

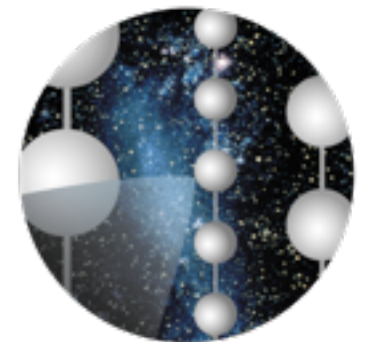
# Particle Physics in Ice with IceCube DeepCore

PENNSTATE



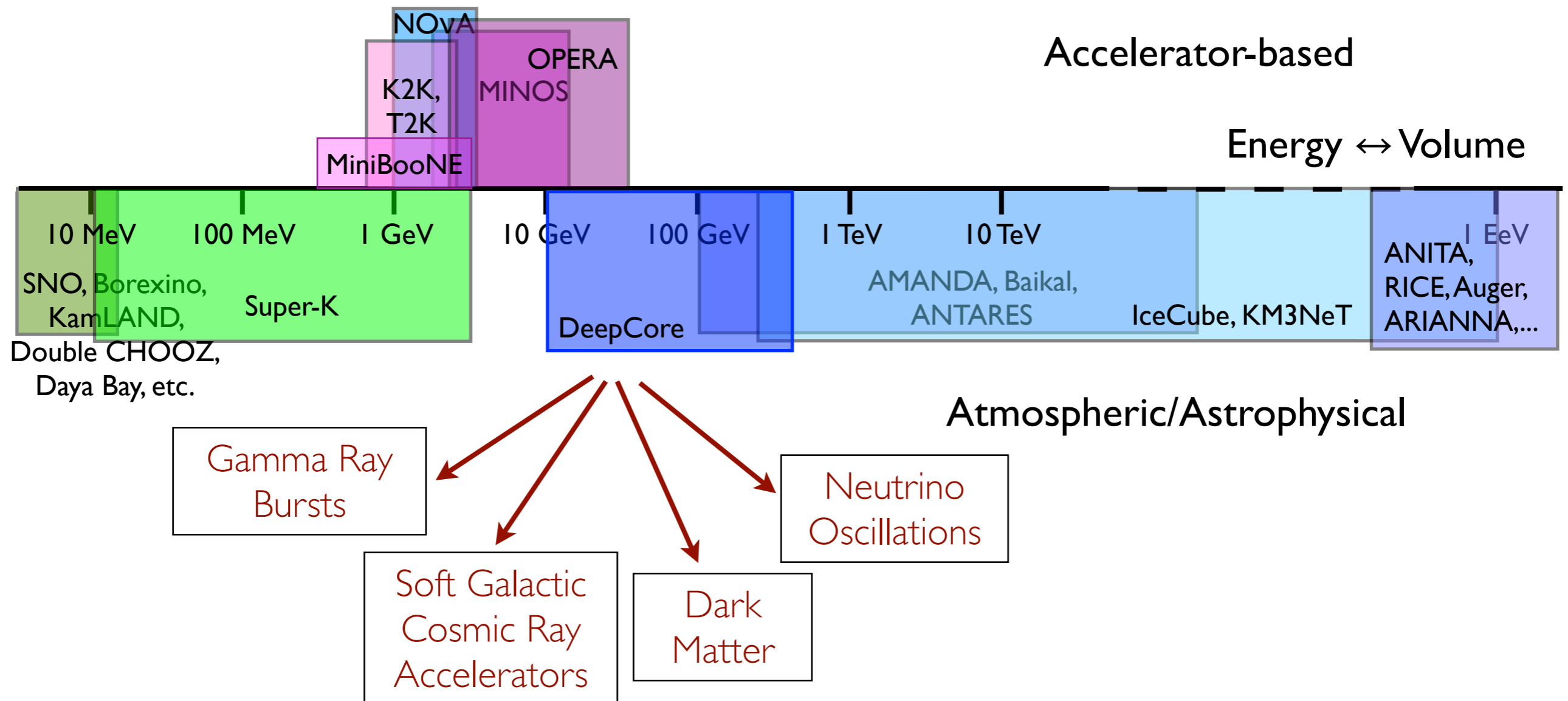
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Department of Physics  
Pennsylvania State University

RICAP '11  
Rome, Italy  
May 25, 2011



I c e C u b e

# The Neutrino Detector Spectrum



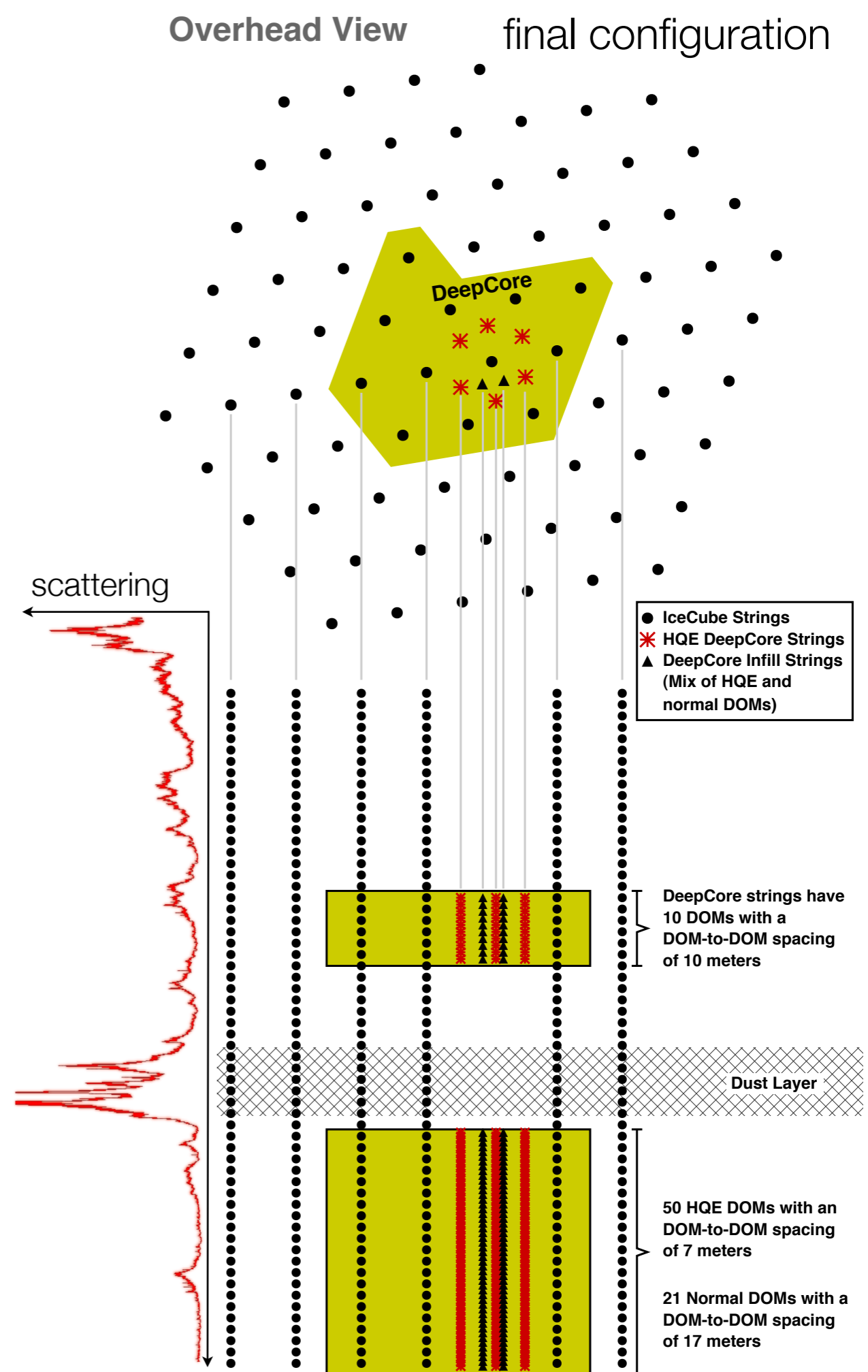
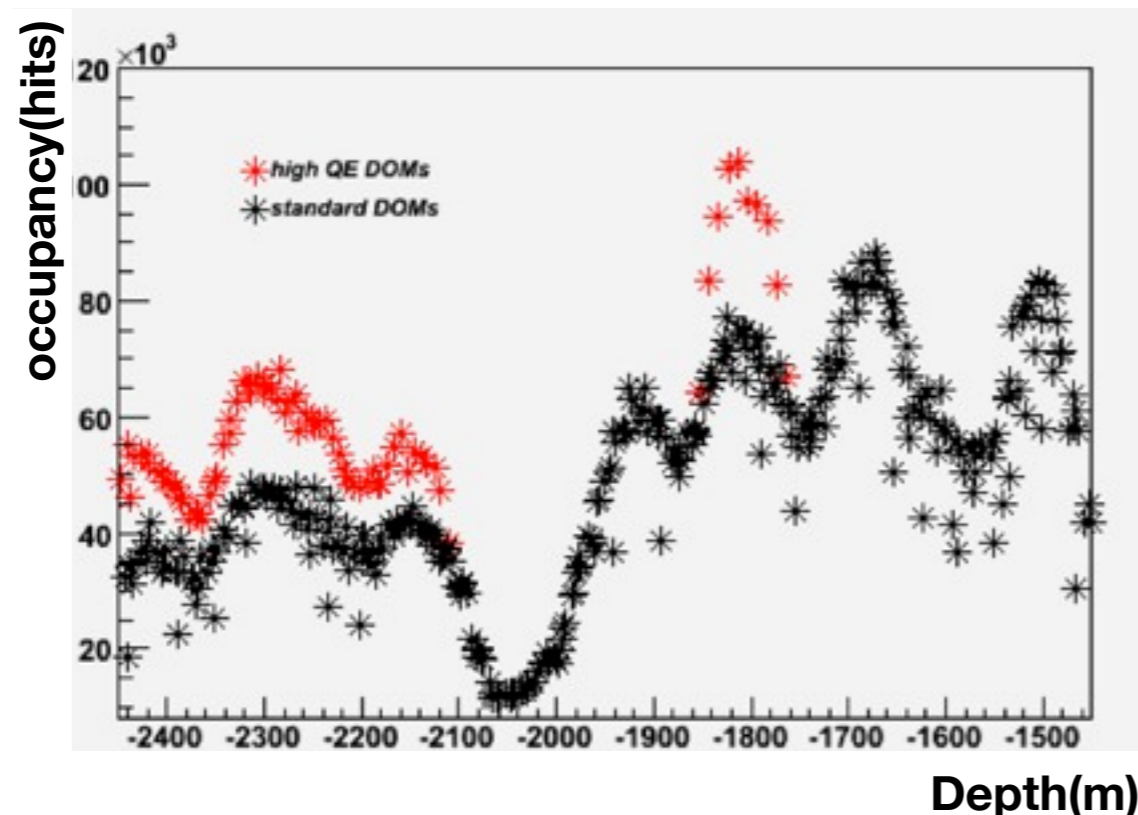
# IceCube DeepCore

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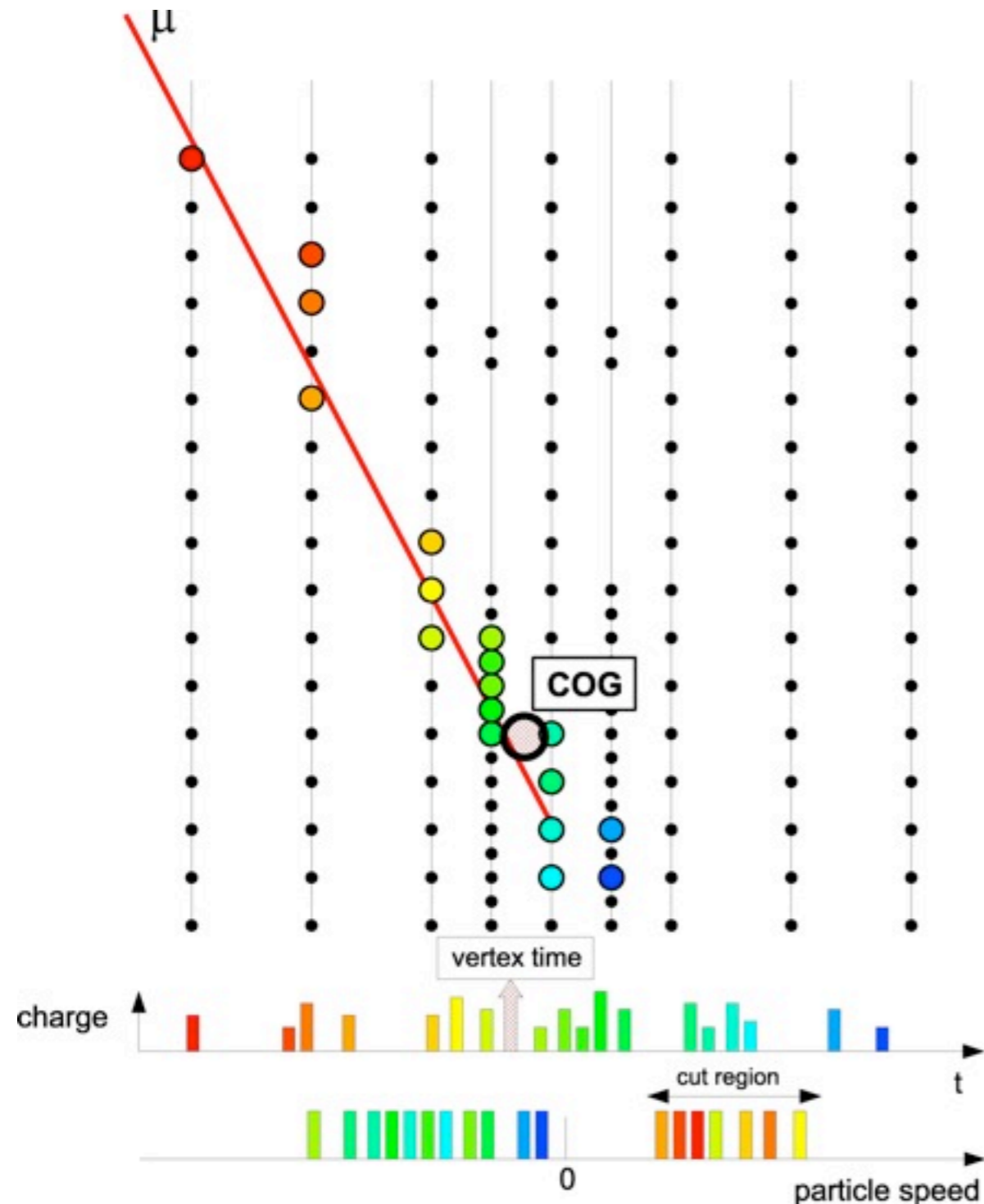
- IceCube collaboration decided to augment “low” energy response with a densely instrumented infill array: DeepCore
  - Significant improvement in capabilities from  $\sim 10$  GeV to  $\sim 300$  GeV ( $\nu_\mu$ )
- Primary scientific rationale is the indirect search for dark matter
- Particle physics 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

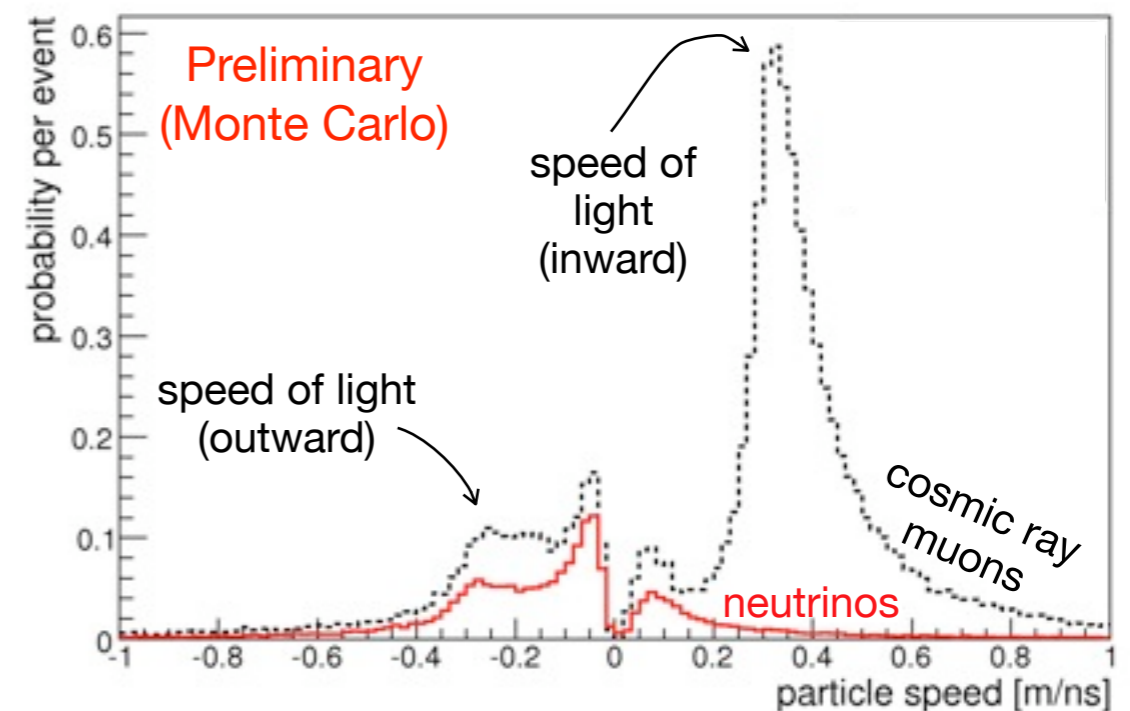
- DeepCore extends the reach of IceCube to lower energies
  - Denser module spacing
  - More sensitive PMTs (Hamamatsu super-bialkali)
  - Deployed in the clearest ice



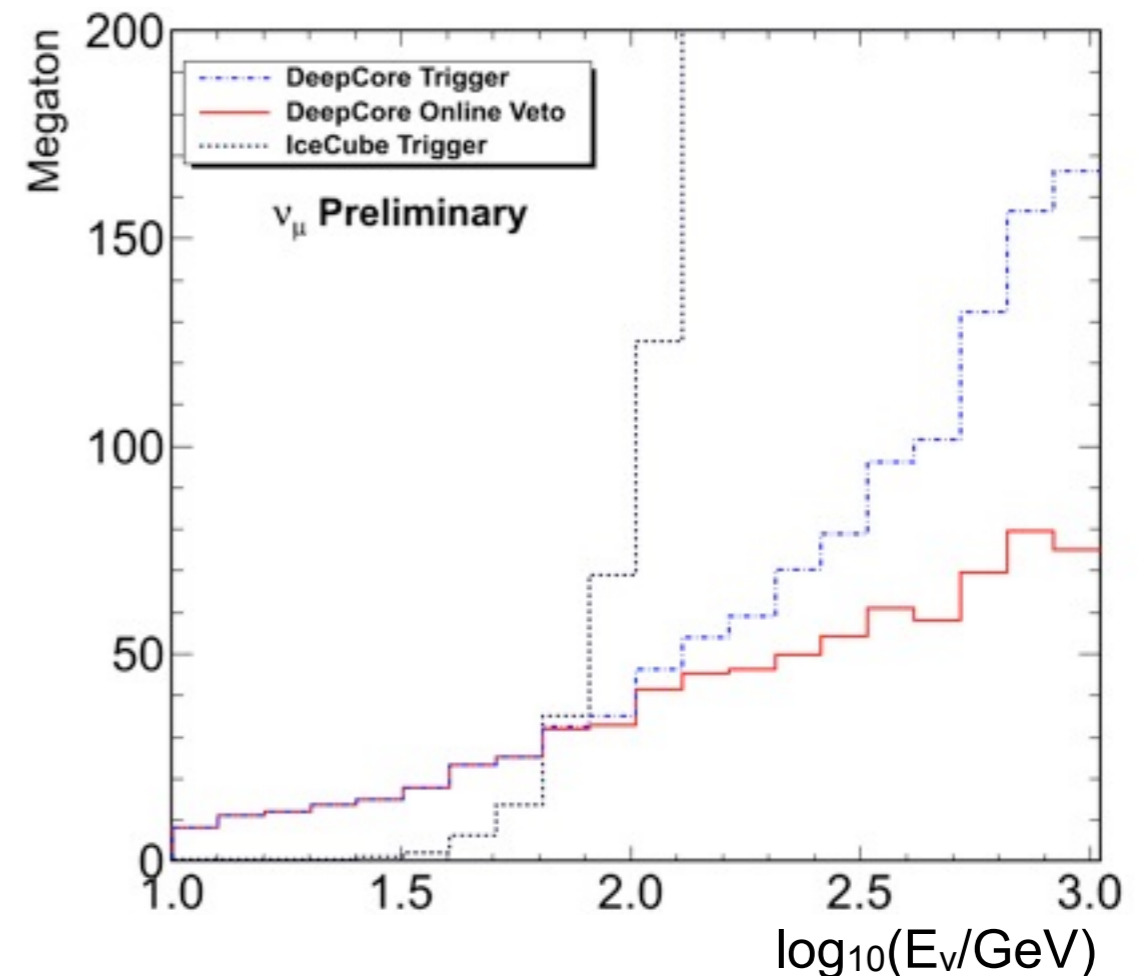
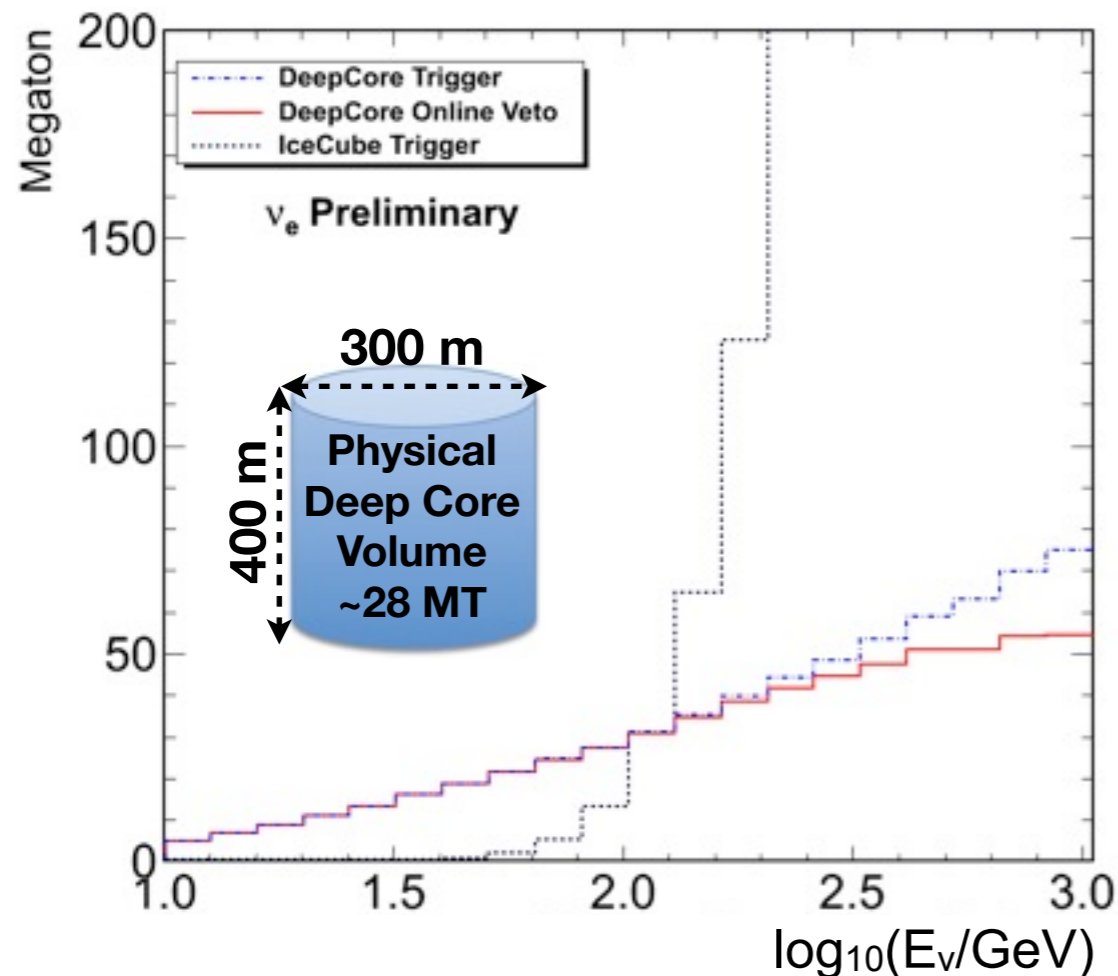
# Online Atmospheric Muon Veto



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

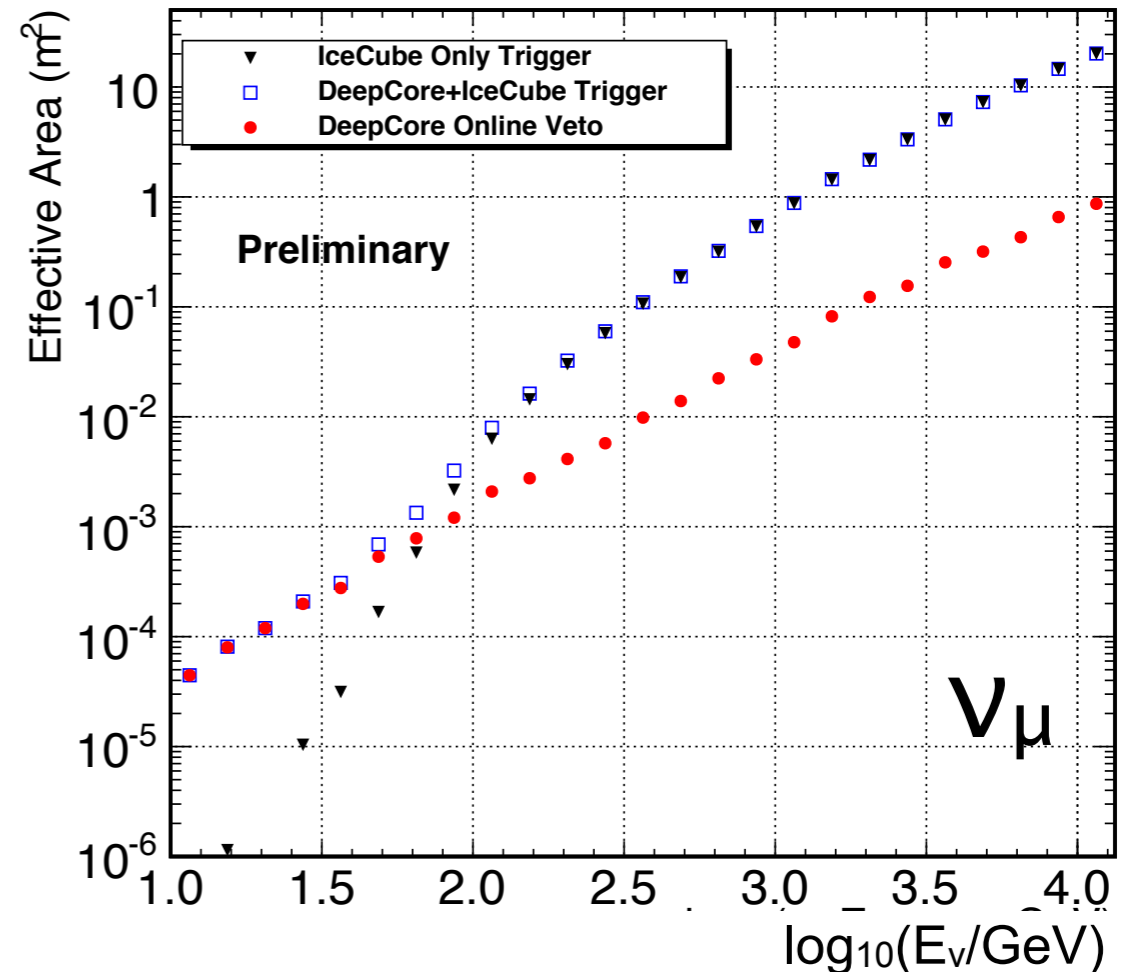
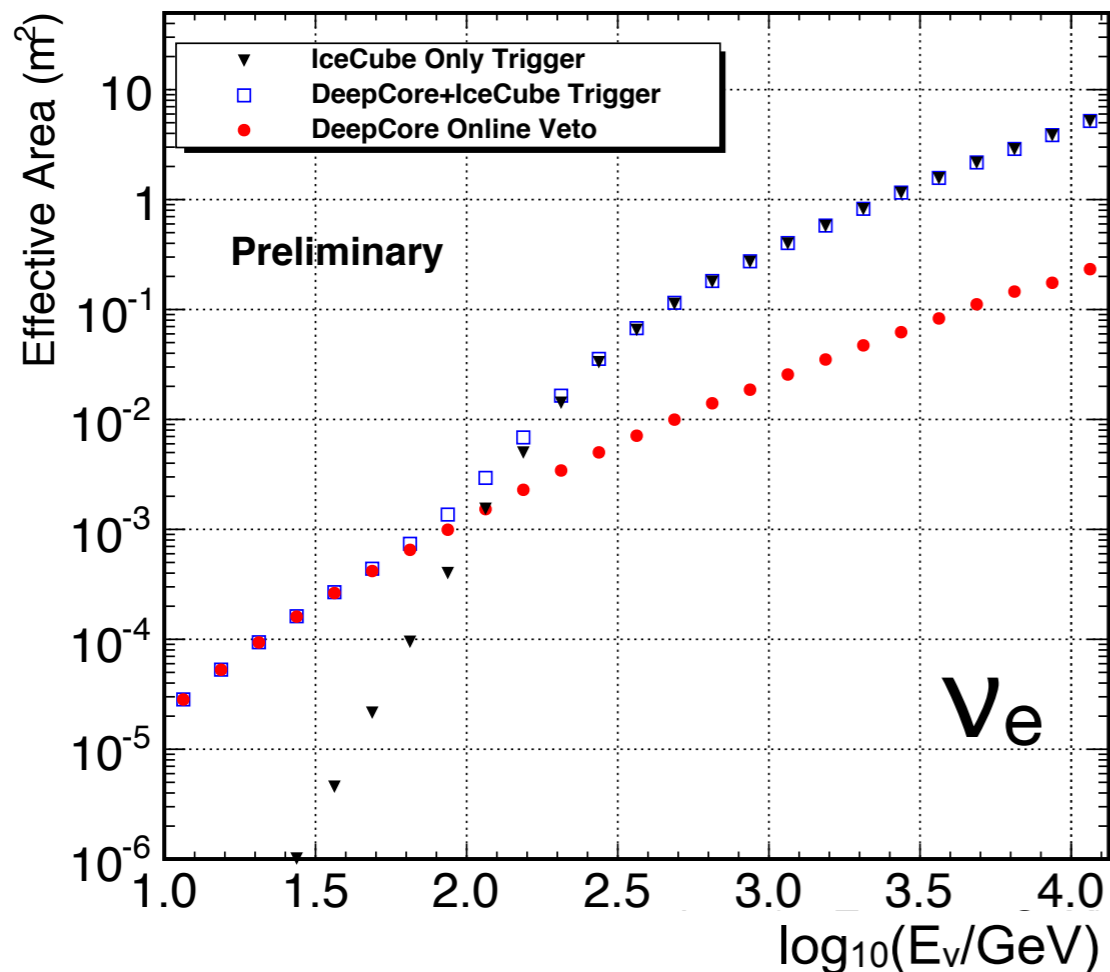


# DeepCore Lepton Effective Volume



- DeepCore is triggered by 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

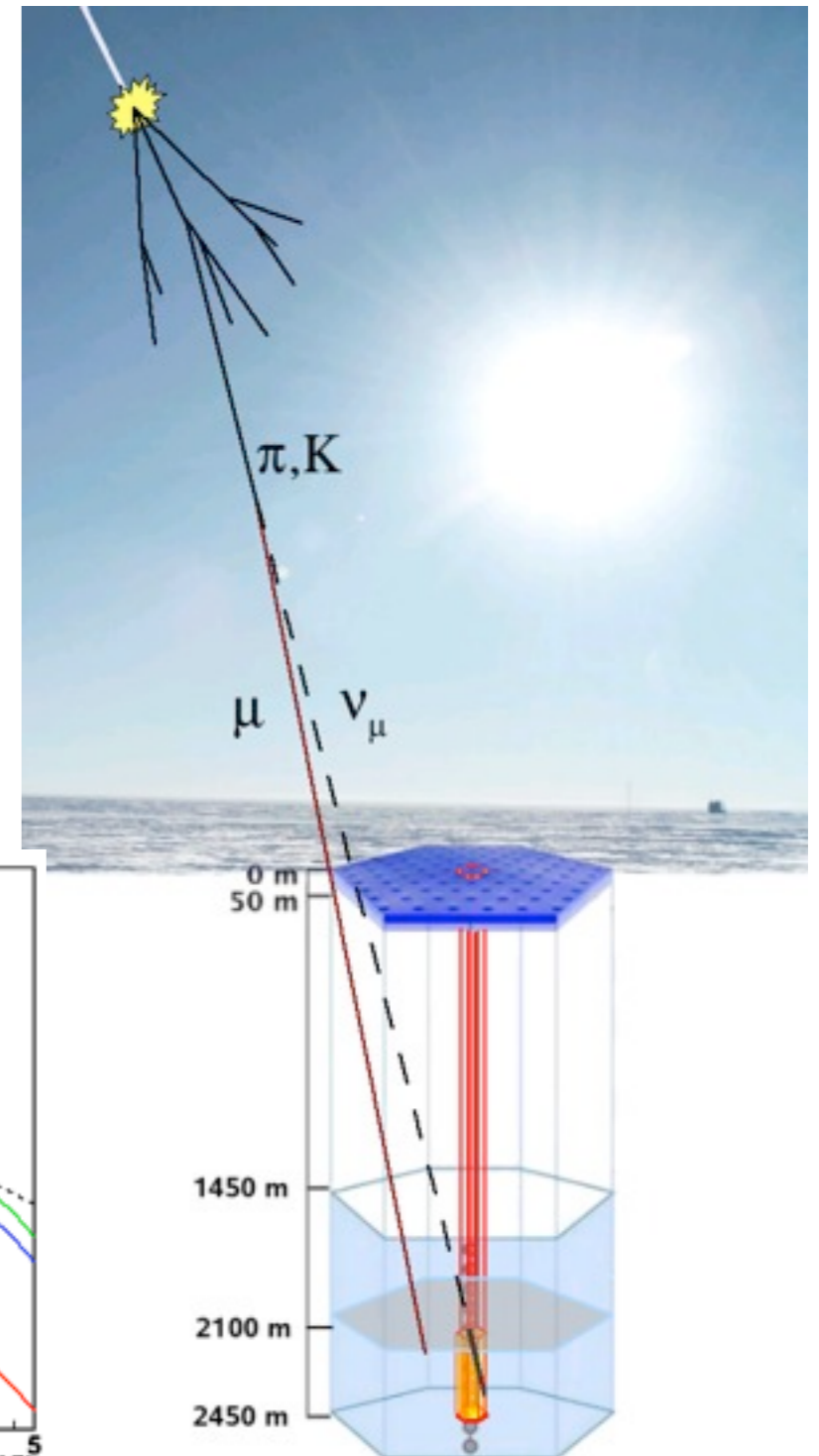
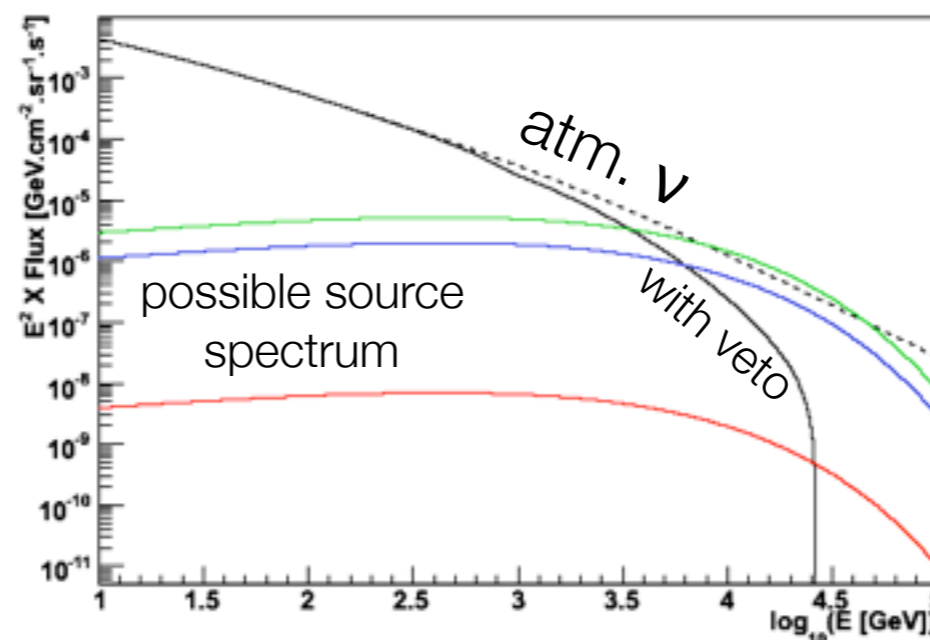
# DeepCore Neutrino Effective Area



- DeepCore dominates total response for  $E_\nu$  below 50-100 GeV, depending on flavor
  - Significant contribution below  $\sim 200$  GeV, despite much smaller volume
  - Linear trend reflects neutrino interaction cross section, not detector efficiency

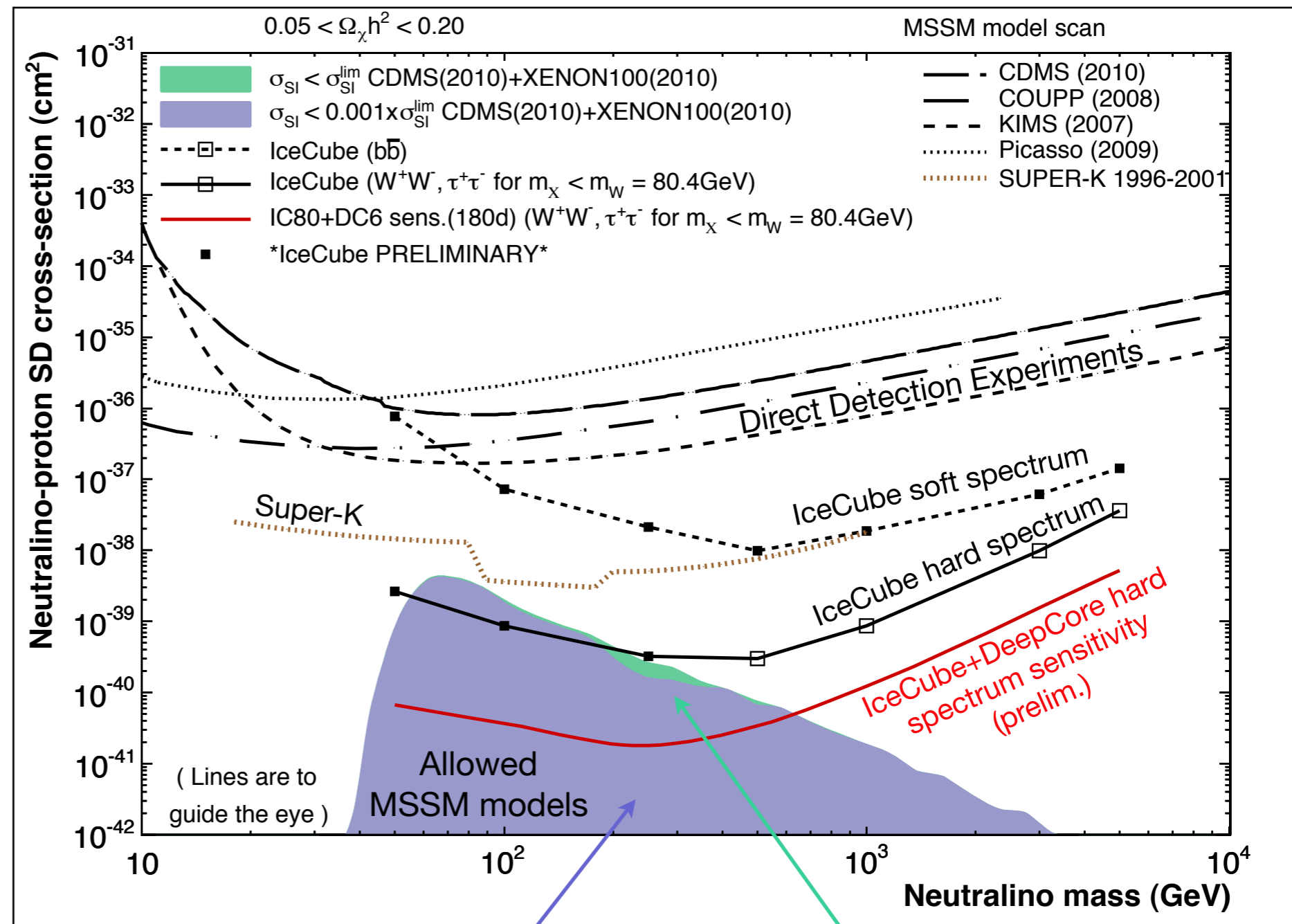
# Neutrino Astronomy with DeepCore

- 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



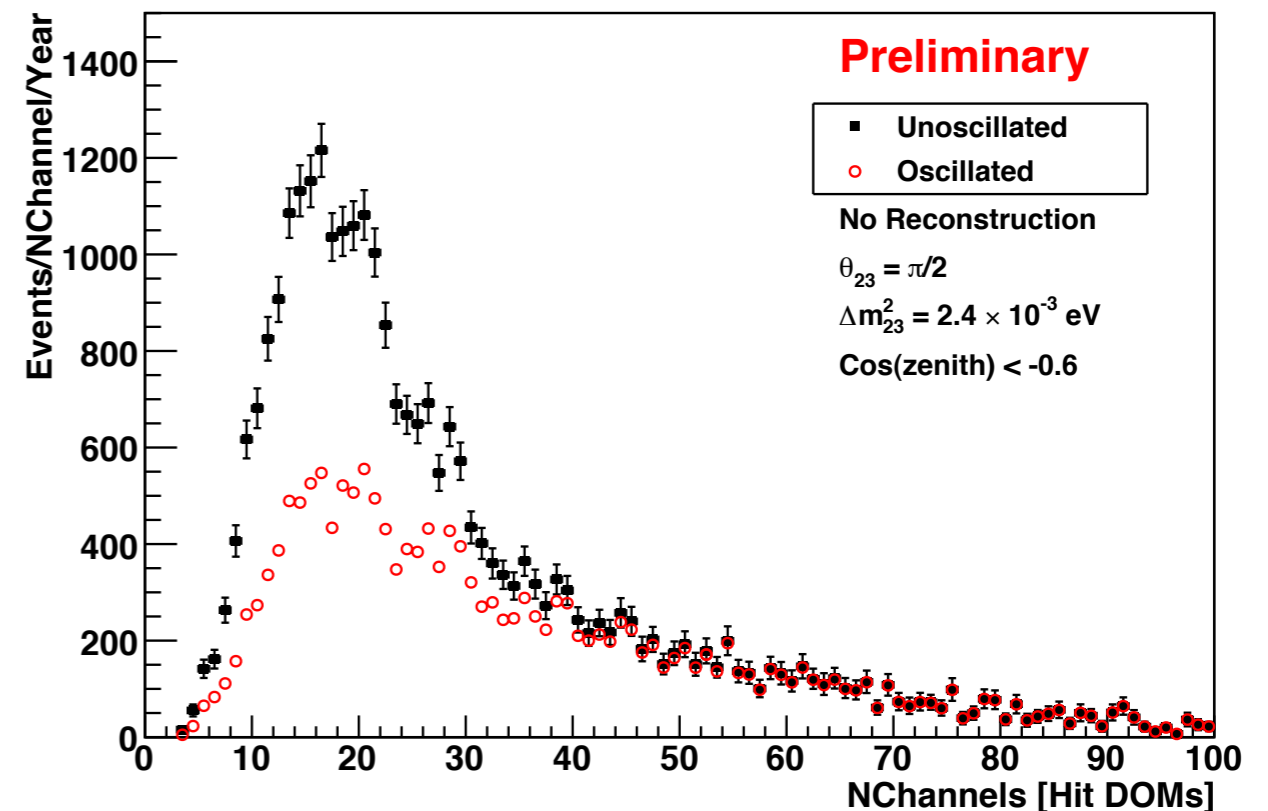
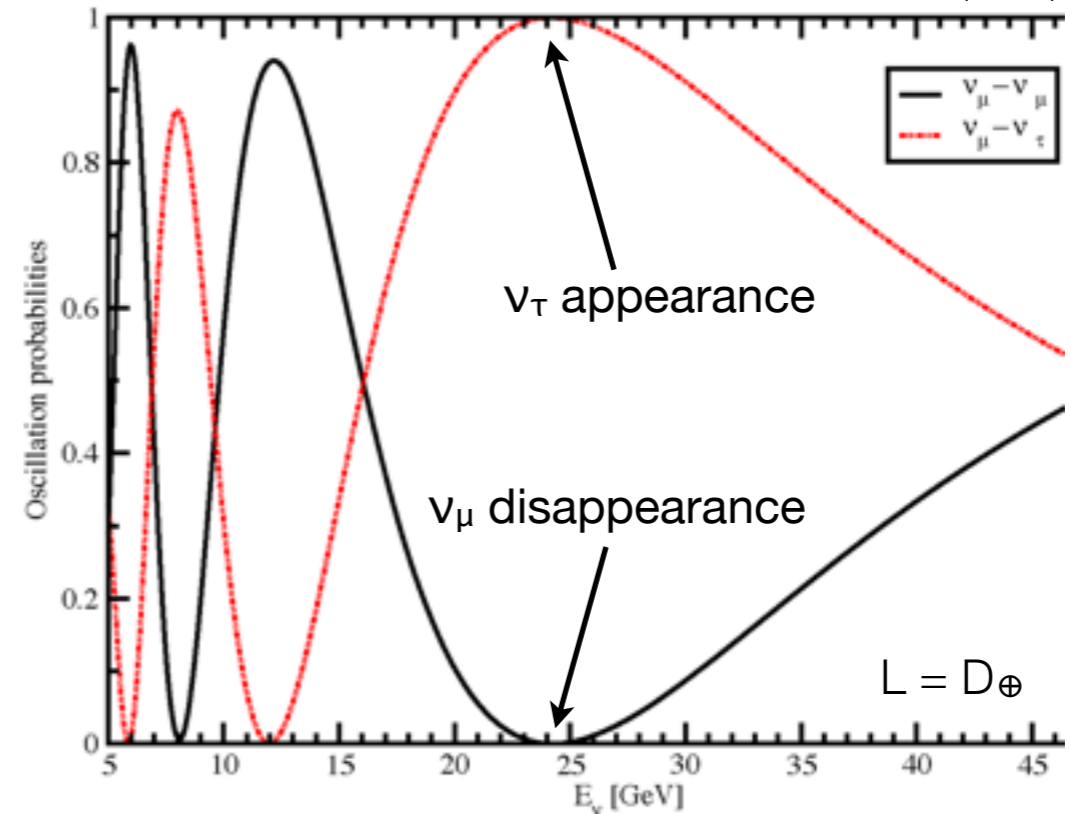
Corresponding  $\sigma_{\text{SI}}$  more than factor  $10^3$  beyond current direct limits

Corresponding  $\sigma_{\text{SI}}$  within factor  $10^3$  of current direct limits

# Neutrino Oscillations

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

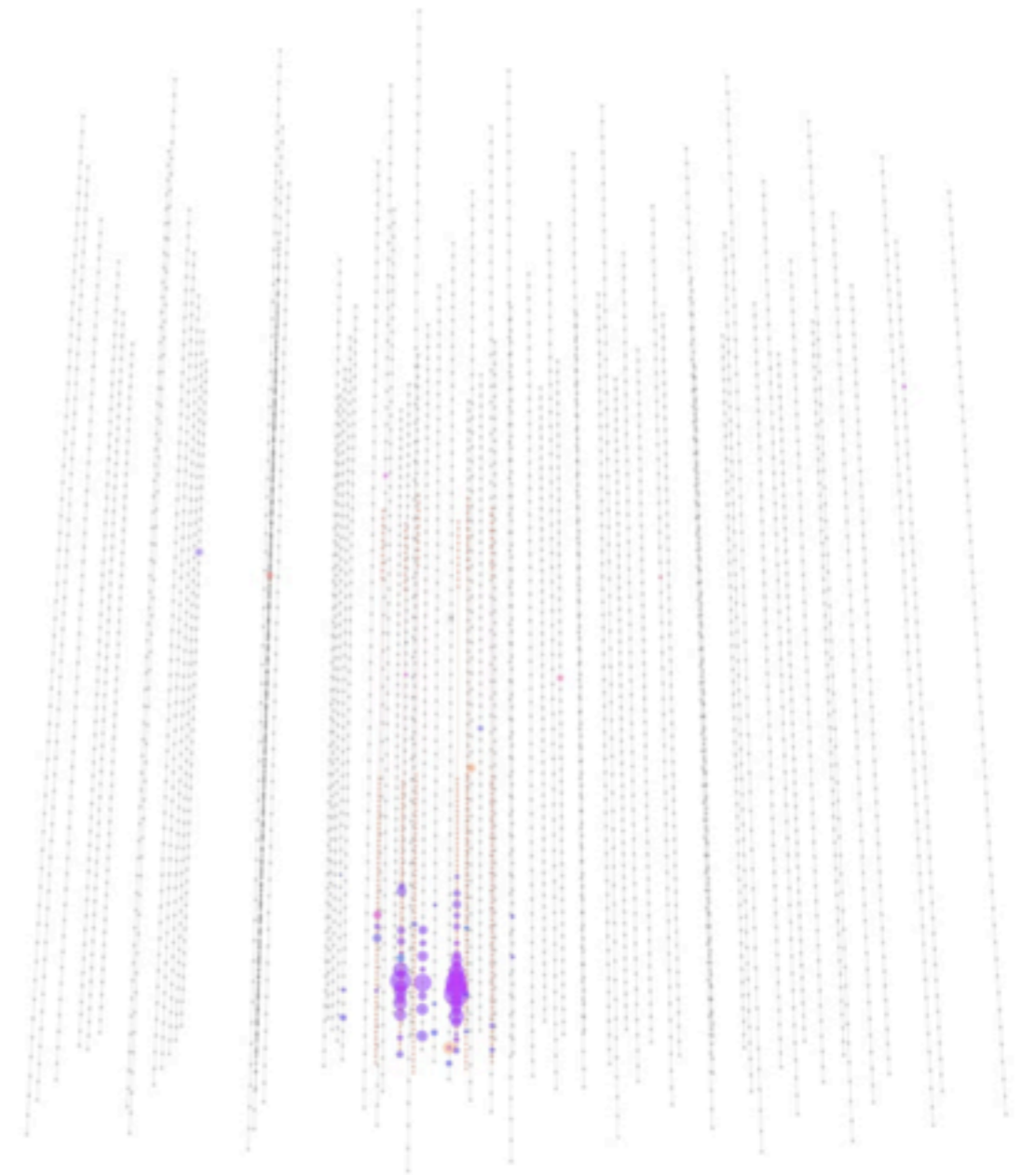
Mena, Mocioiu & Razzaque, *Phys. Rev. D* **78**, 093003 (2008)



# Observation of Neutrino Cascades (Preliminary)

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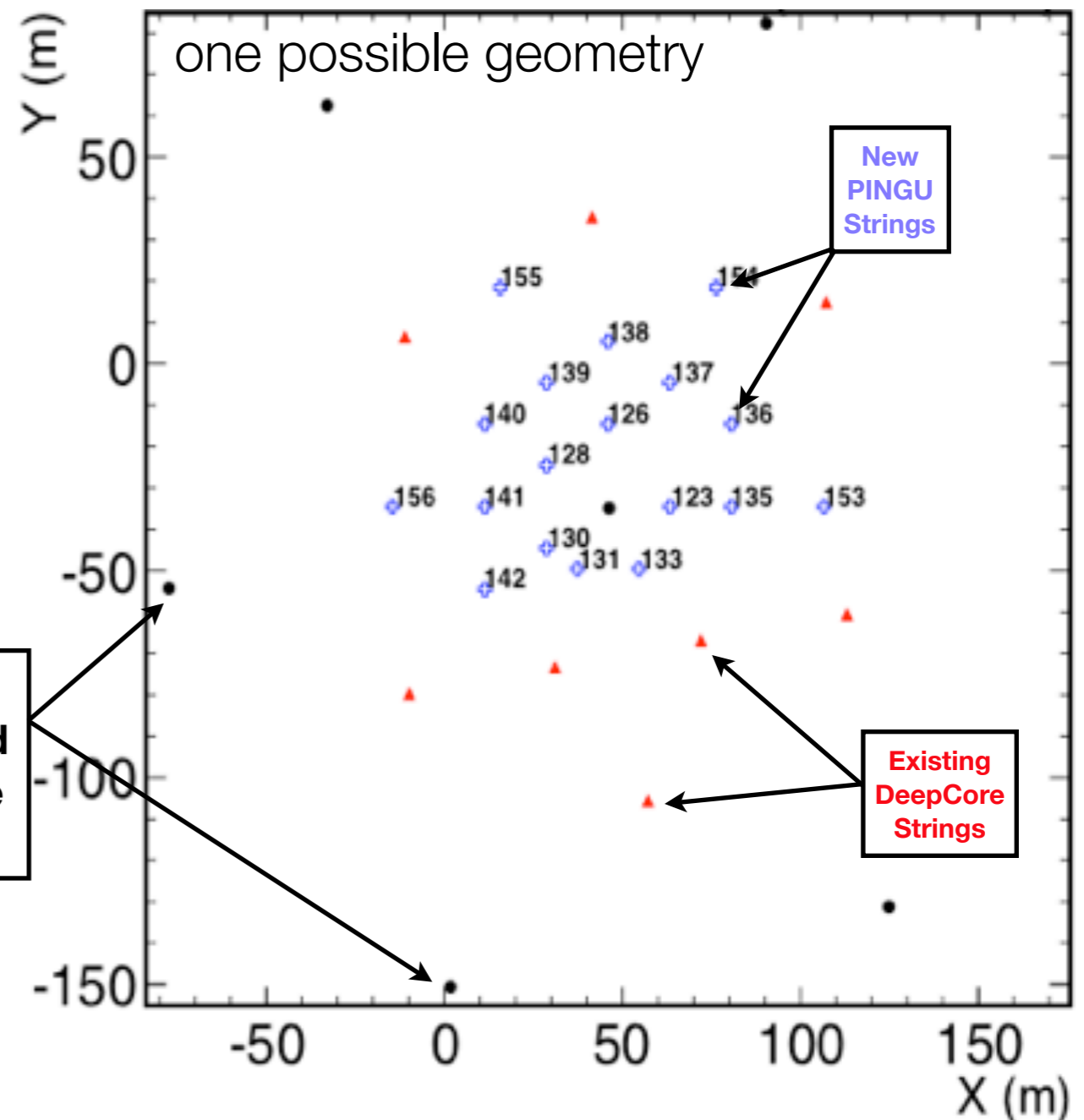
- Disappearing  $\nu_\mu$  should appear in IceCube as  $\nu_\tau$  cascades
  - Effectively identical to neutral current or  $\nu_e$  CC events
  - Could observe  $\nu_\tau$  appearance as a distortion of the energy spectrum, if cascades can be separated from muon background
- We believe we see neutrino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



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

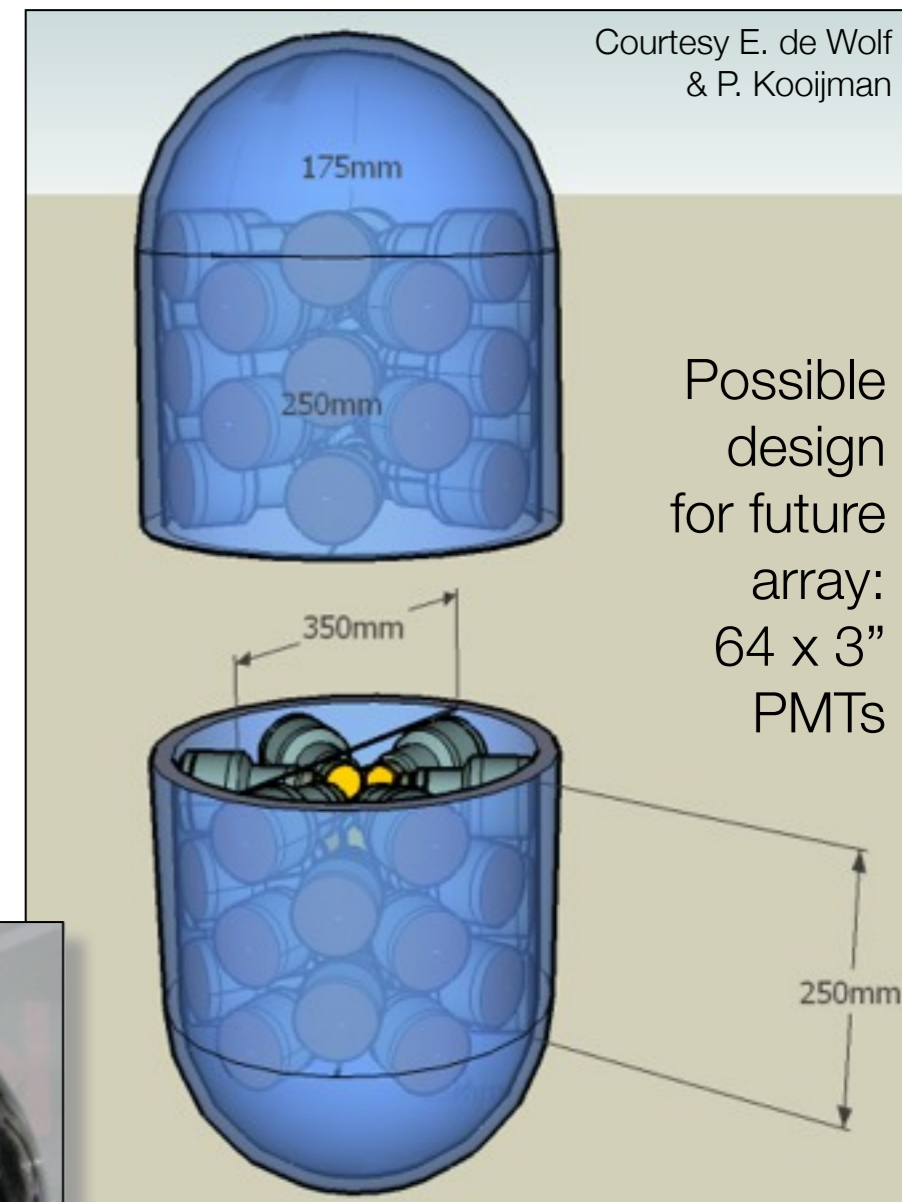
# Beyond DeepCore: PINGU

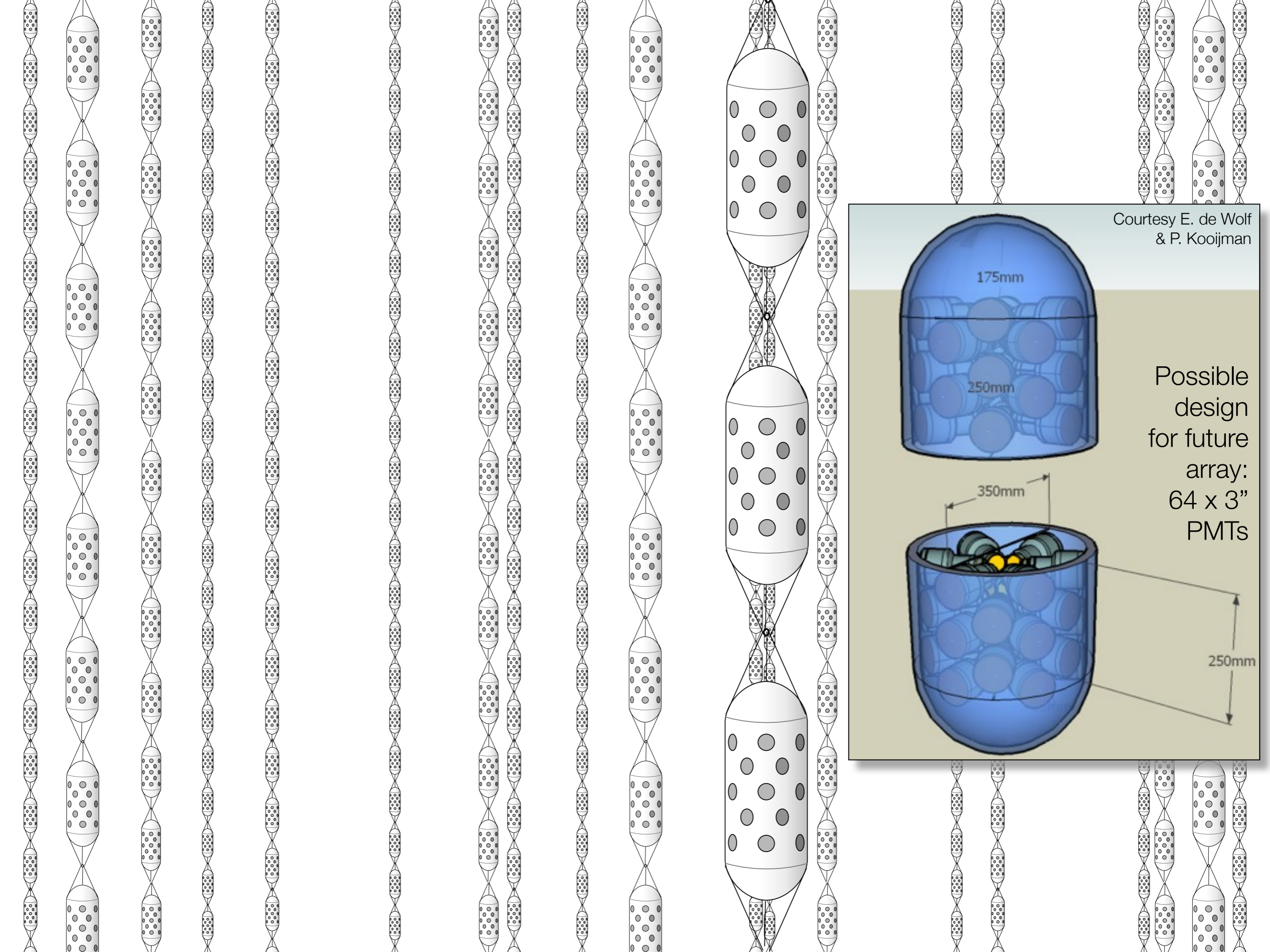
- Now developing a proposal to continue to instrument the DeepCore volume
  - An additional 18-20 strings, 1000-1200 DOMs
  - Make use of well-established IceCube drilling technology
  - Might get to a threshold of  $\sim 1$  GeV in a  $\sim 10$  Mton volume
  - Also an R&D platform for future detectors on a  $\sim$ decade timeline
- Price tag expected to be around \$20M



# 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?





# Conclusions

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- 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  $\sim 10$  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?