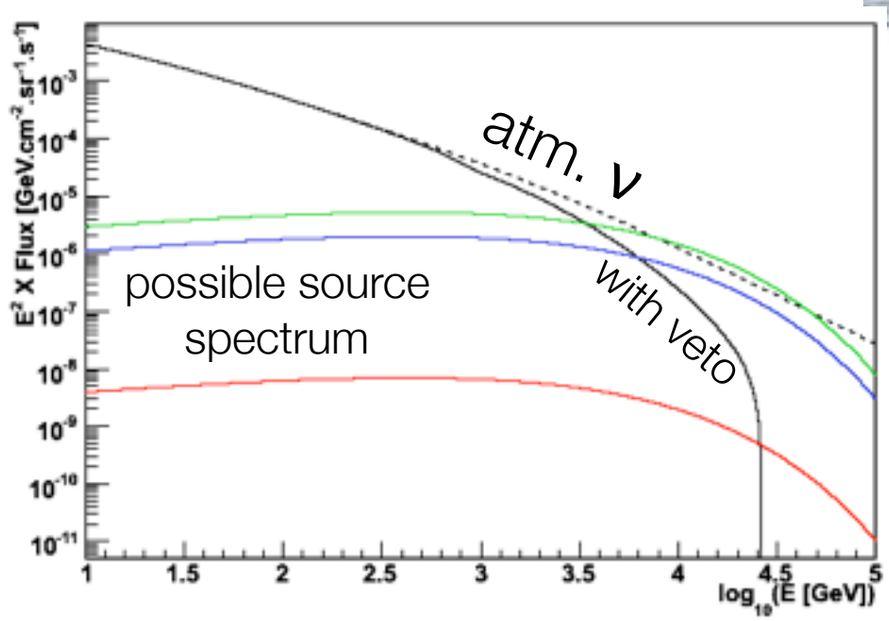


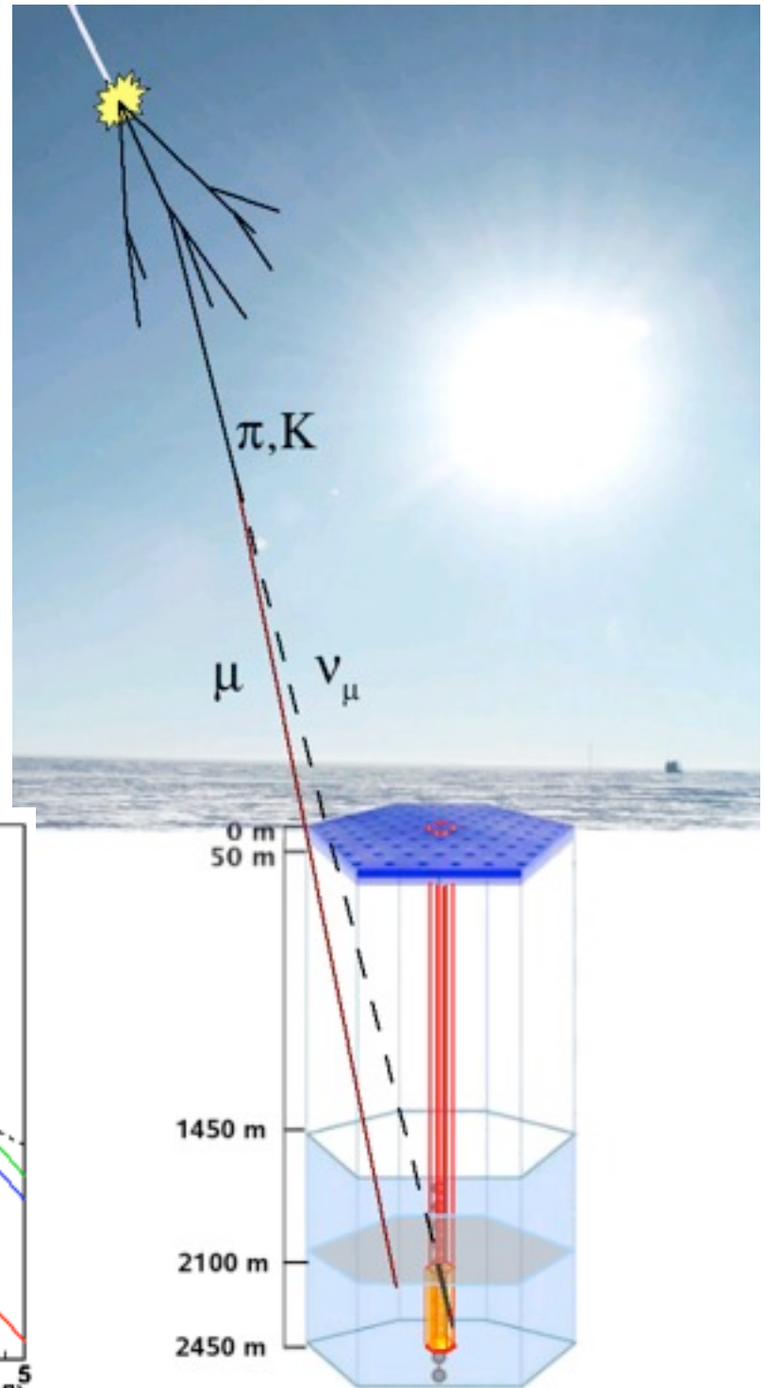
- DeepCore dominates total response for E_ν below ~100 GeV, depending on flavor
  - Improved trigger efficiency overcomes much smaller volume
  - Linear growth at high energies reflects neutrino interaction cross section, not detector efficiency

Neutrino Astronomy with DeepCore

- Atmospheric neutrino veto
  - May allow observation of sources in the Southern hemisphere with fluxes too low to be seen above atmospheric background
    (Schönert et al. 2009)

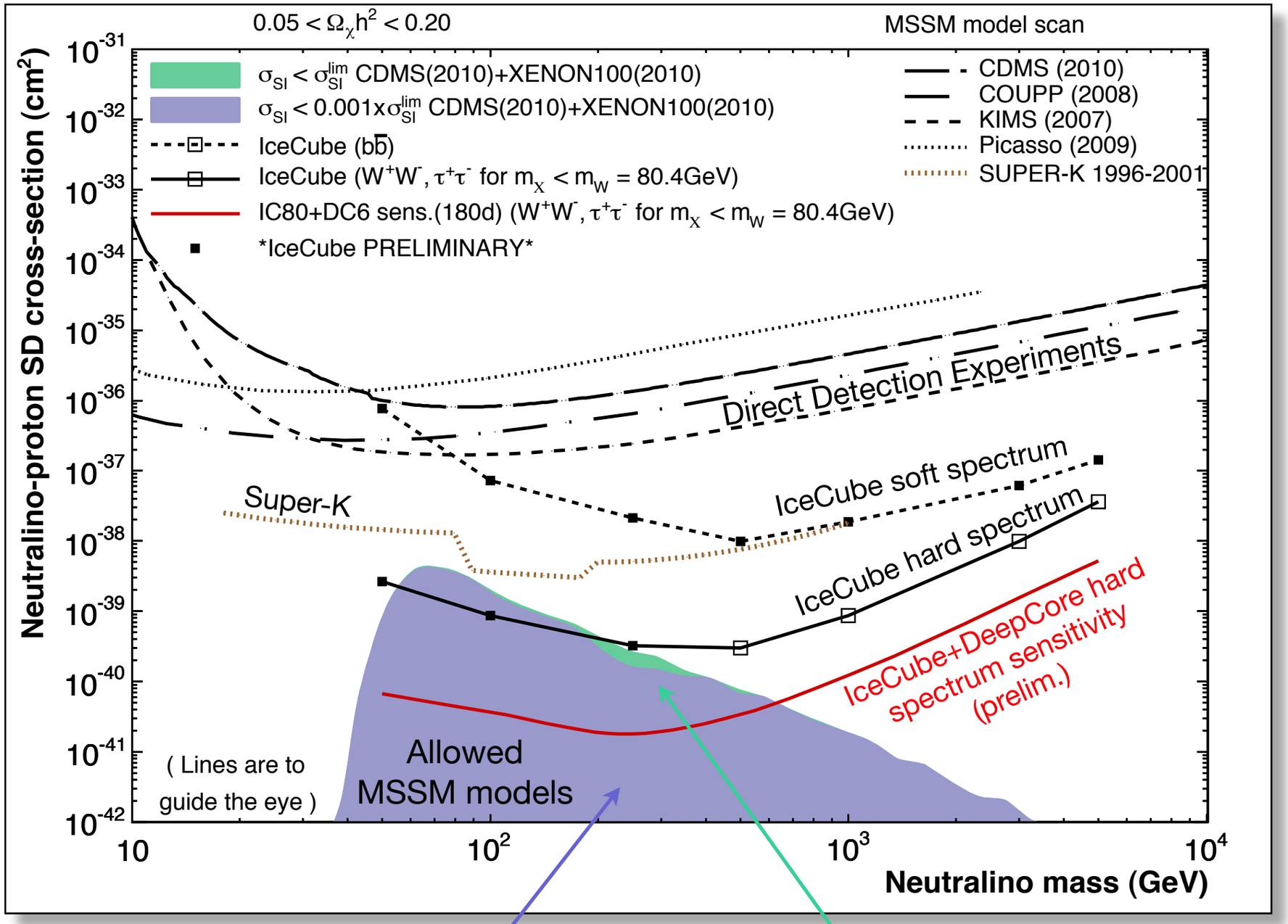
- Sensitivity to low energy neutrinos from transients
  - E.g. choked or magnetically dominated GRBs
    (e.g., Ando & Beacom 2005; Razzaque, Meszaros & Waxman 2005; Meszaros & Rees 2011)





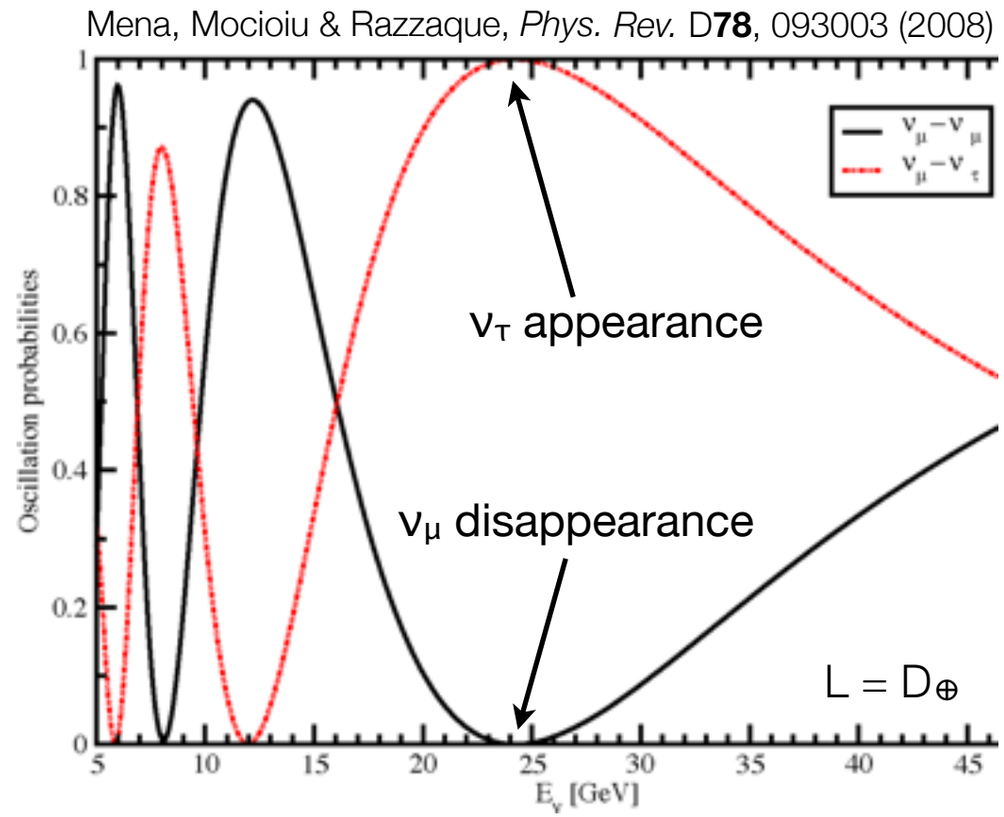
Sensitivity to MSSM WIMPs

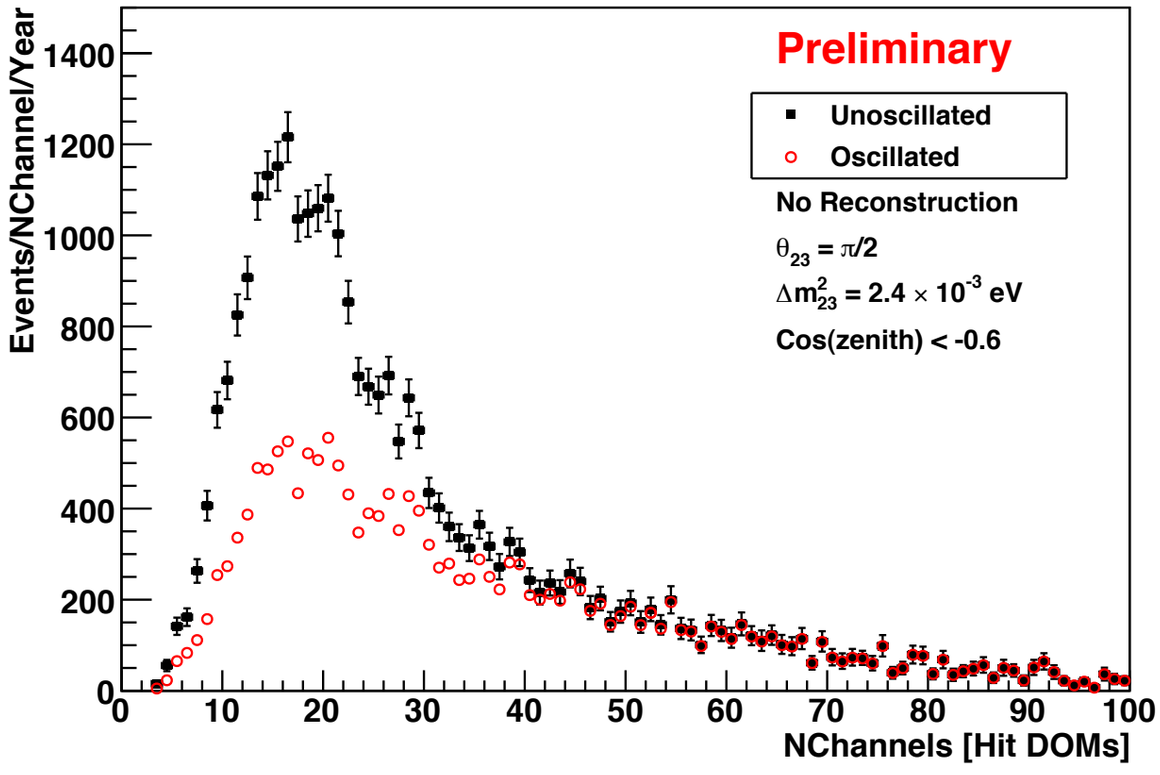
- Solar WIMP dark matter searches probe SD scattering cross section
  - SI cross section constrained well by direct search experiments
- DeepCore will probe large region of allowed phase space



Neutrino Oscillations

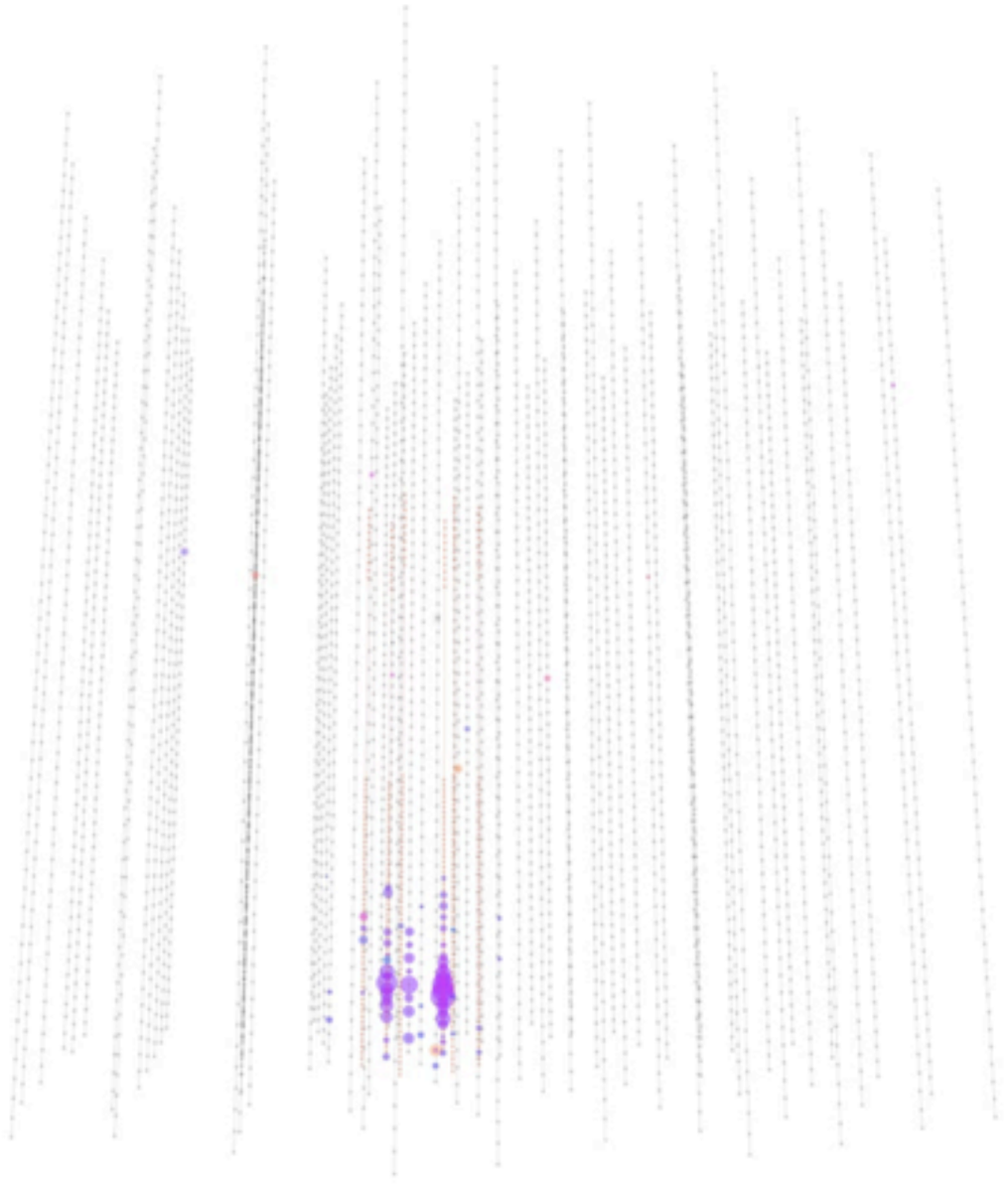
- Atmospheric neutrinos from Northern Hemisphere oscillating over one earth diameter have ν_μ oscillation minimum at ~25 GeV
  - Higher energy region than accelerator-based experiments
- Plot of ν_μ disappearance shows only simulated signal
  - Analysis efficiencies not included yet – work ongoing
  - Uses number of hit DOMs as a simple energy estimator





Observation of Neutrino Cascades (Preliminary)

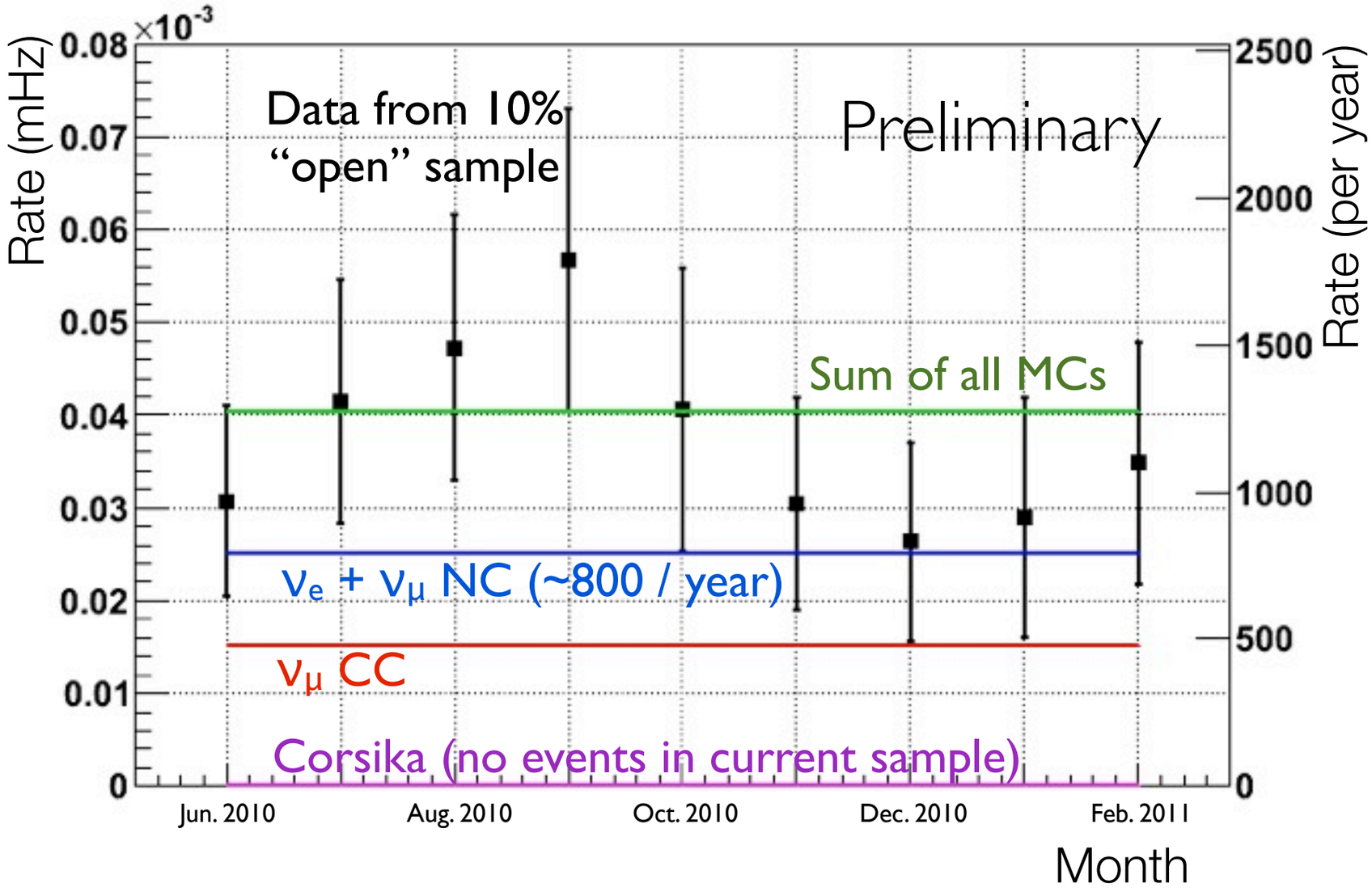
- Disappearing ν_μ should appear in IceCube as ν_τ cascades
  - Effectively identical to neutral current or ν_e CC events
  - Could observe ν_τ appearance as a distortion of the energy spectrum, if cascades can be separated from muon background
- We believe we see neutrino cascade events for the first time
  - The dominant background now is CC ν_μ events with short tracks



Candidate cascade event
Run 116020, Event 20788565, 2010/06/06

Observation of Neutrino Cascades (Preliminary)

- With harsh cuts to eliminate the ν_μ background we expect to obtain a sample of ~800 neutrino cascades per year
  - Approximately 500 background ν_μ CC events expected
  - Contamination from atmospheric muons still being evaluated



- Efforts to increase ν_e yield and reduce ν_μ CC background ongoing

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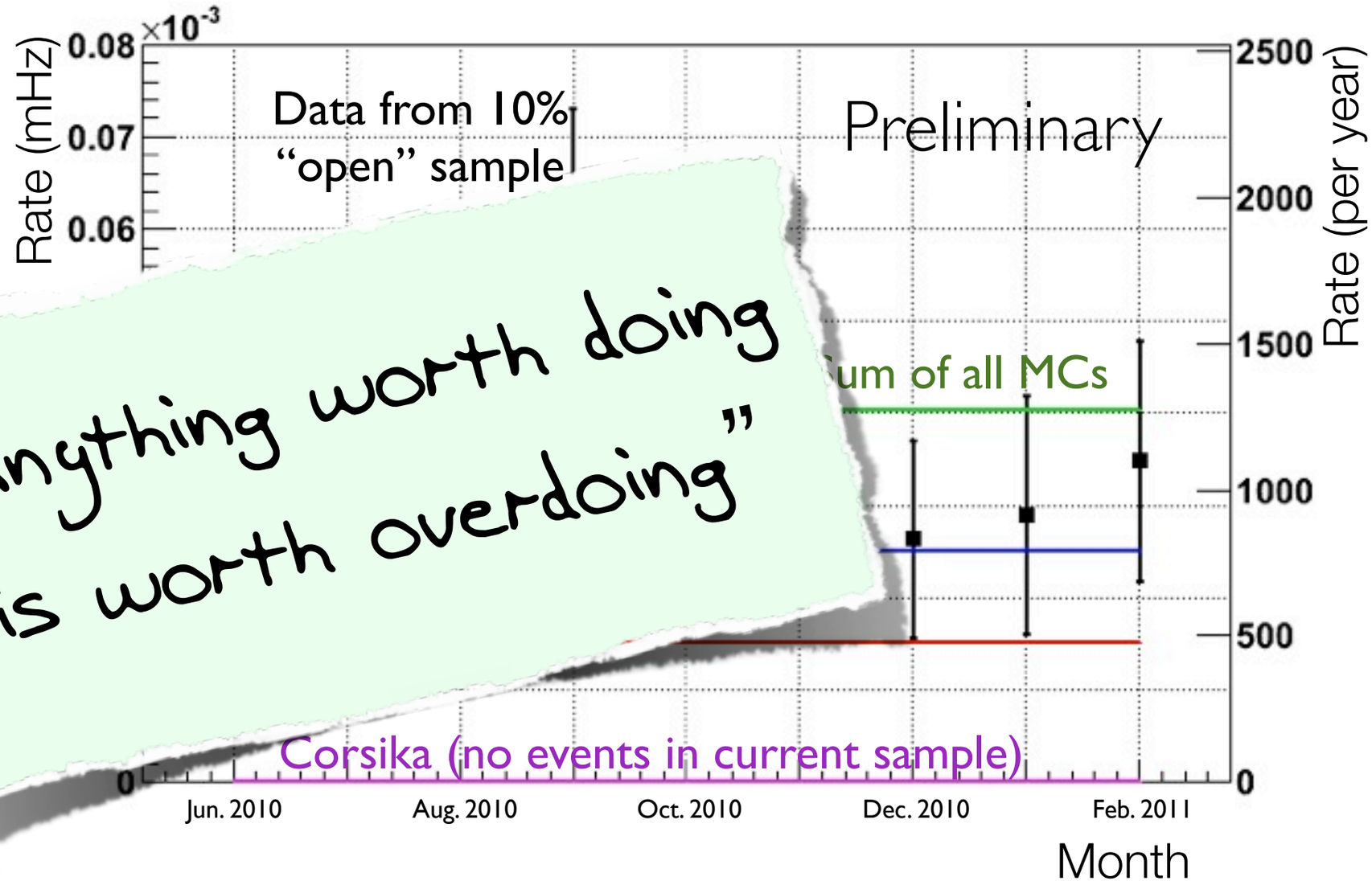
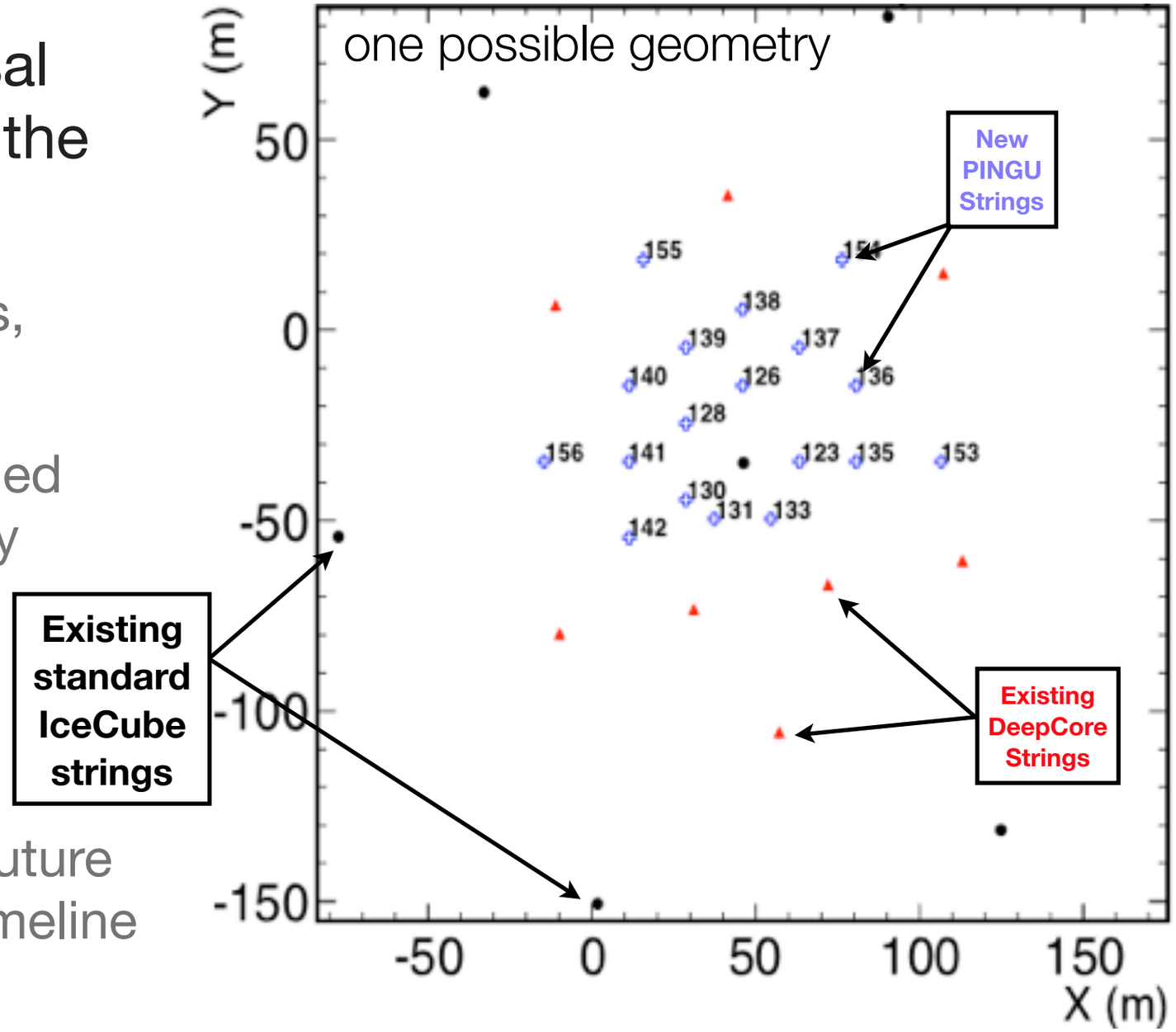


Beyond DeepCore: PINGU

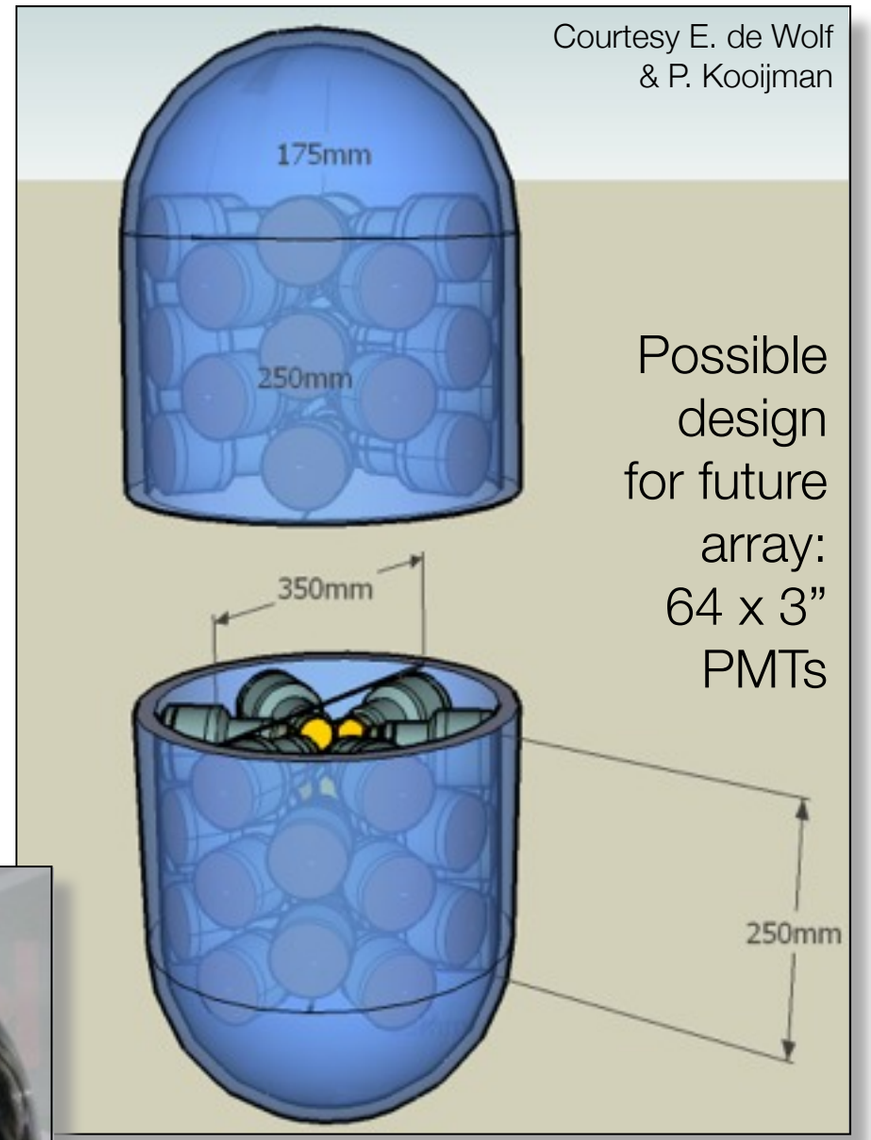
- Now developing a proposal to continue to instrument the DeepCore volume
  - An additional 18-20 strings, 1000-1200 DOMs
  - Make use of well-established IceCube drilling technology
  - Might get to a threshold of ~1 GeV in a ~10 MTon volume
  - Also an R&D platform for future detectors on a ~decade timeline

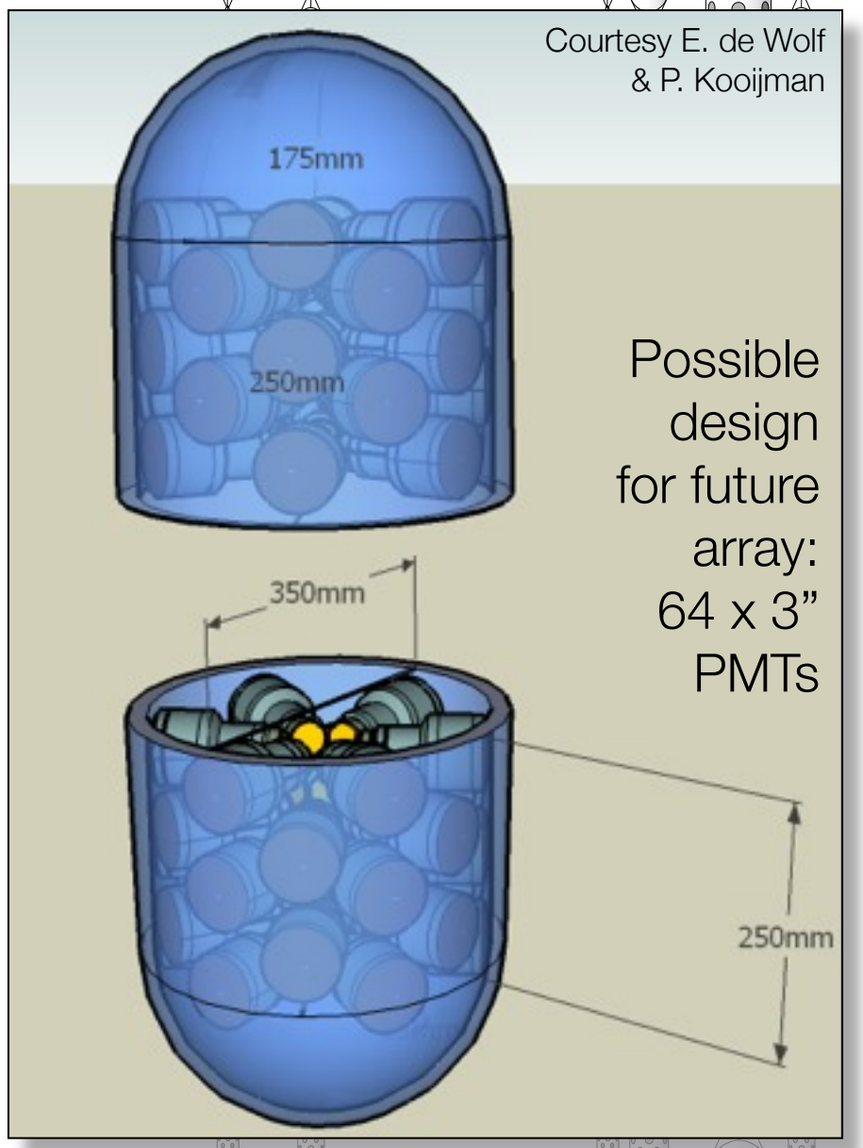


- Price tag expected to be around $25M – $30M

R&D: Multi-PMT Digital Optical Module

- Based on a KM3NeT prototype
- Glass cylinder containing 64 3” PMTs and associated electronics
  - Effective photocathode area >6x that of a standard IceCube 10” PMT
  - Diameter similar to IceCube DOM, single connector
- Might enable Cherenkov ring imaging in the ice
  - Feasible to build a multi-MTon detector in ice with an energy threshold of 10’s of MeV?





Possible design for future array: 64 x 3” PMTs

Conclusions

- DeepCore has been running for 1 year, just commenced taking data in final configuration
  - Additional 8 strings, densely instrumenting the inner 30 MTon of IceCube
  - Reduce energy threshold to ~10 GeV
- Significant improvement in sensitivity to dark matter, potential for measurements of neutrino oscillations, low energy astrophysical neutrinos
  - Preliminary analysis suggests we may have detected atmospheric electron neutrinos for the first time in a high energy neutrino telescope
- Thinking about a future upgrade of IceCube to further extend its particle physics capabilities – PINGU
  - In the more distant future, could we build a Cherenkov ring imager in ice?