

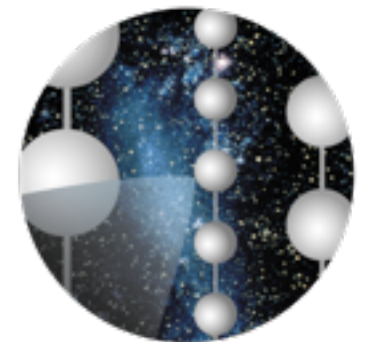
Particle Physics in Ice with IceCube DeepCore

PENNSTATE



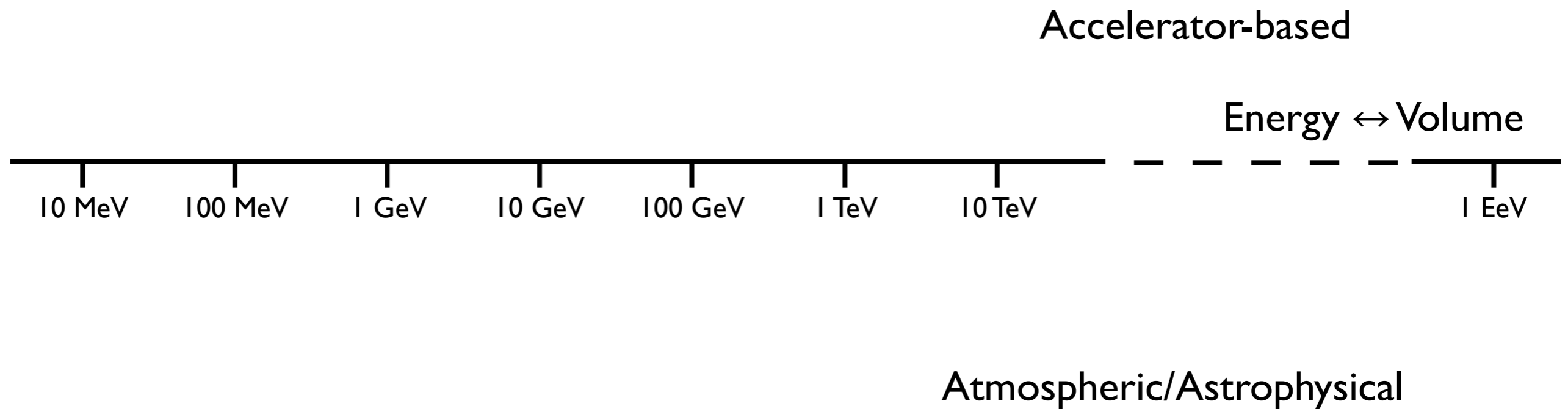
Tyce DeYoung
Department of Physics
Pennsylvania State University
for the IceCube Collaboration

RICAP '11
Rome, Italy
May 25, 2011

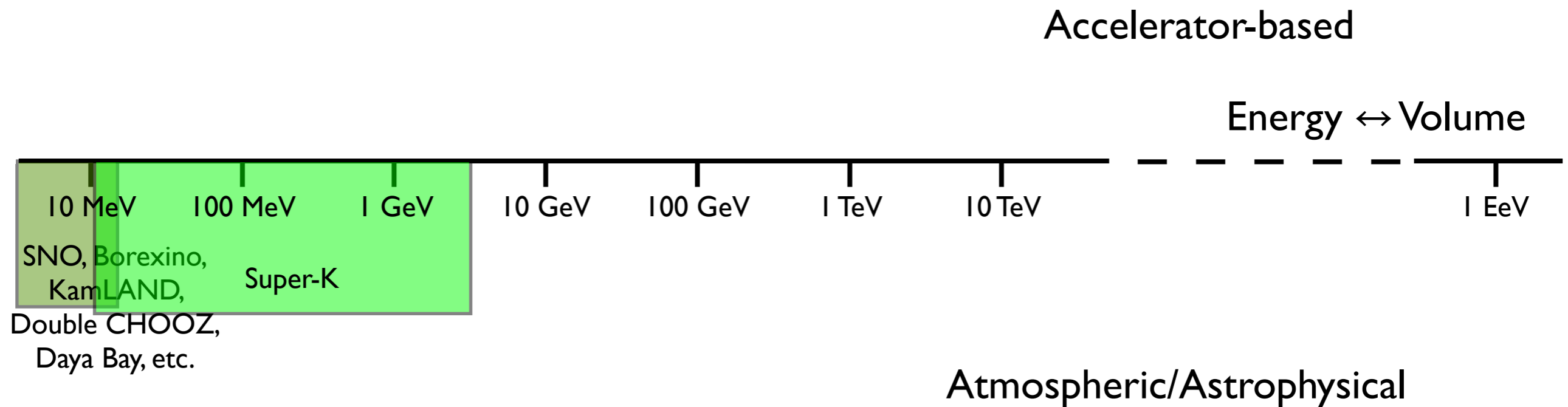


I c e C u b e

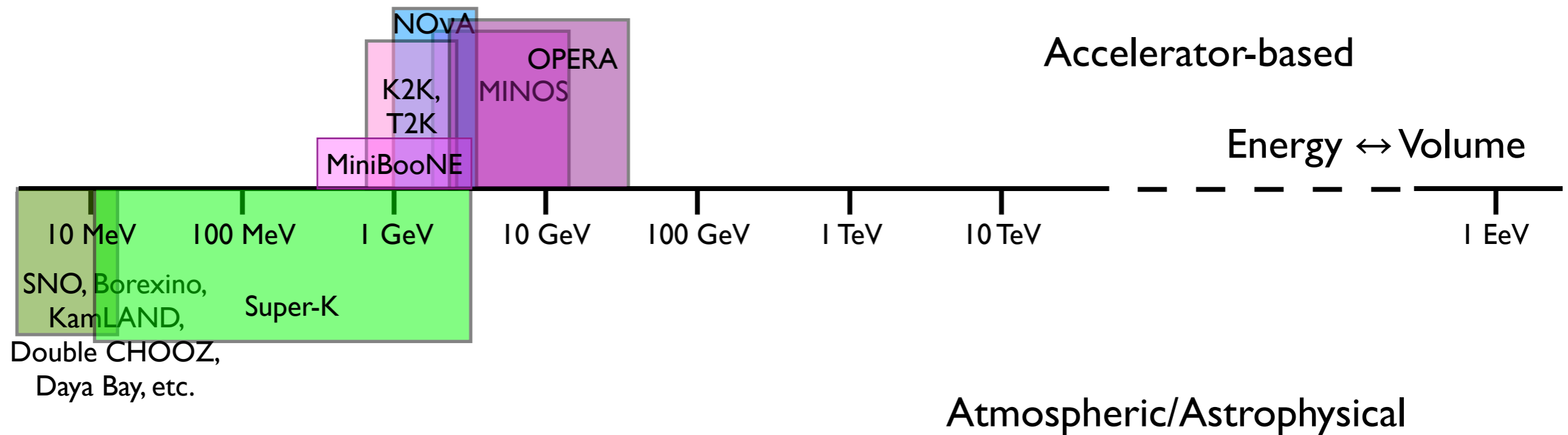
The Neutrino Detector Spectrum



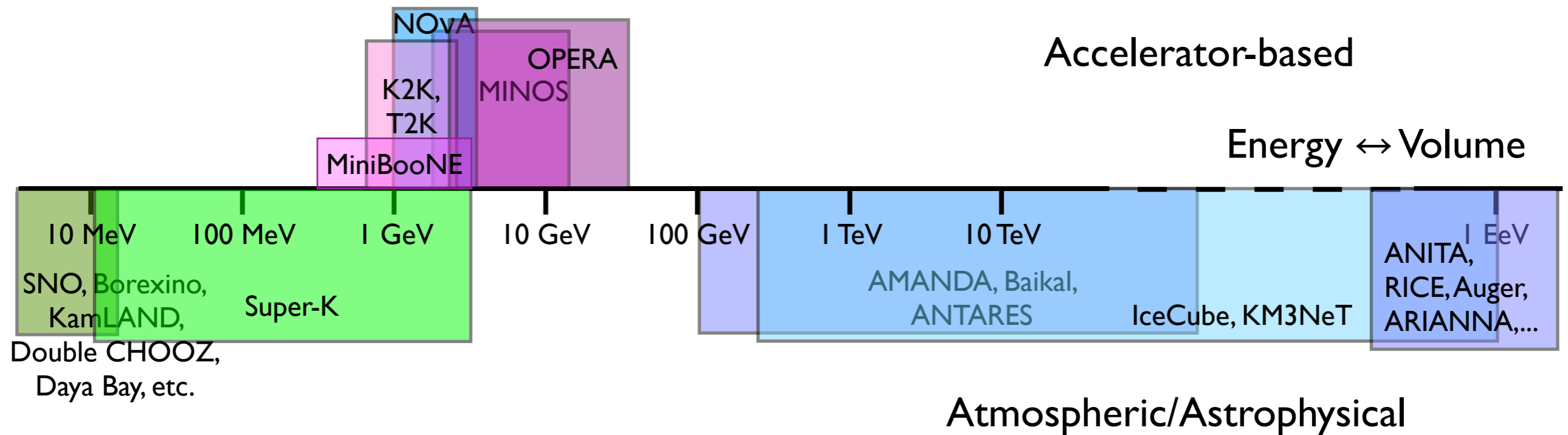
The Neutrino Detector Spectrum



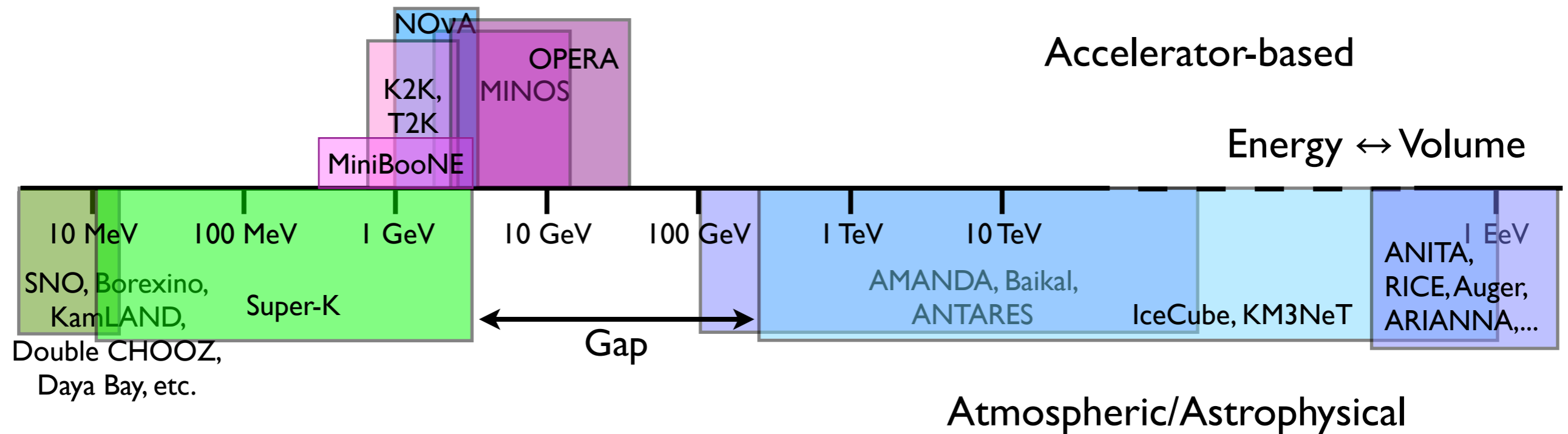
The Neutrino Detector Spectrum



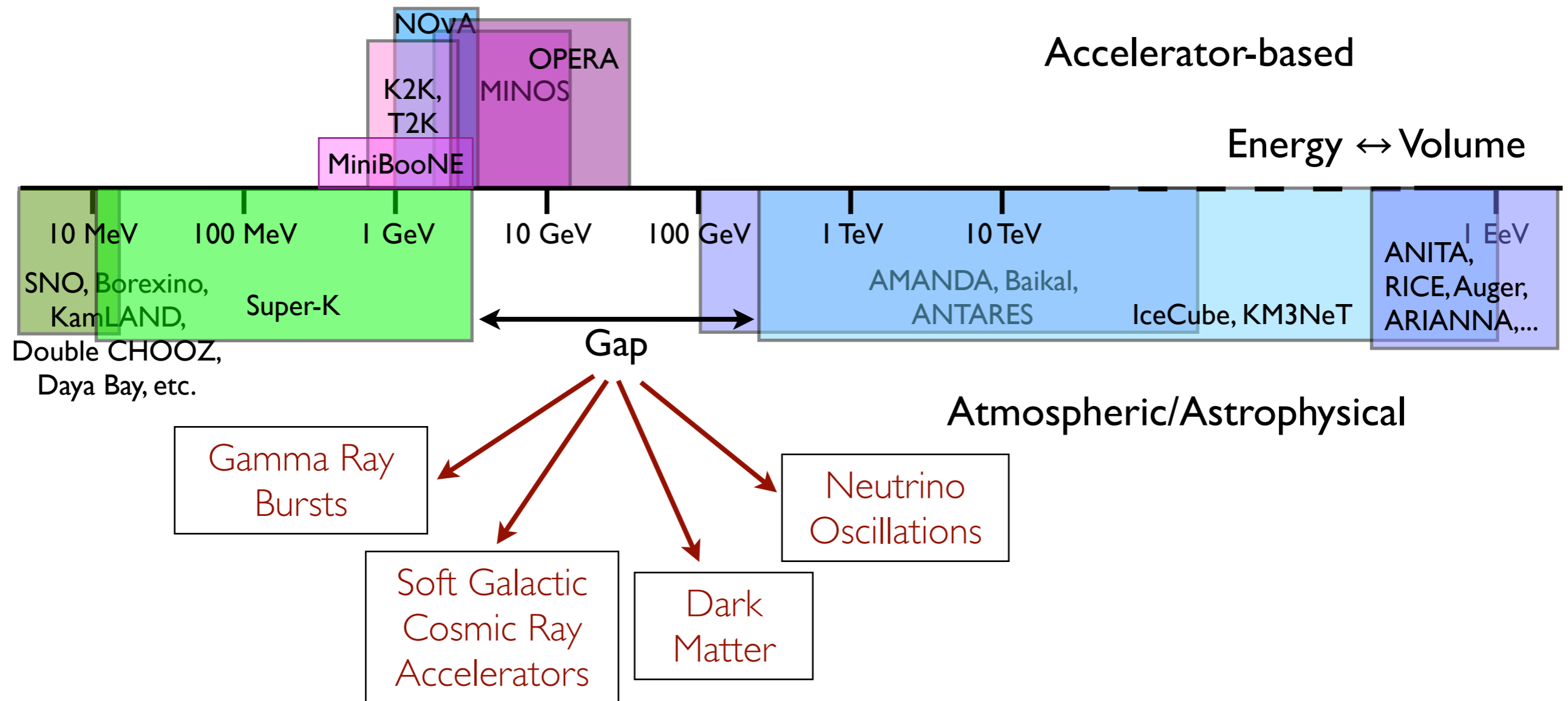
The Neutrino Detector Spectrum



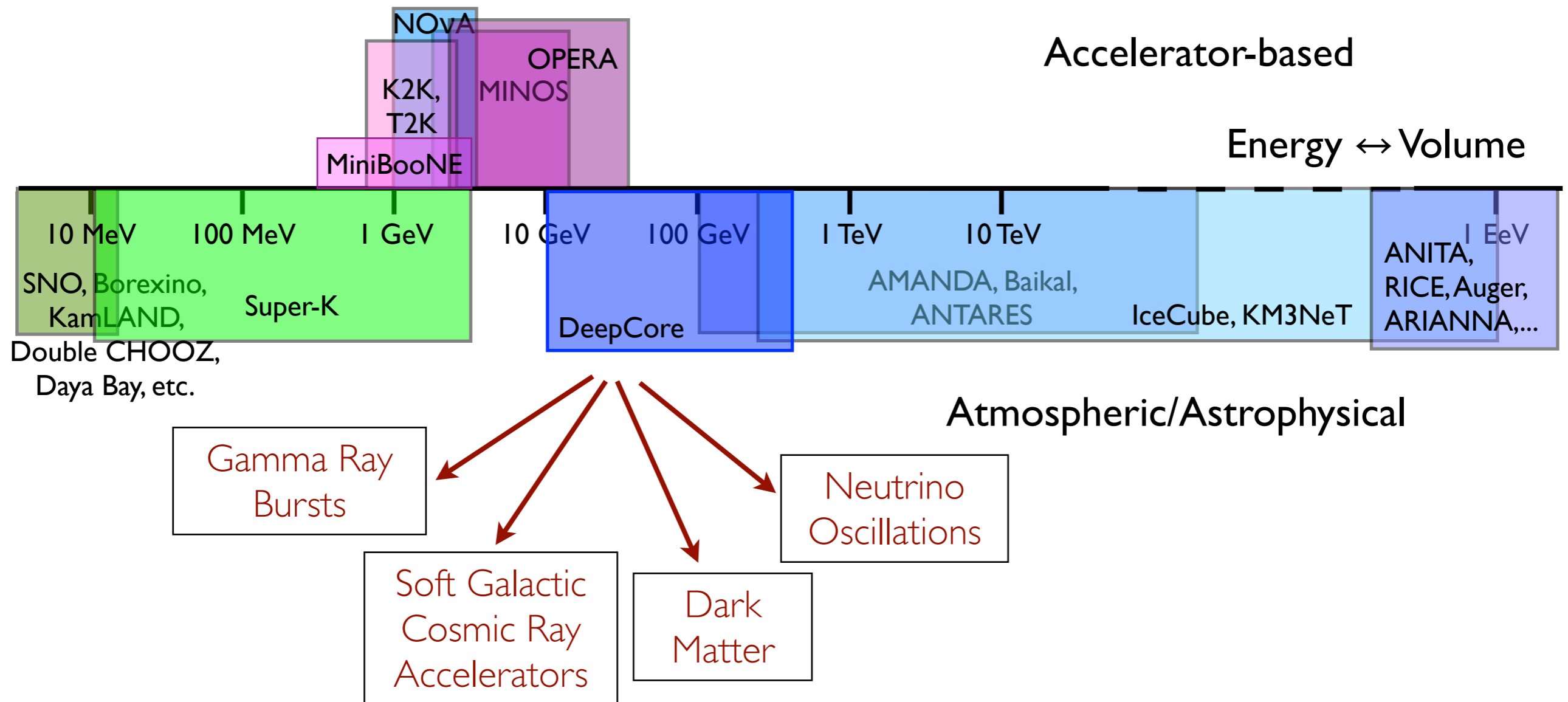
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The Neutrino Detector Spectrum



The Neutrino Detector Spectrum

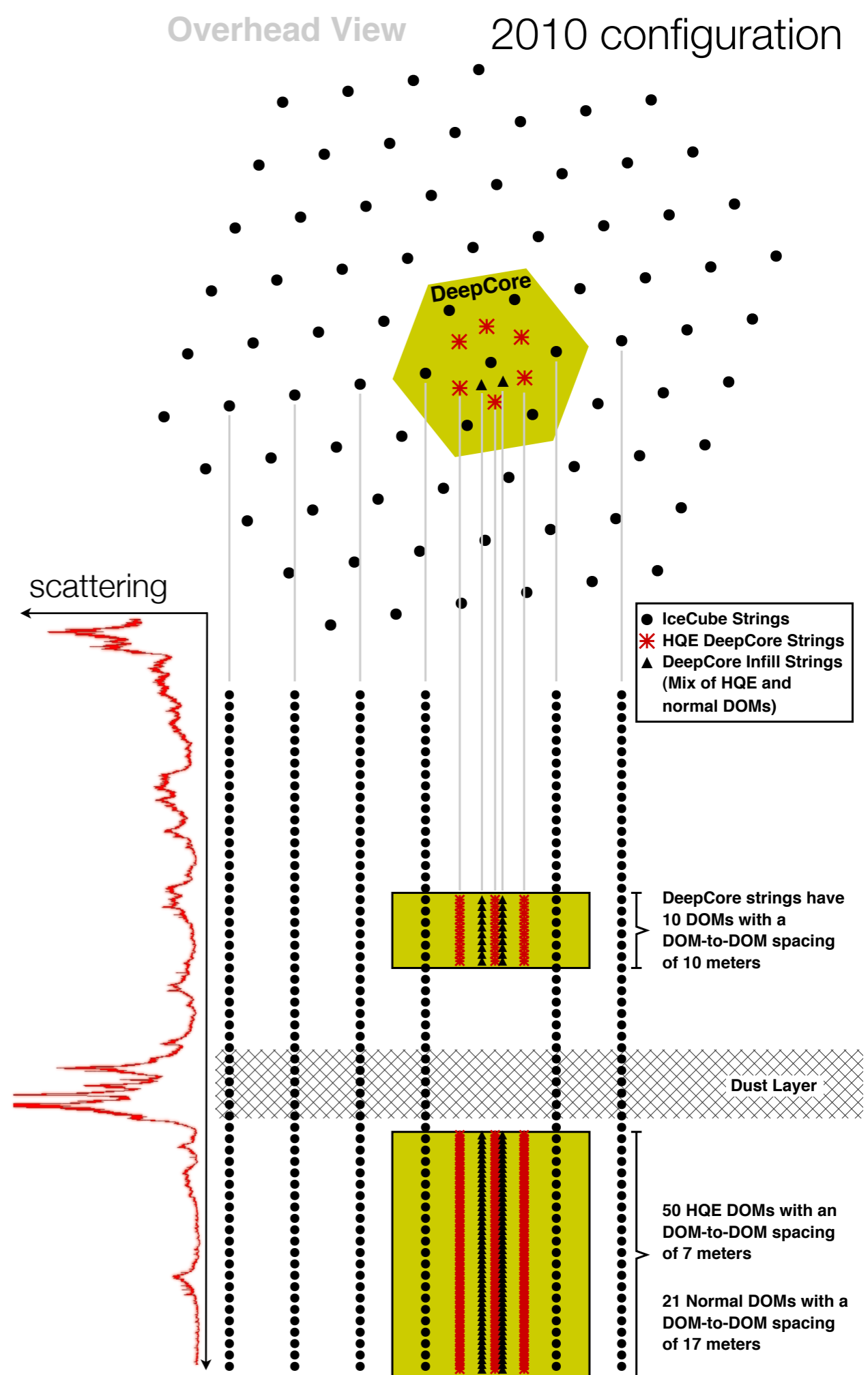
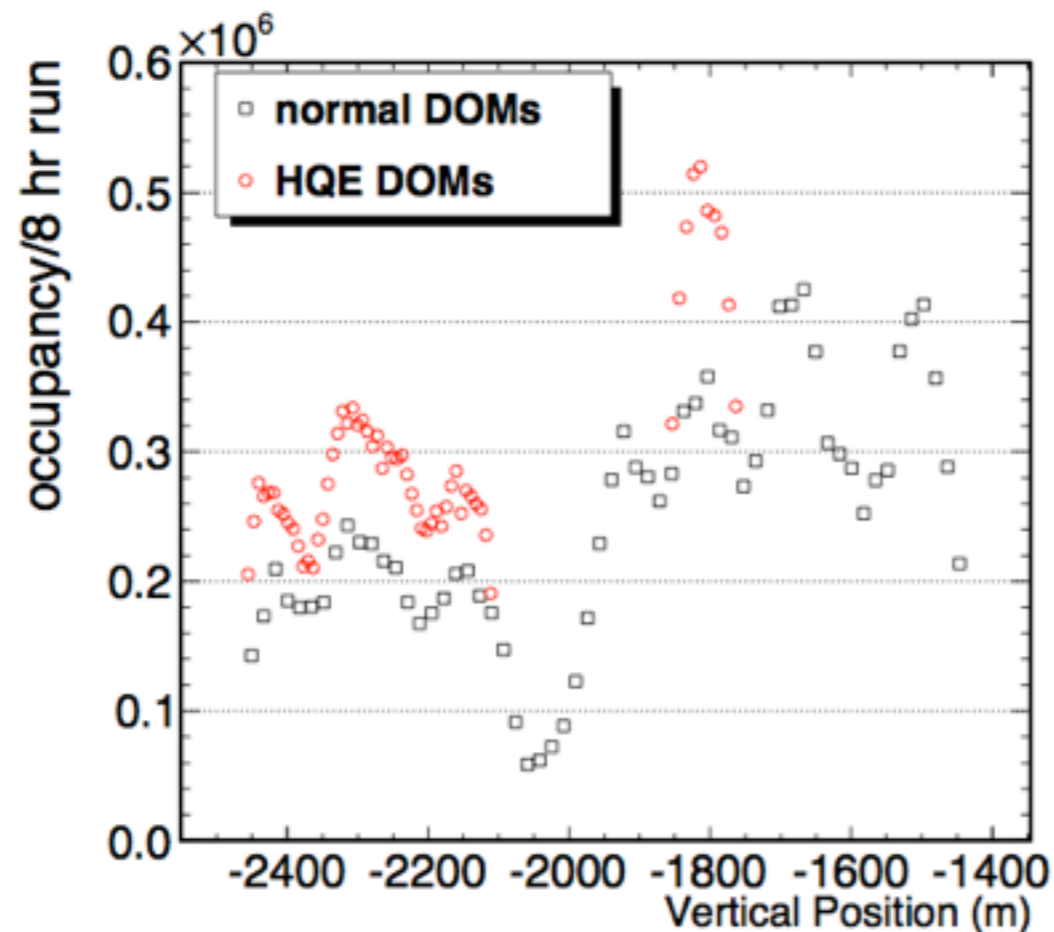


IceCube DeepCore

- 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)

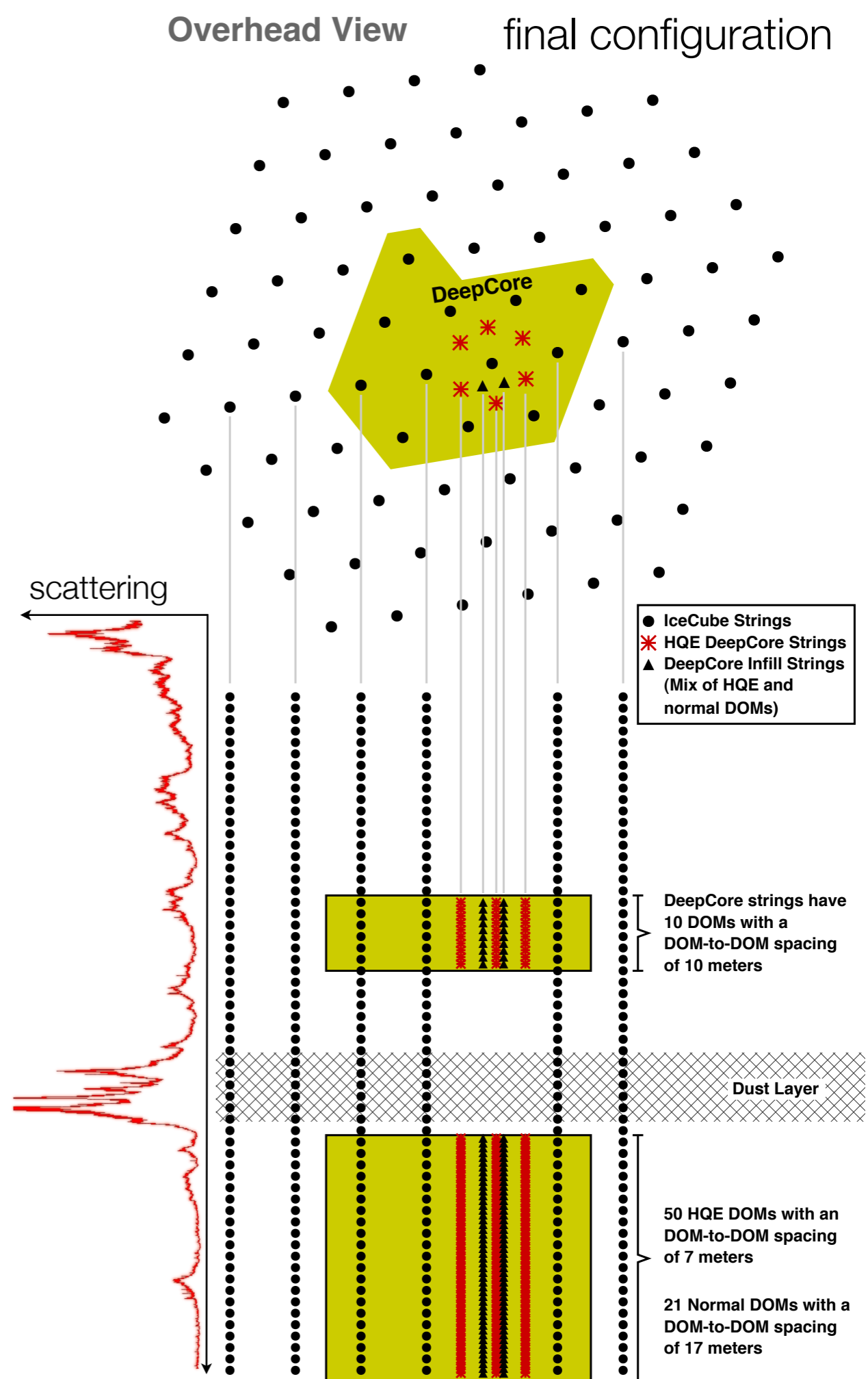
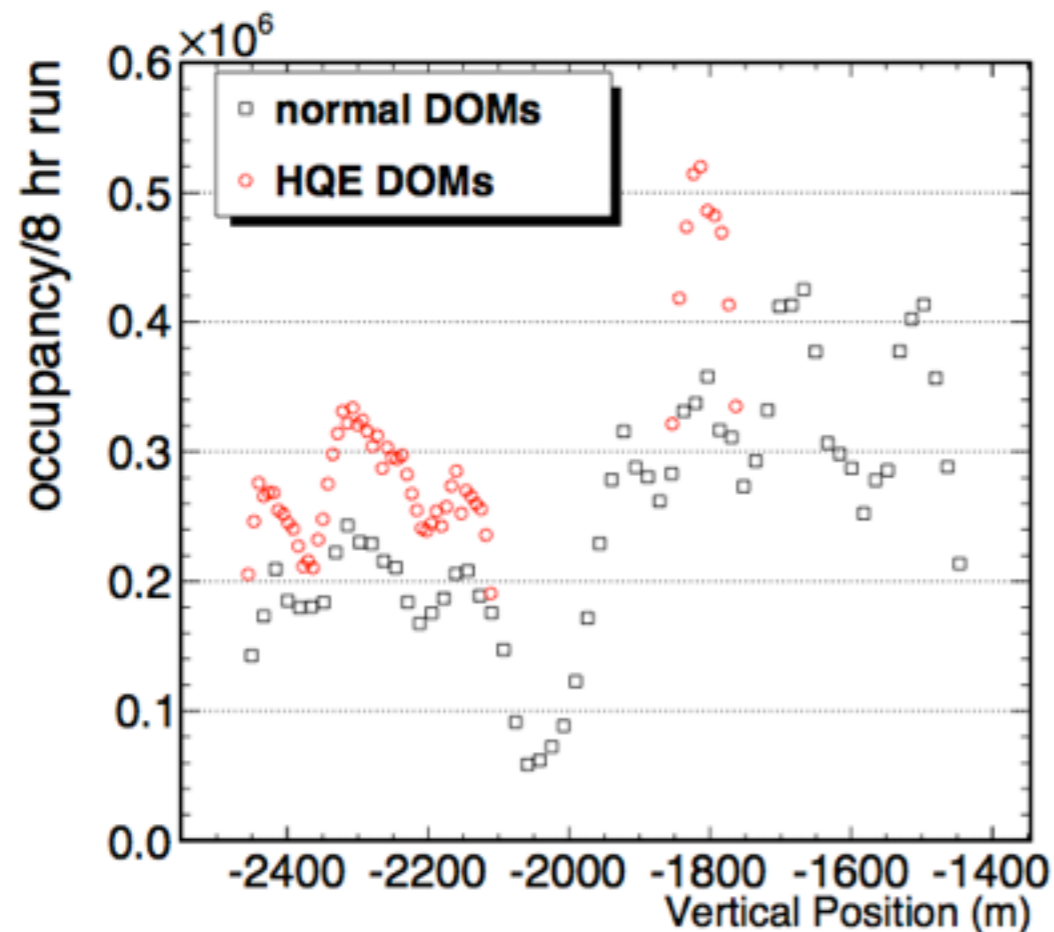
IceCube DeepCore

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

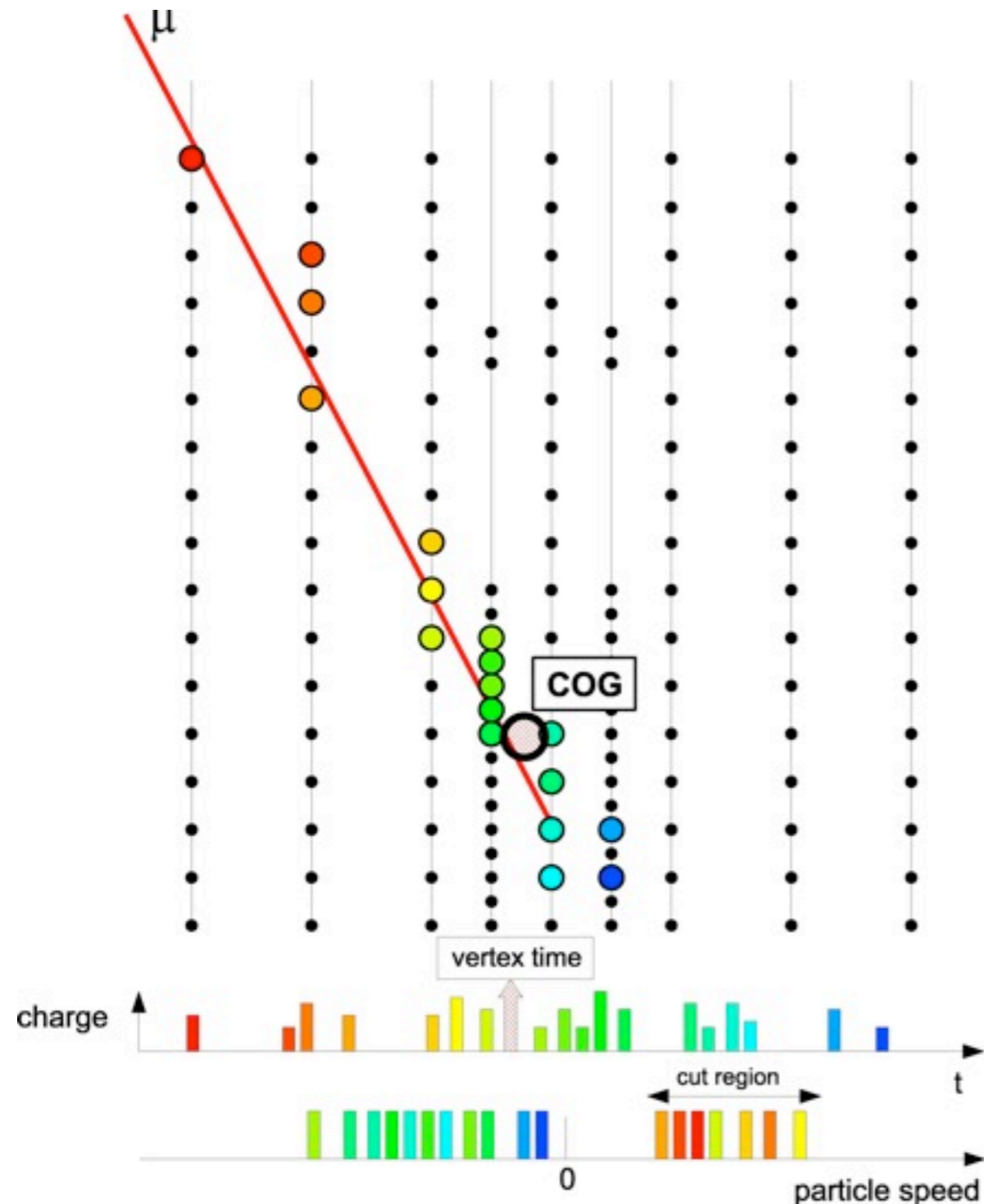


IceCube DeepCore

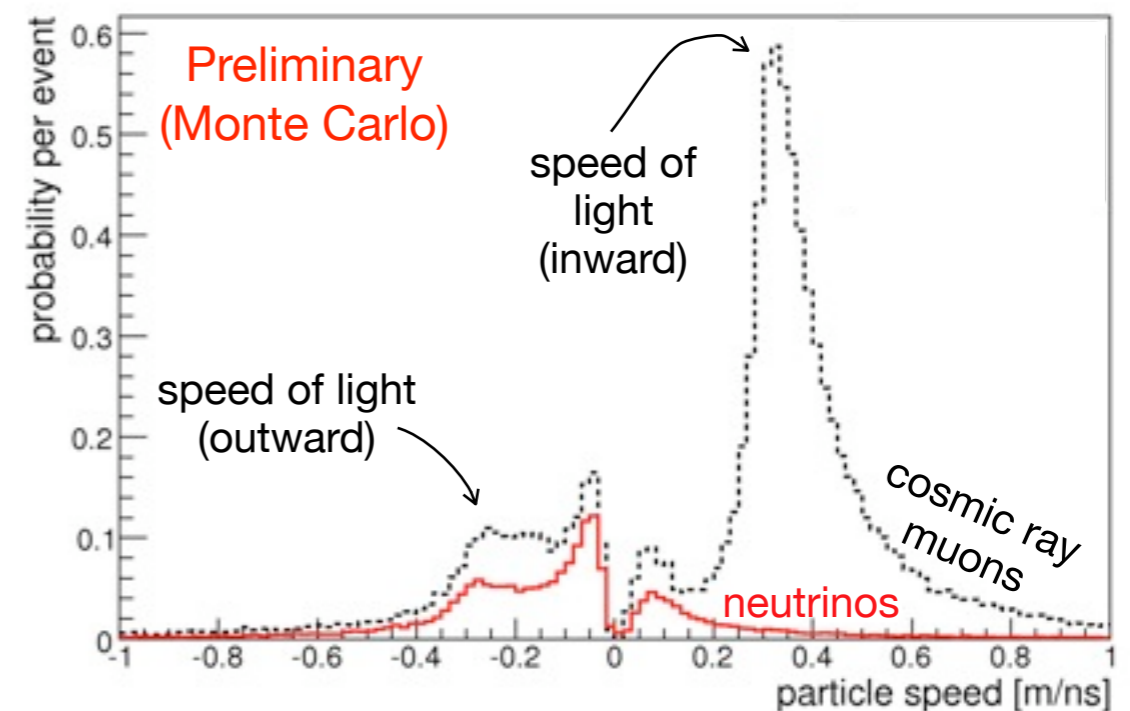
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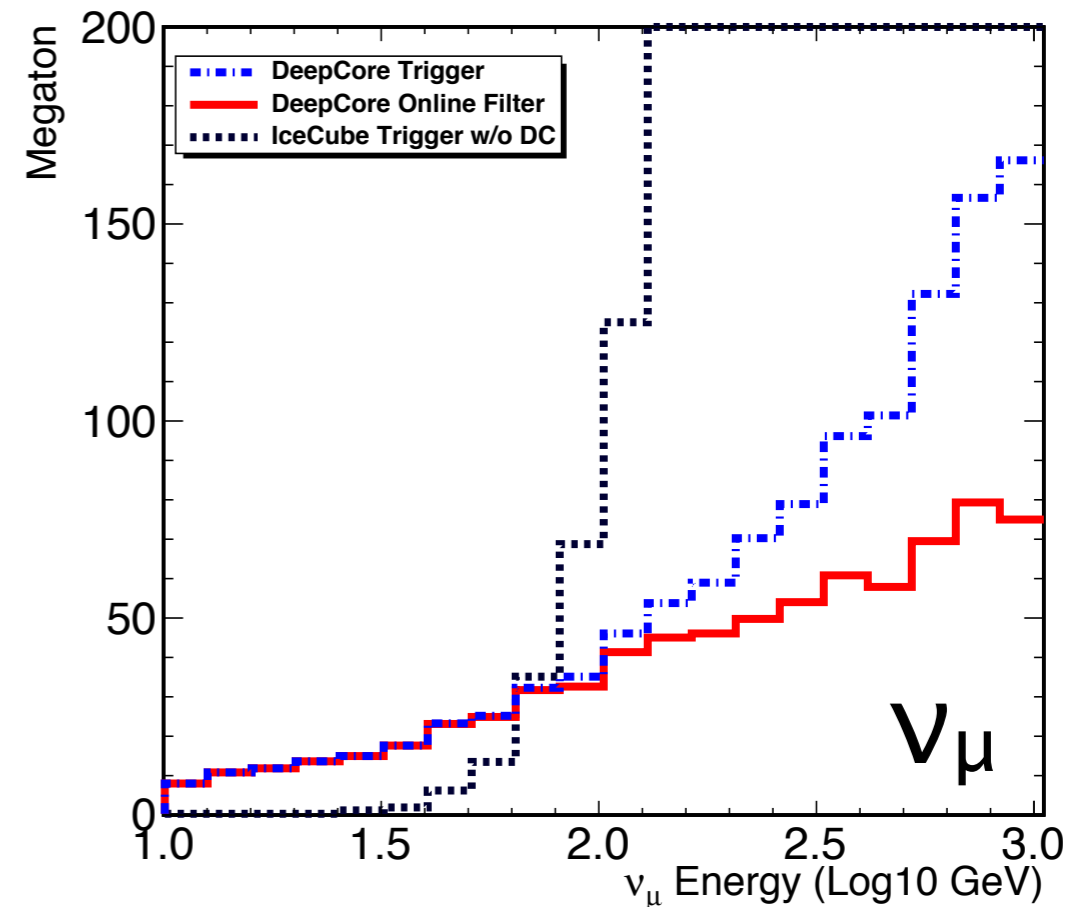
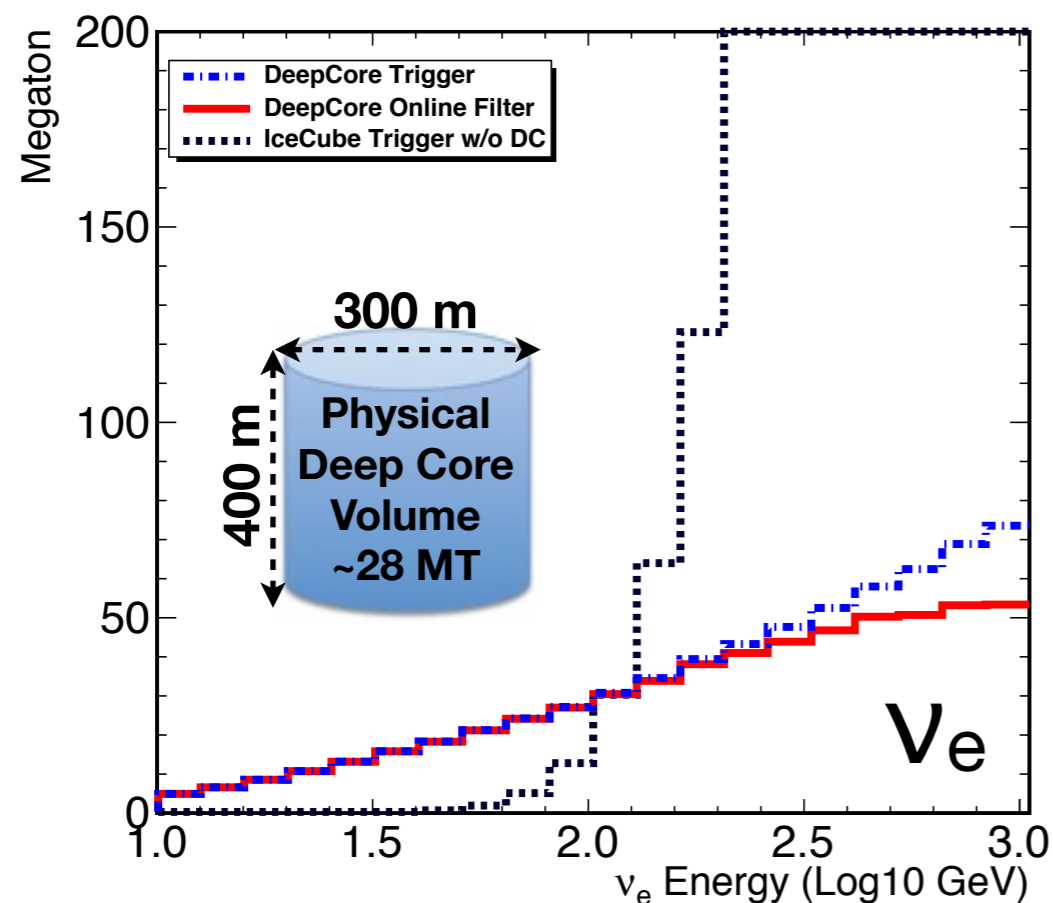
Online Atmospheric Muon Veto



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

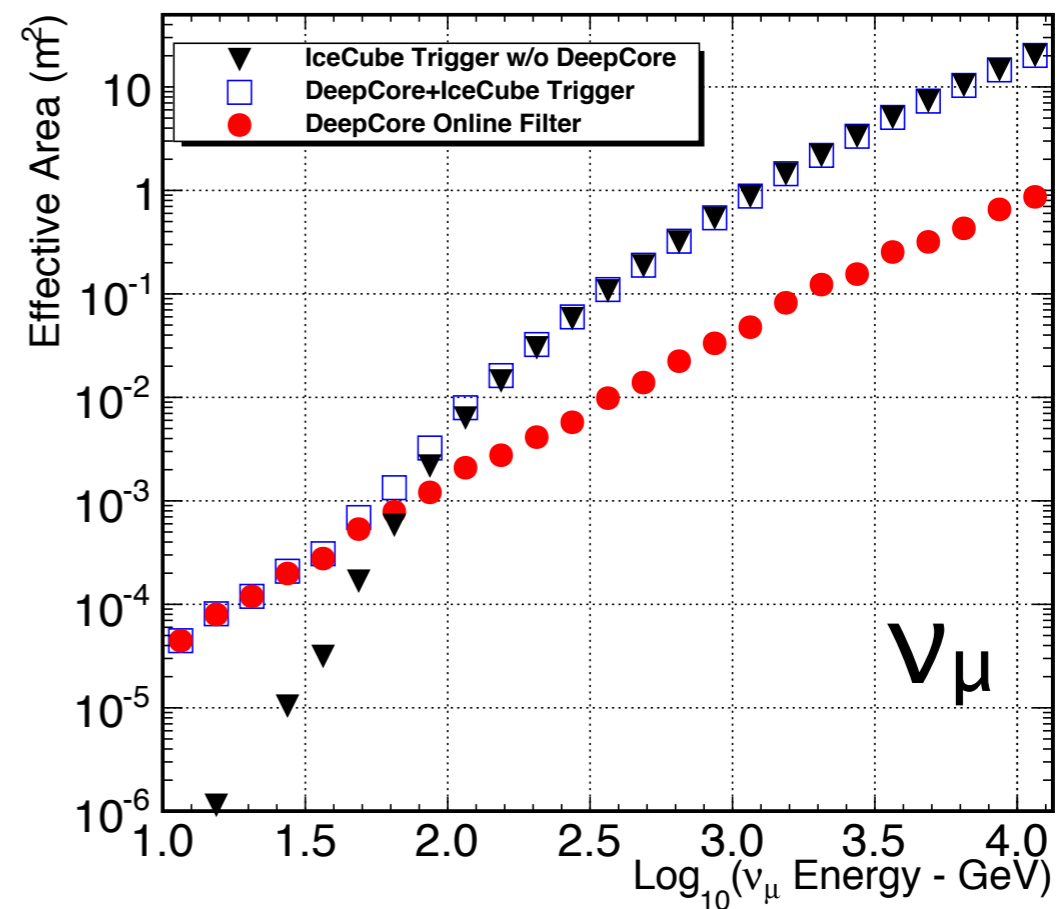
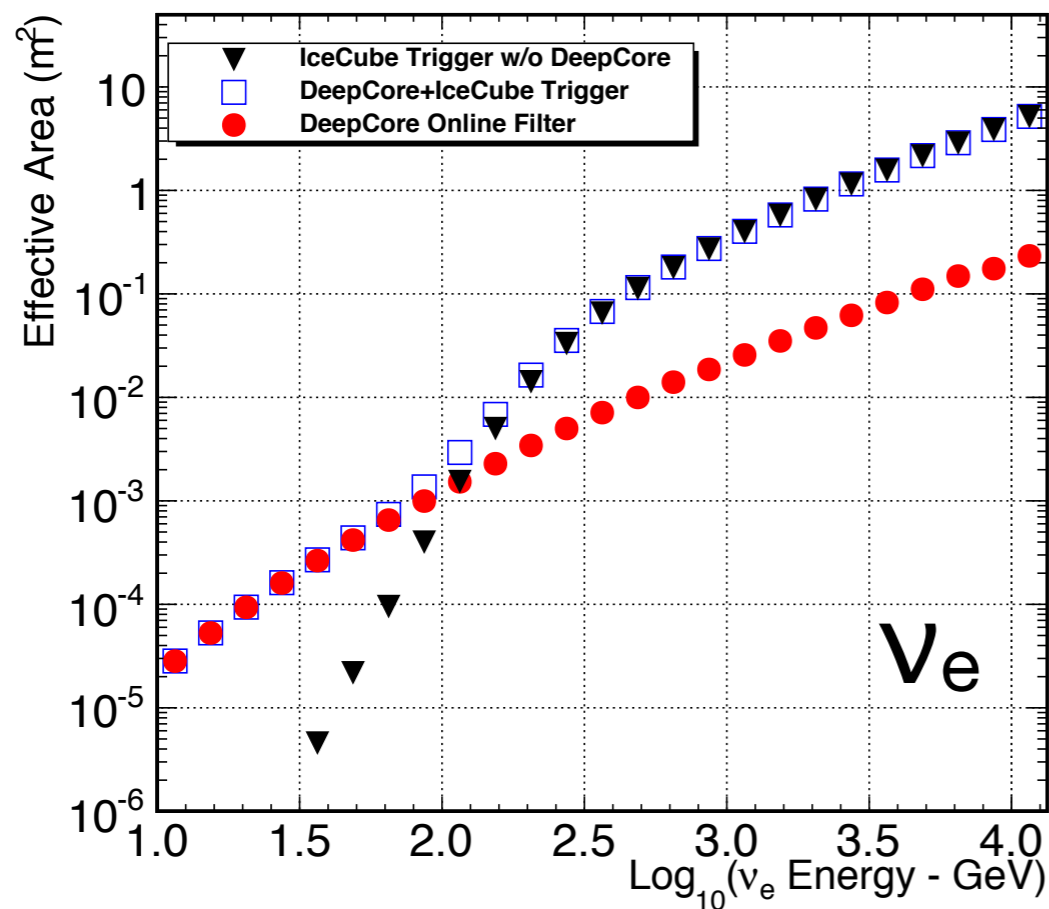


DeepCore Lepton Effective Volume



- 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

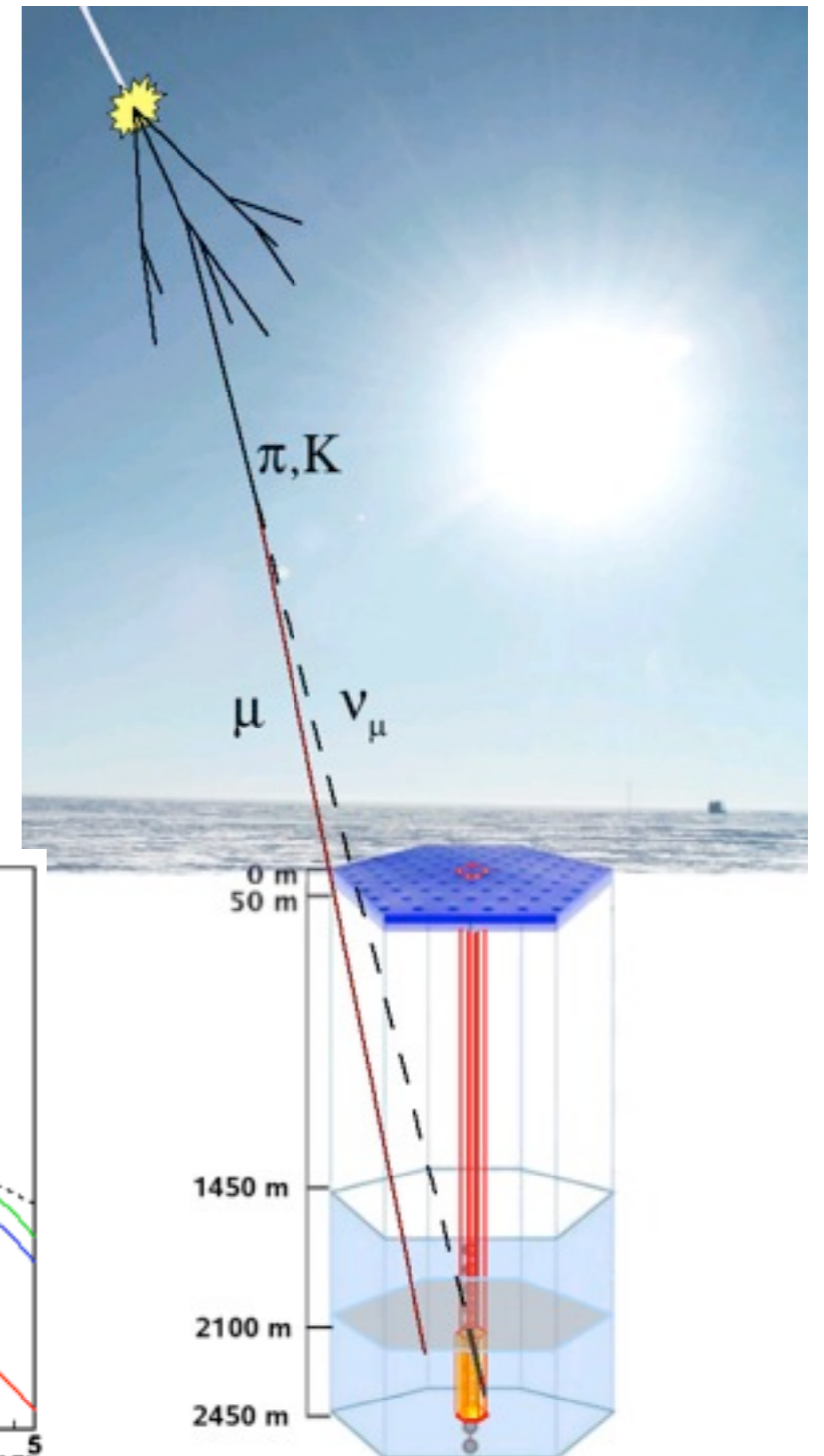
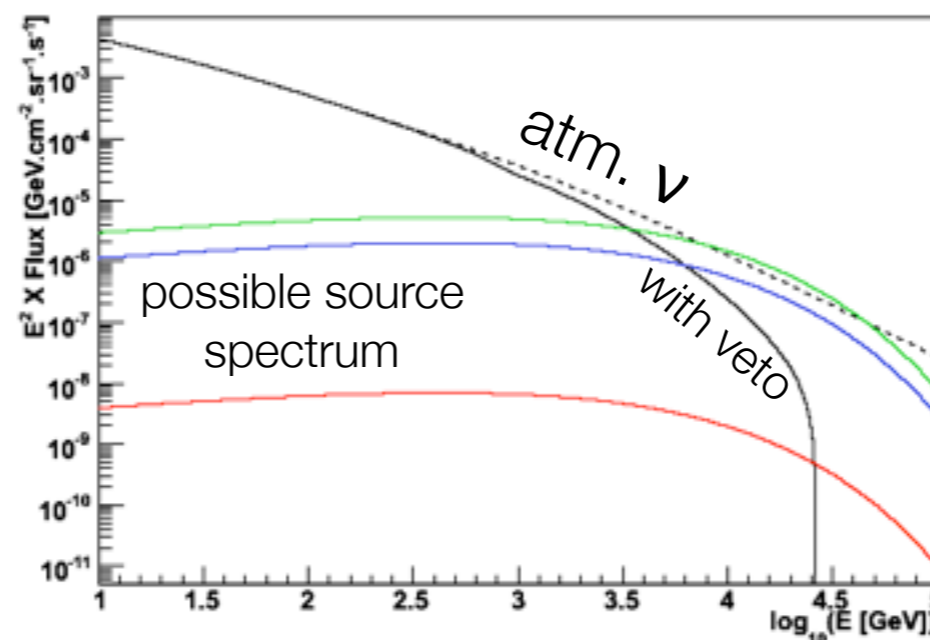
DeepCore Neutrino Effective Area



- 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

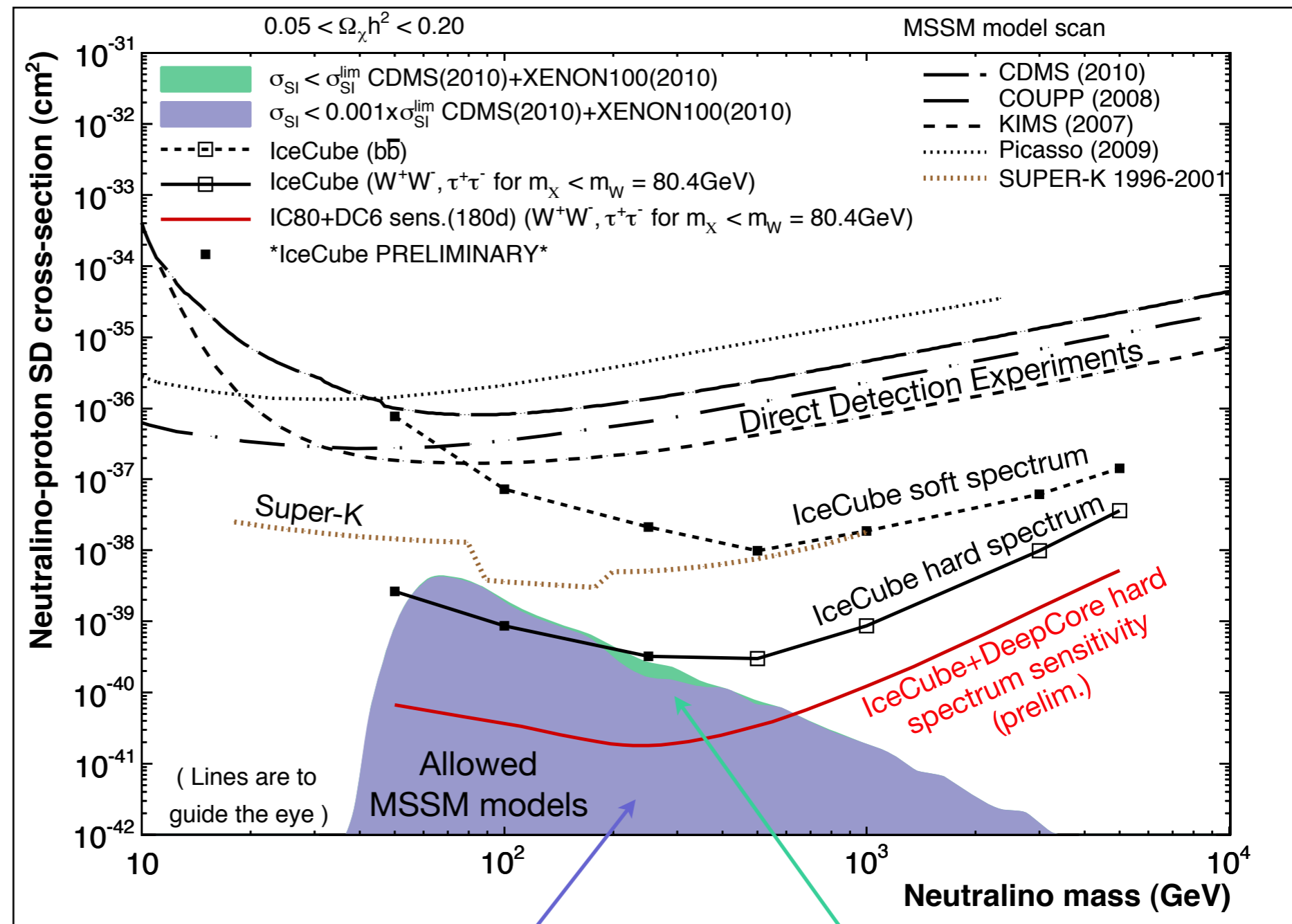
Neutrino Astronomy with DeepCore

- 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



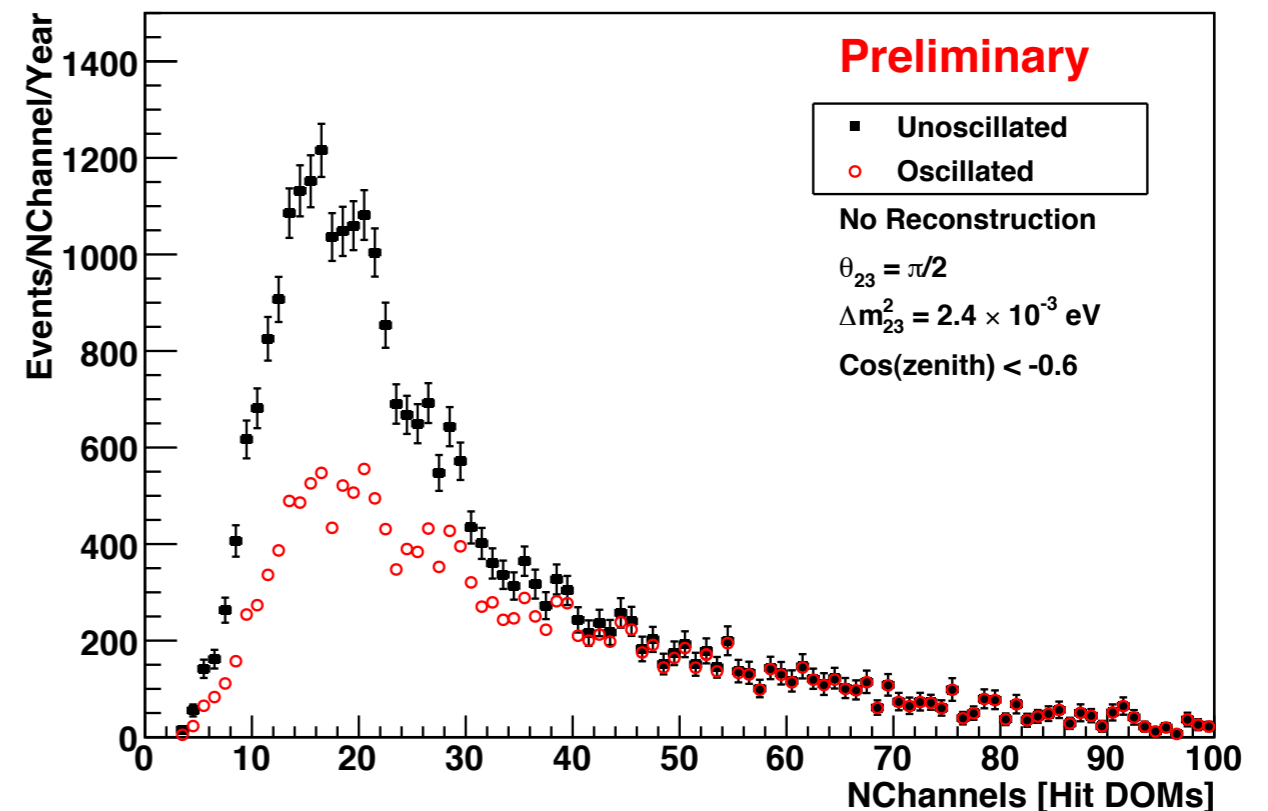
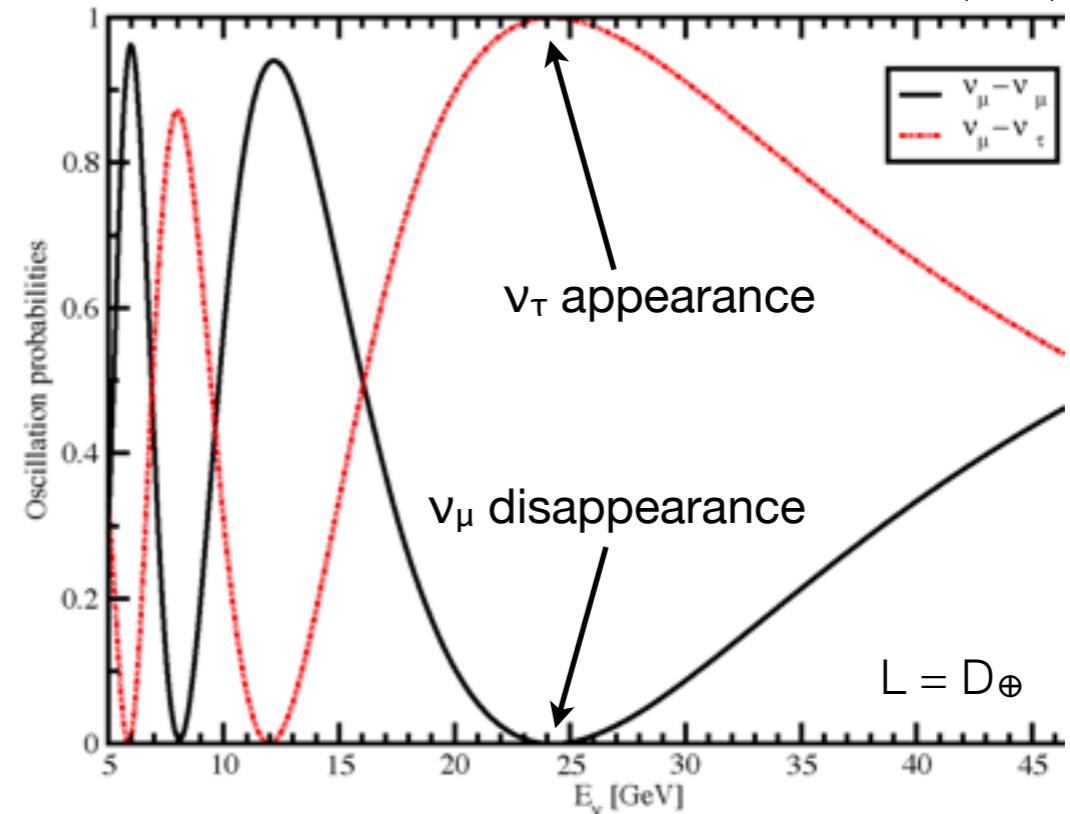
Corresponding σ_{SI} more than factor 10^3 beyond current direct limits

Corresponding σ_{SI} within factor 10^3 of current direct limits

Neutrino Oscillations

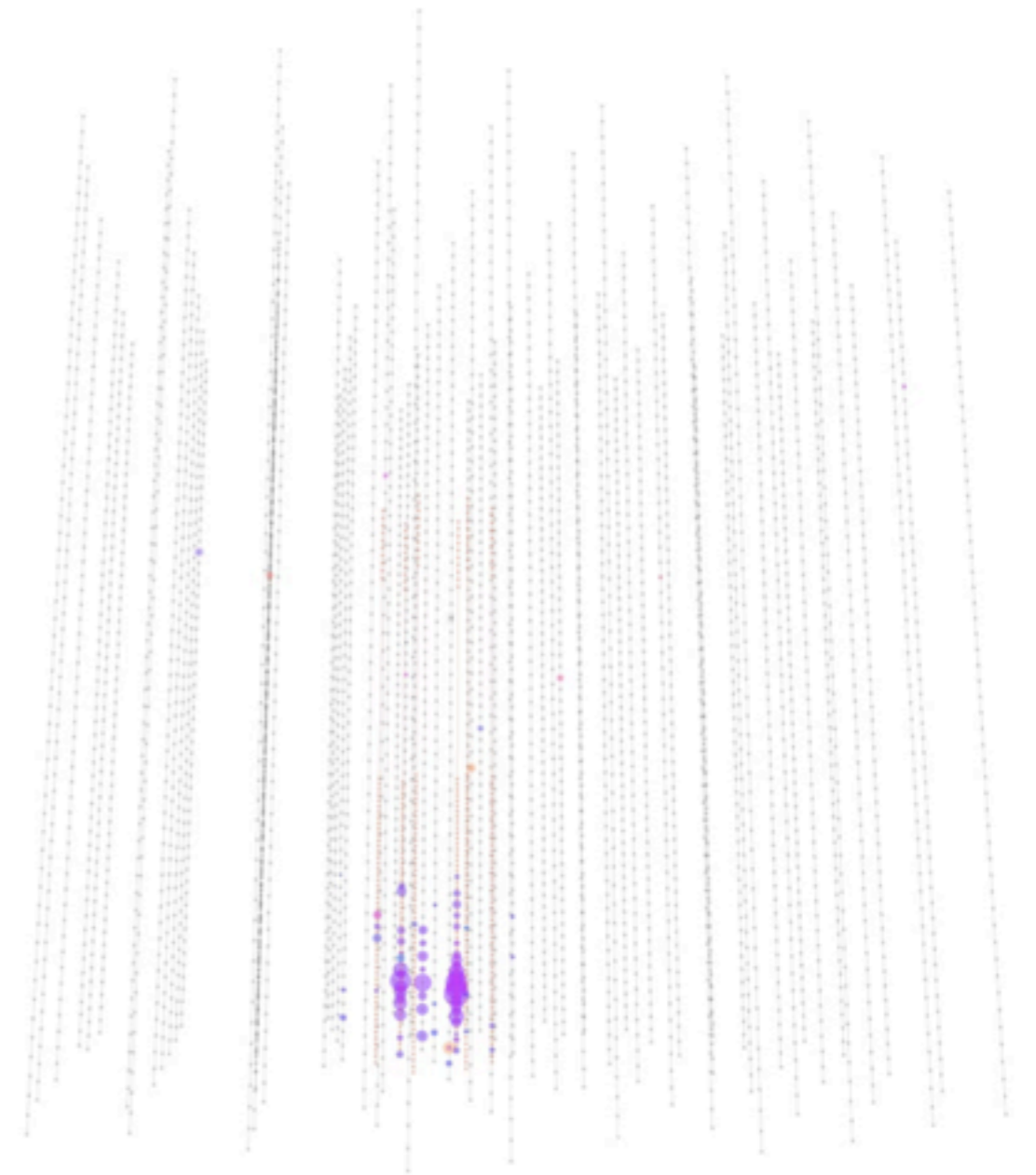
- Atmospheric neutrinos from Northern Hemisphere oscillating over one earth diameter have ν_μ oscillation minimum at ~ 25 GeV
 - Higher energy region than accelerator-based experiments
- Plot of ν_μ disappearance shows only simulated signal
 - Analysis efficiencies not included yet – work ongoing
 -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

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



Observation of Neutrino Cascades (Preliminary)

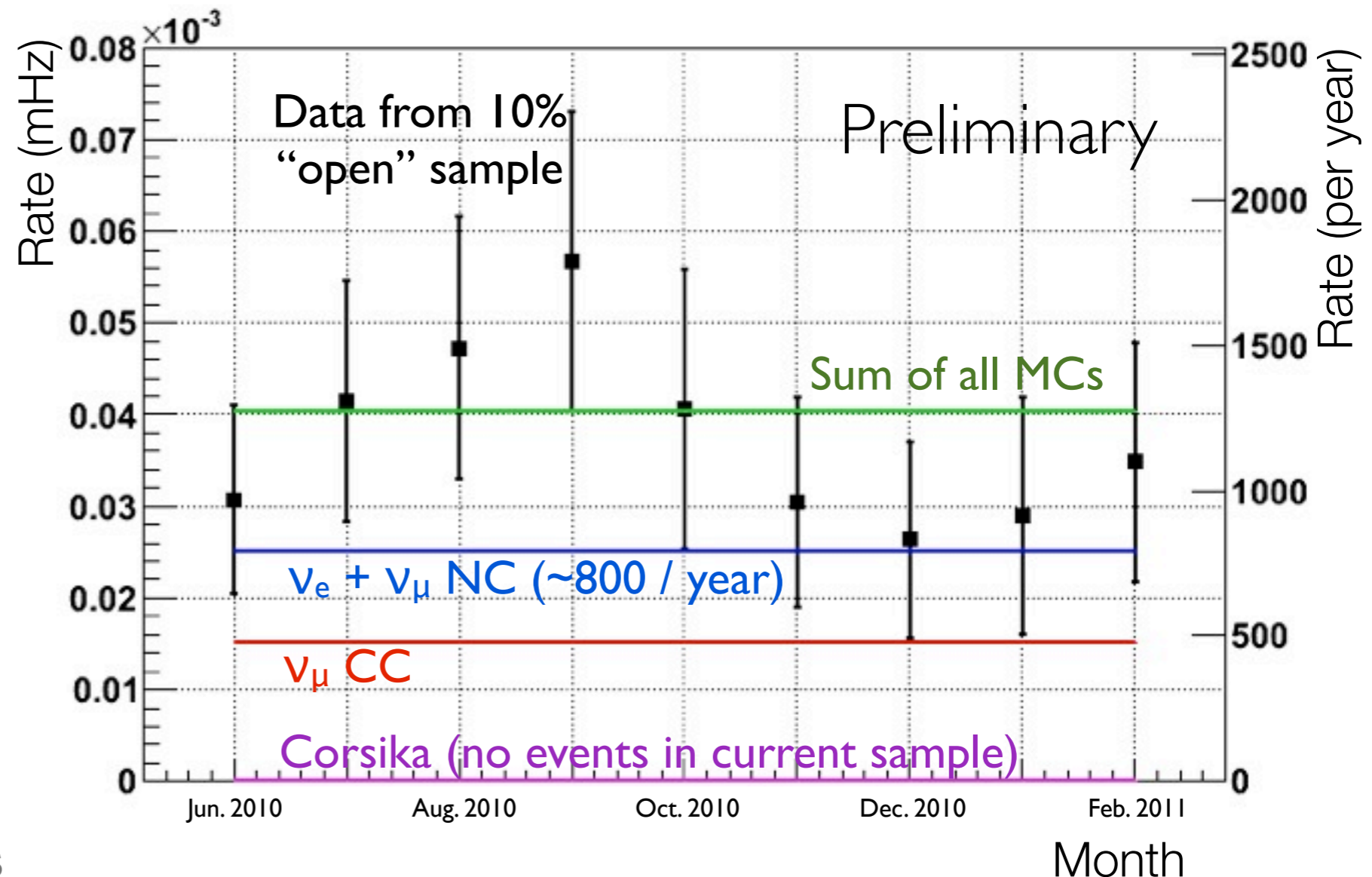
- Disappearing ν_μ should appear in IceCube as ν_τ cascades
 - Effectively identical to neutral current or ν_e CC events
 - Could observe ν_τ appearance as a distortion of the energy spectrum, if cascades can be separated from muon background
- We believe we see neutrino cascade events for the first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



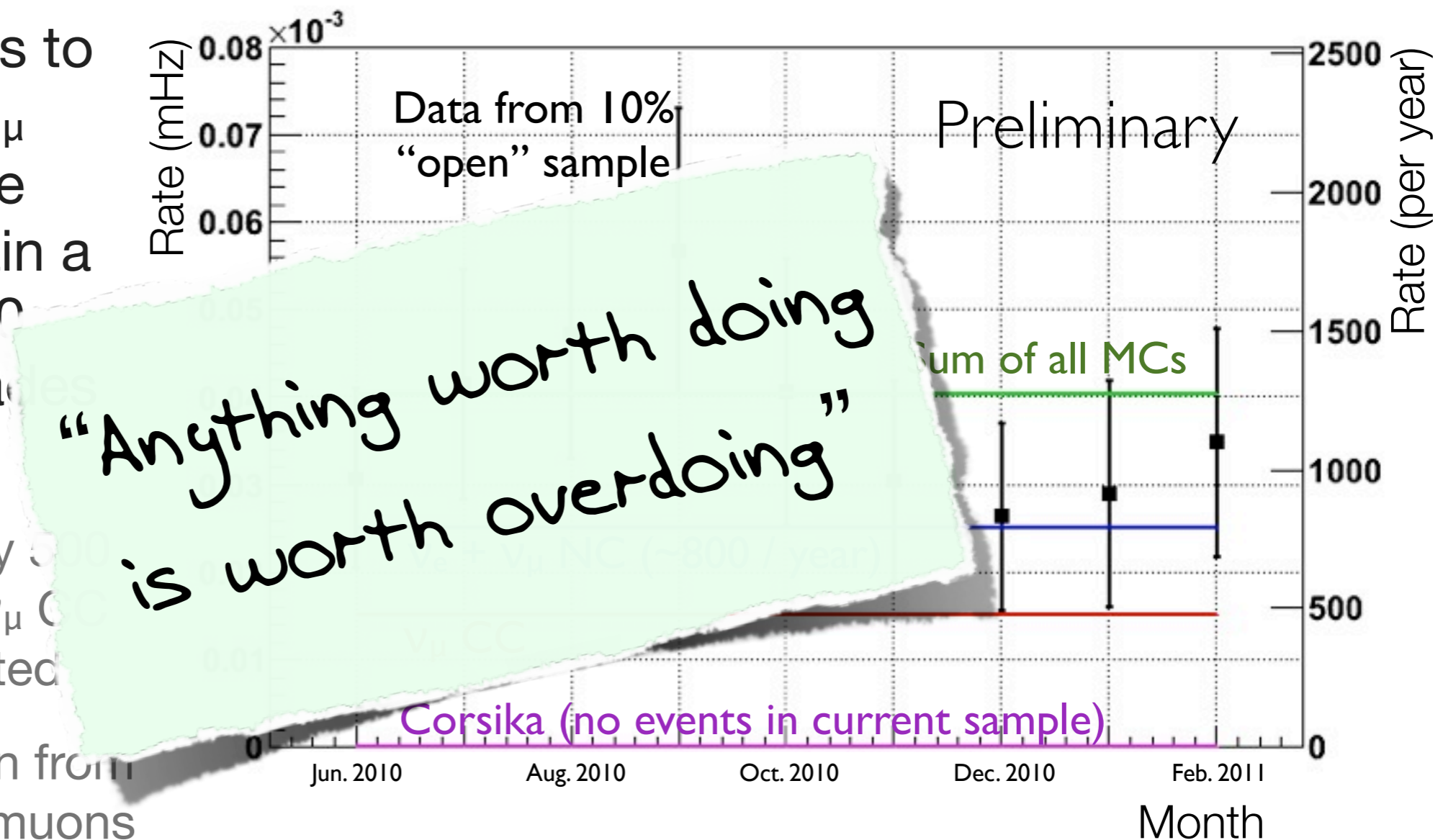
Observation of Neutrino Cascades (Preliminary)

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- Approximately ~ 100 background ν_μ CC events expected

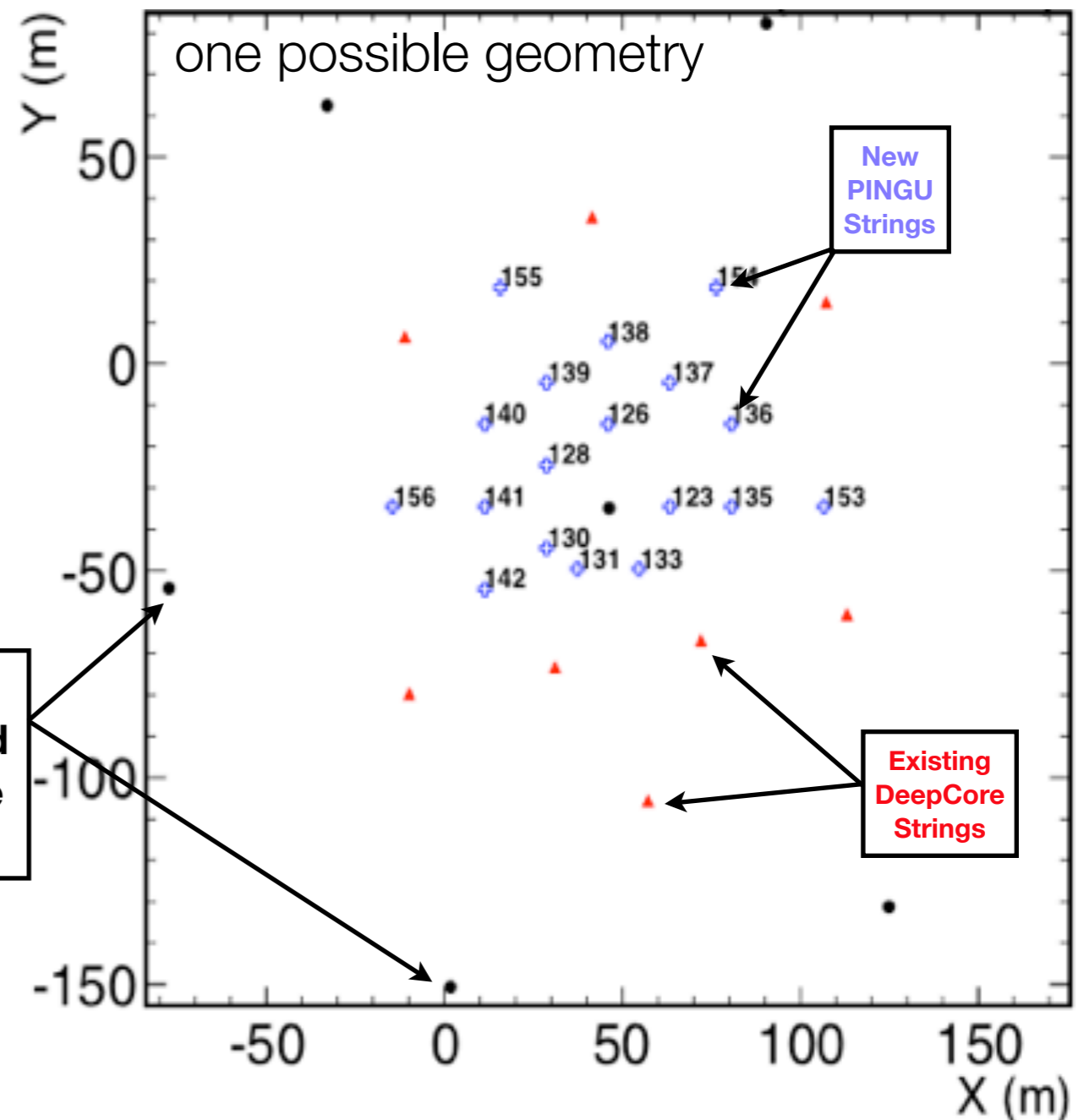
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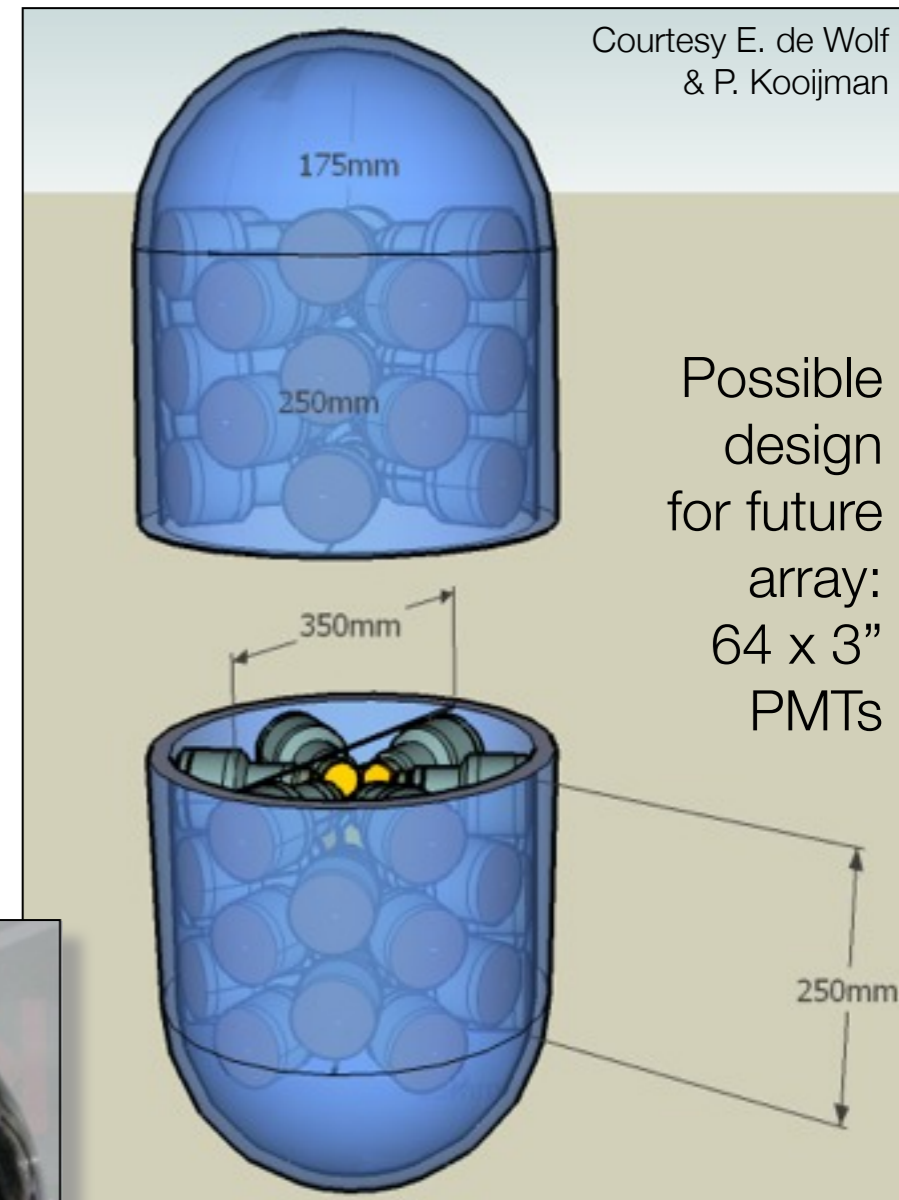
Beyond DeepCore: PINGU

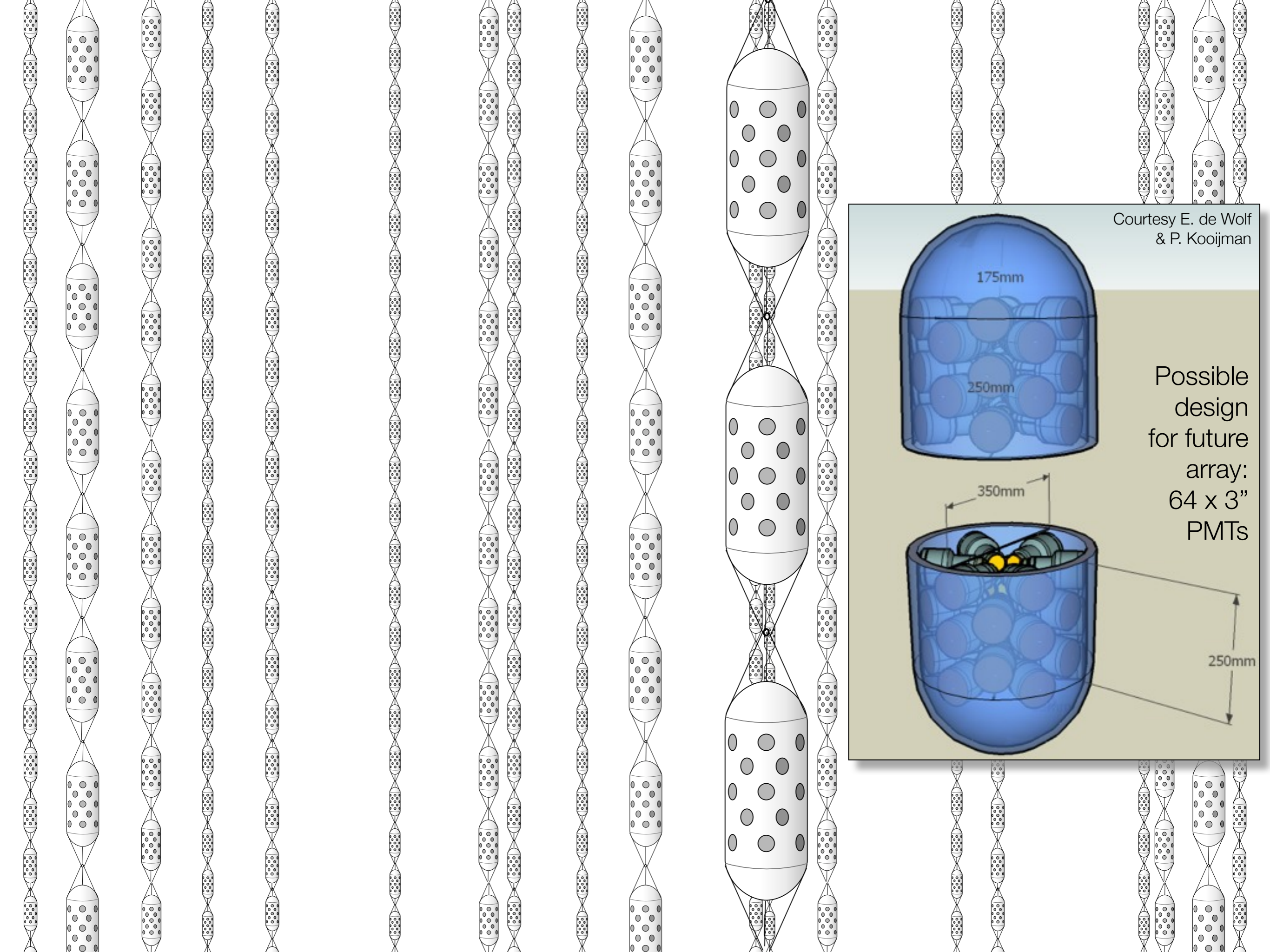
- Now developing a proposal to continue to instrument the DeepCore volume
 - An additional 18-20 strings, 1000-1200 DOMs
 - Make use of well-established IceCube drilling technology
 - Might get to a threshold of ~ 1 GeV in a ~ 10 Mton volume
 - Also an R&D platform for future detectors on a \sim decade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





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?