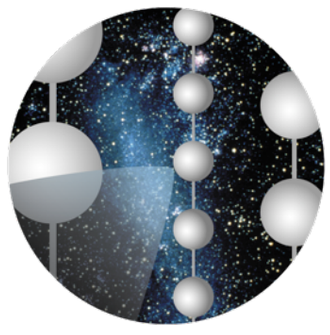
DeepCore and Beyond

Toward Precision Physics with Neutrino Telescopes

PENNSTATE

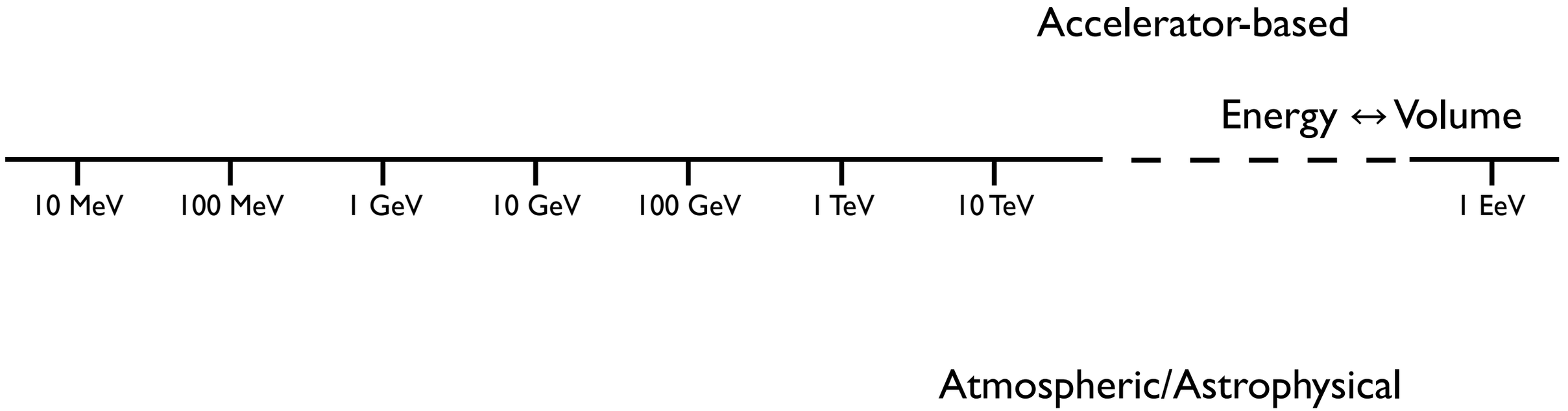
Tyce DeYoung
Department of Physics
Pennsylvania State University

MANTS ’11
Uppsala, Sweden
September 25, 2011

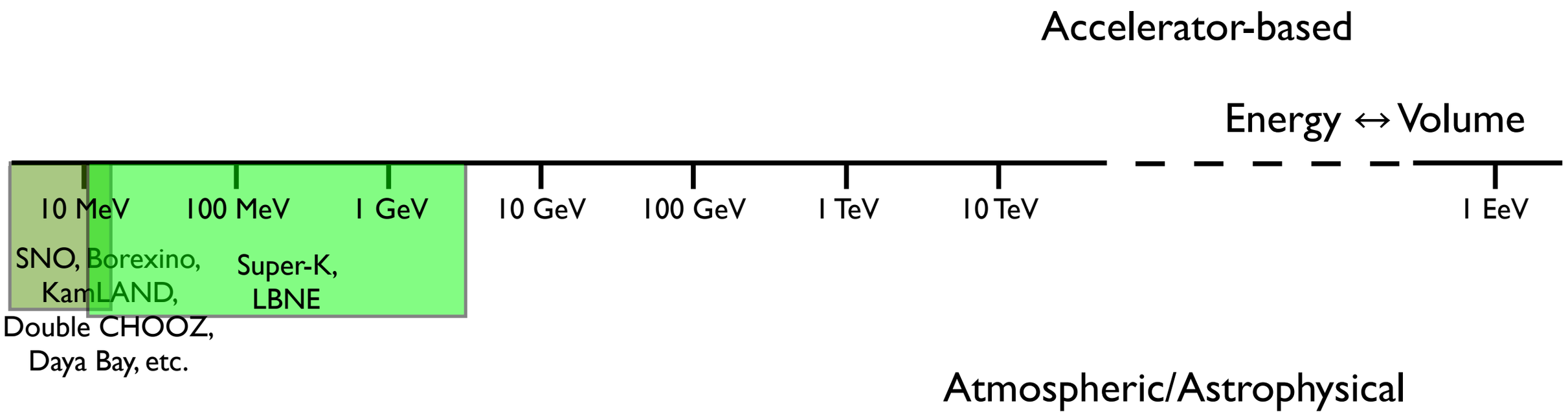


IceCube

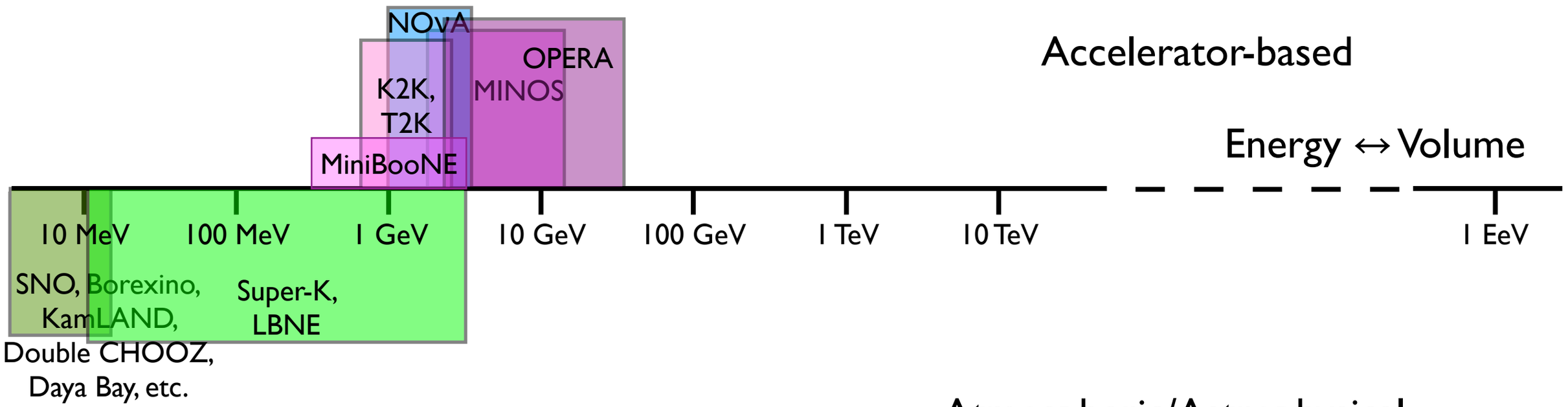
The Neutrino Detector Spectrum



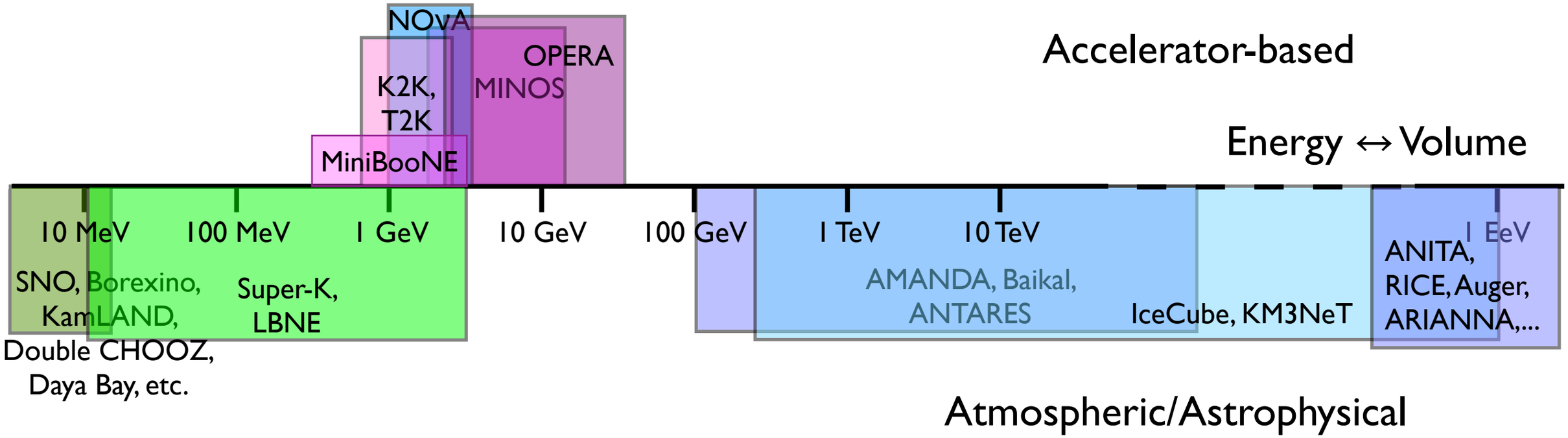
The Neutrino Detector Spectrum



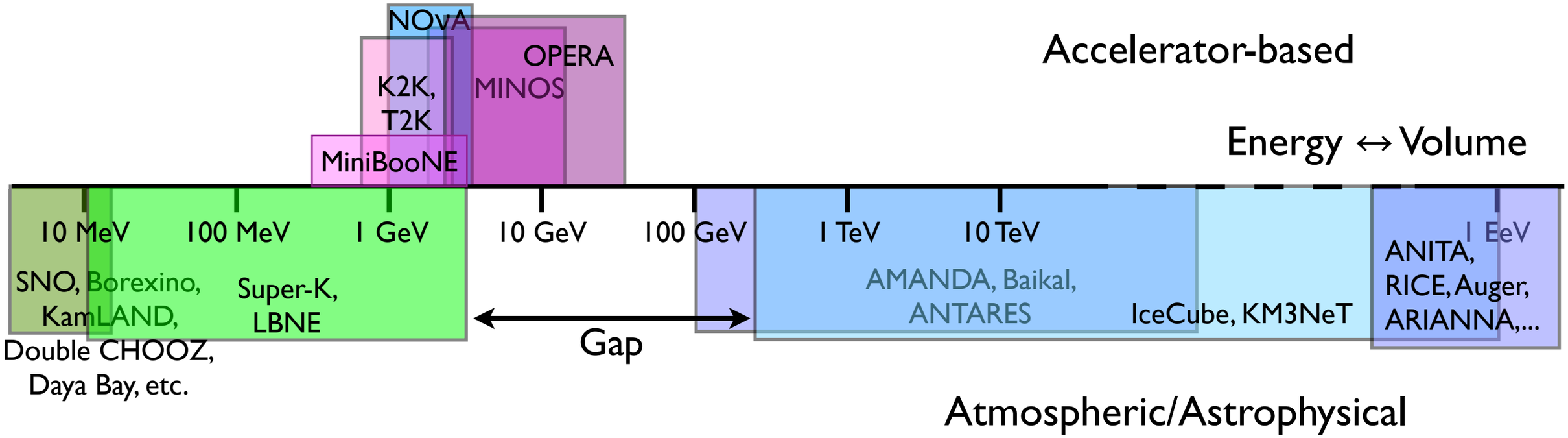
The Neutrino Detector Spectrum



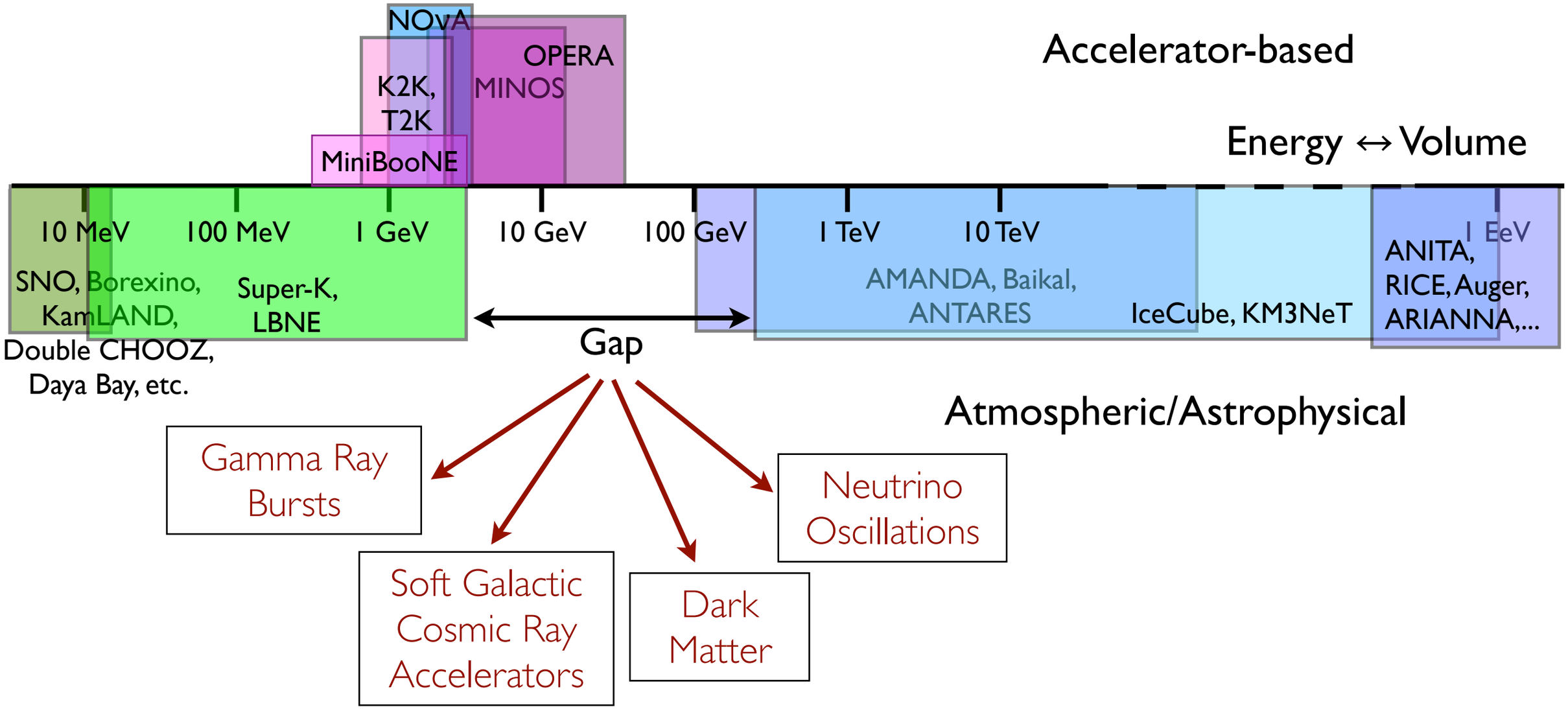
The Neutrino Detector Spectrum



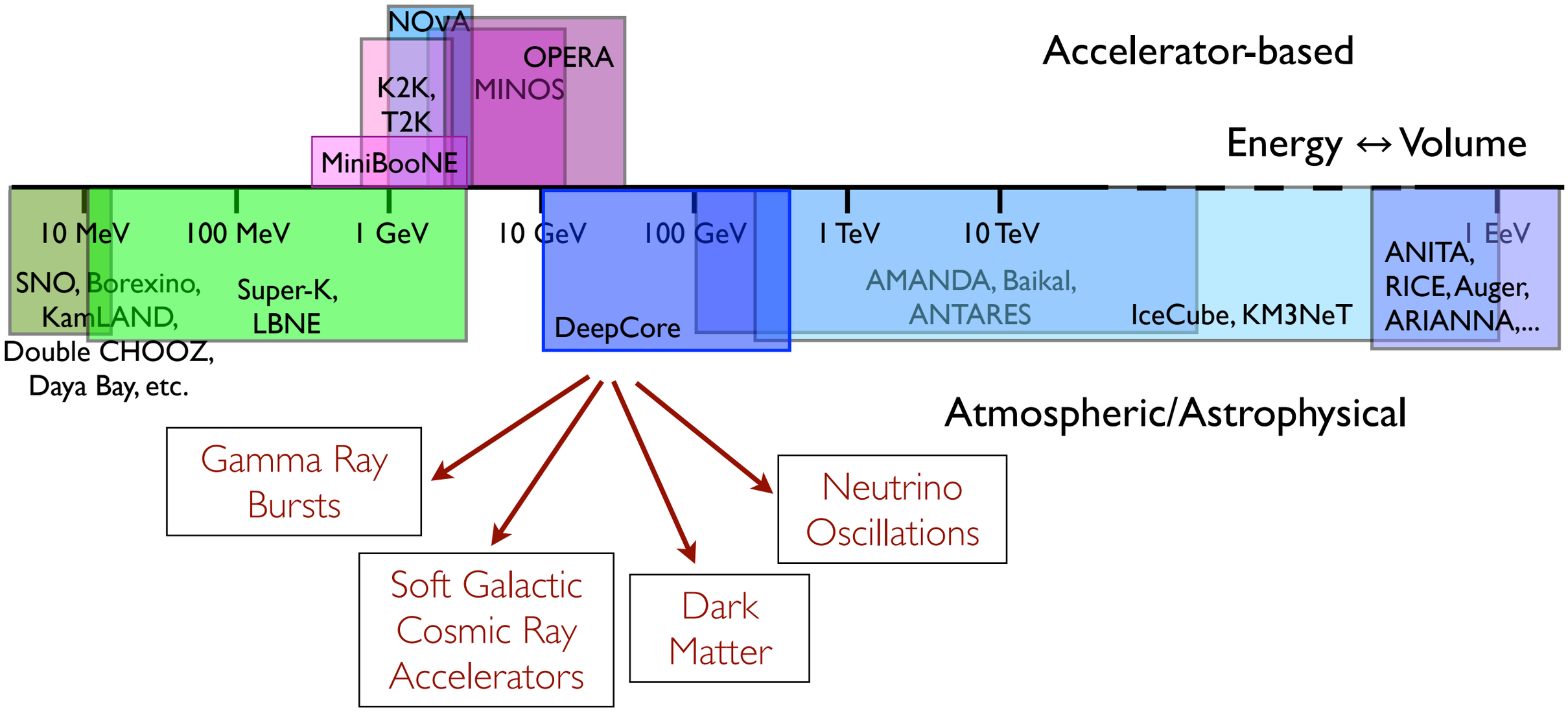
The Neutrino Detector Spectrum



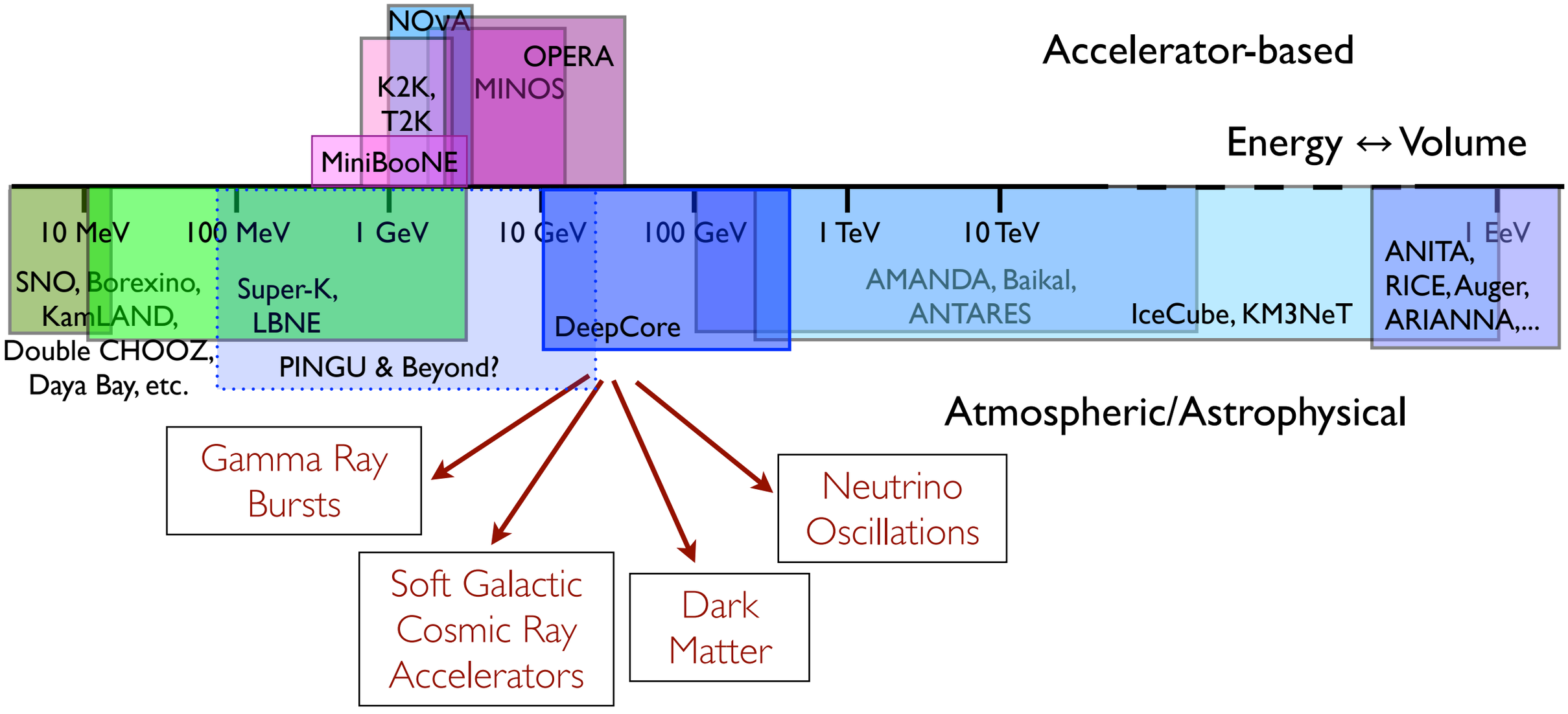
The Neutrino Detector Spectrum



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)

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 was the indirect search for dark matter

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 was the indirect search for dark matter
- Particle physics using atmospheric neutrinos
  - Neutrino oscillations, including tau neutrino appearance

IceCube DeepCore

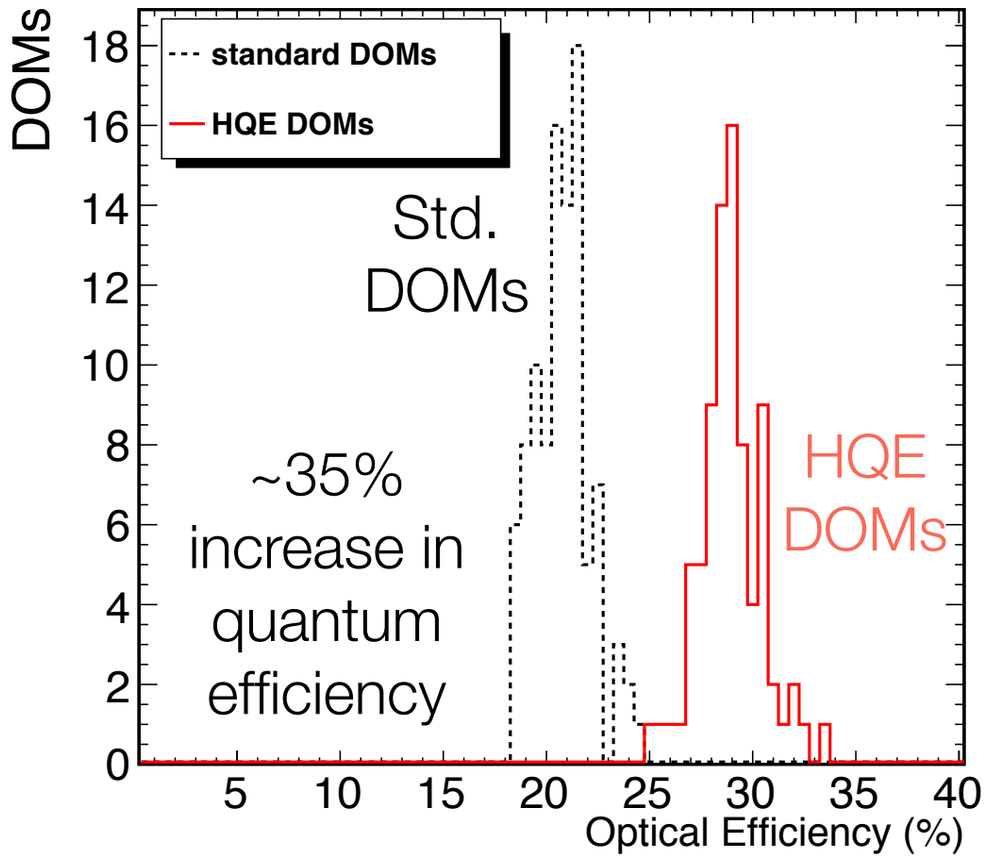
- IceCube collaboration decided to augment “low” energy response with a densely instrumented infill array: DeepCore
  - Significant improvement in capabilities from ~10 GeV to ~100 GeV (ν_μ)
- Primary scientific rationale was the indirect search for dark matter
  - Particle physics using atmospheric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

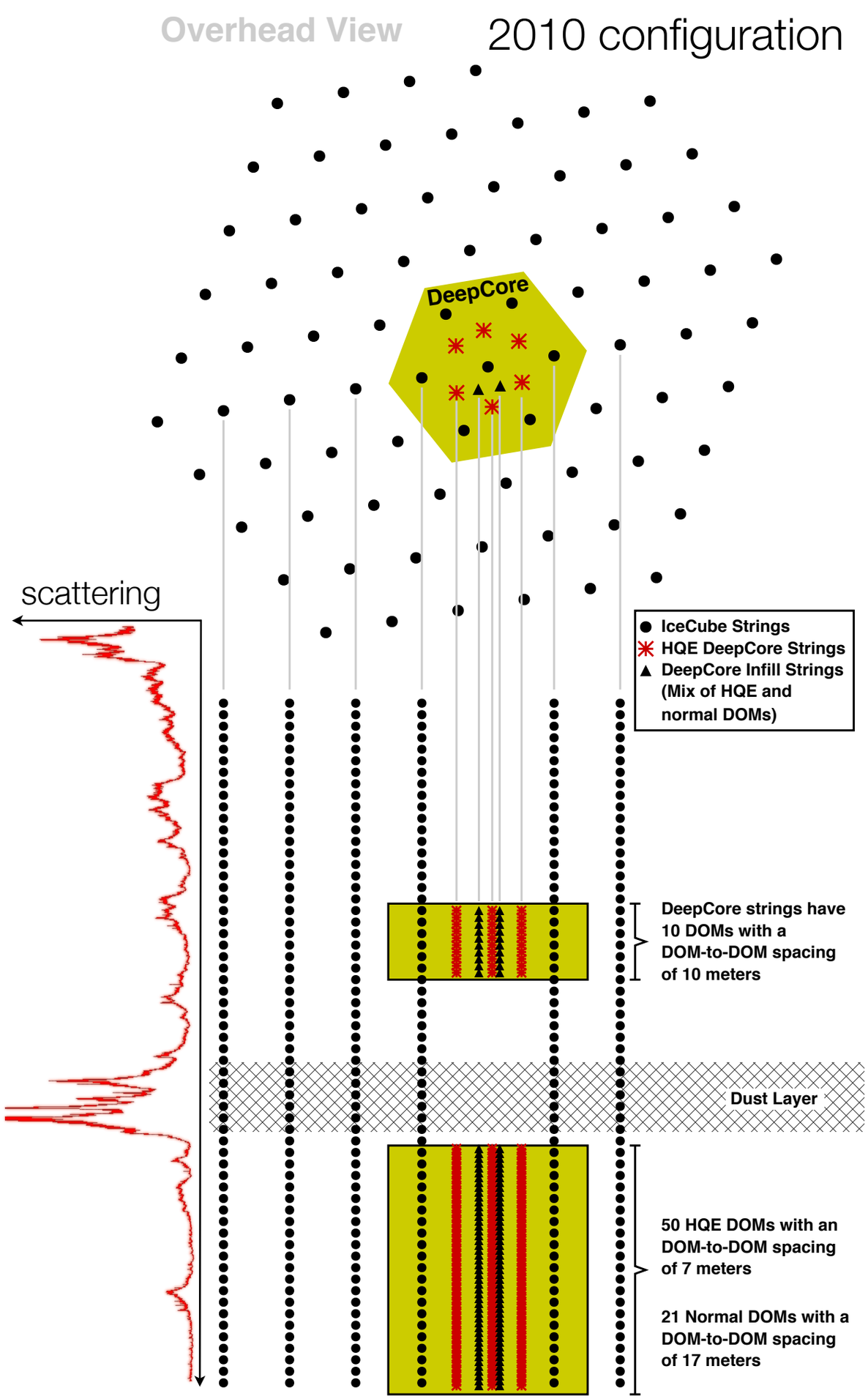
IceCube DeepCore

- 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 was 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

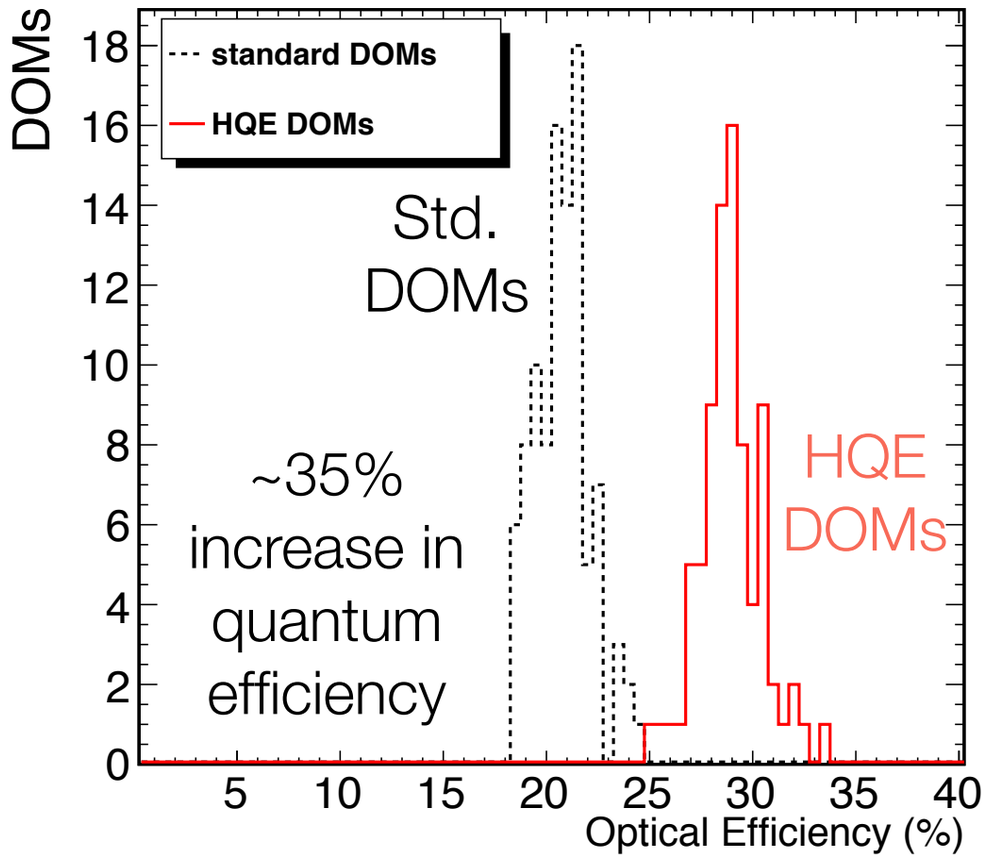
- DeepCore extends the reach of IceCube to lower energies
  - Denser module spacing
  - Hamamatsu super-bialkali PMTs
  - Deployed in the clearest ice

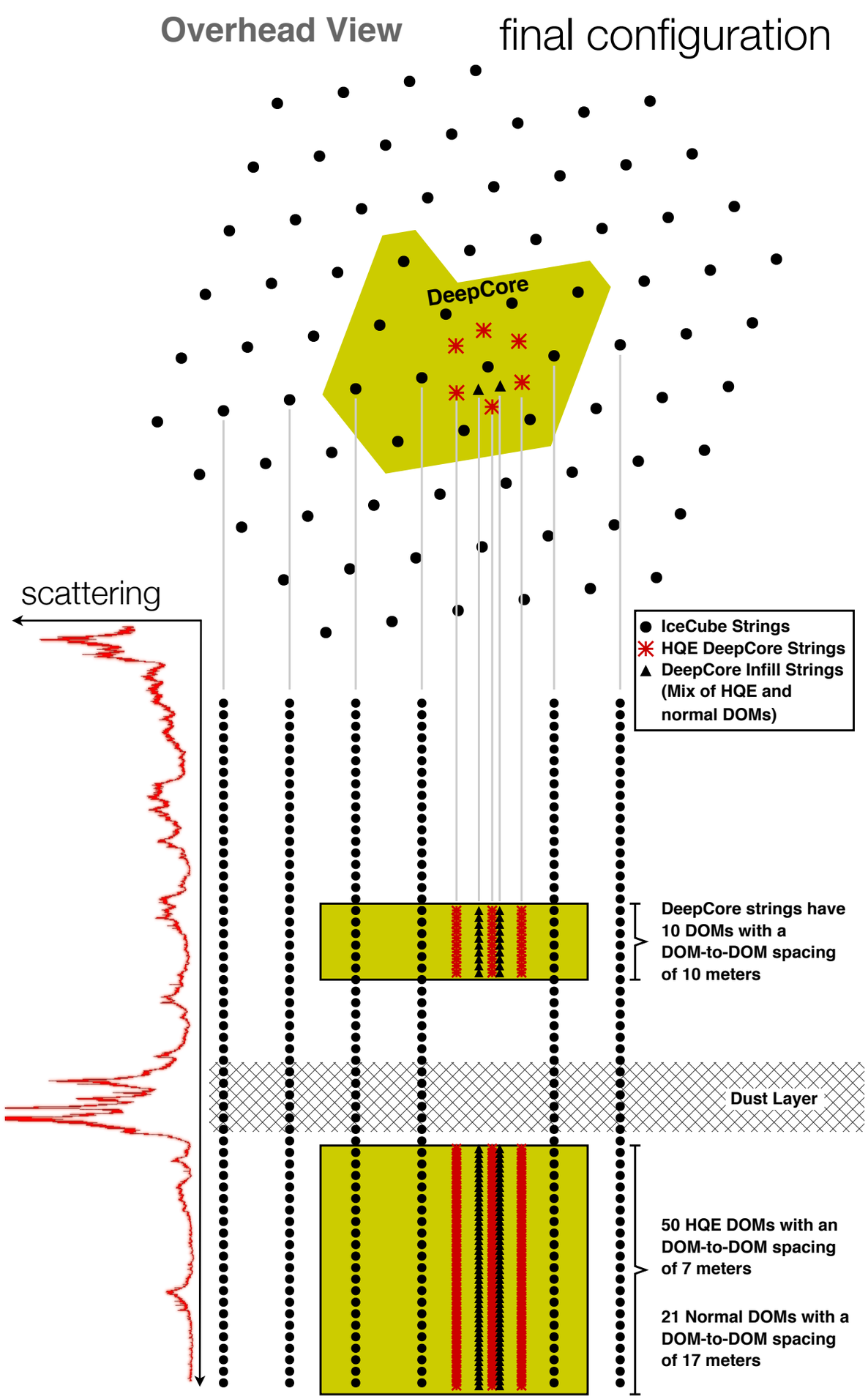




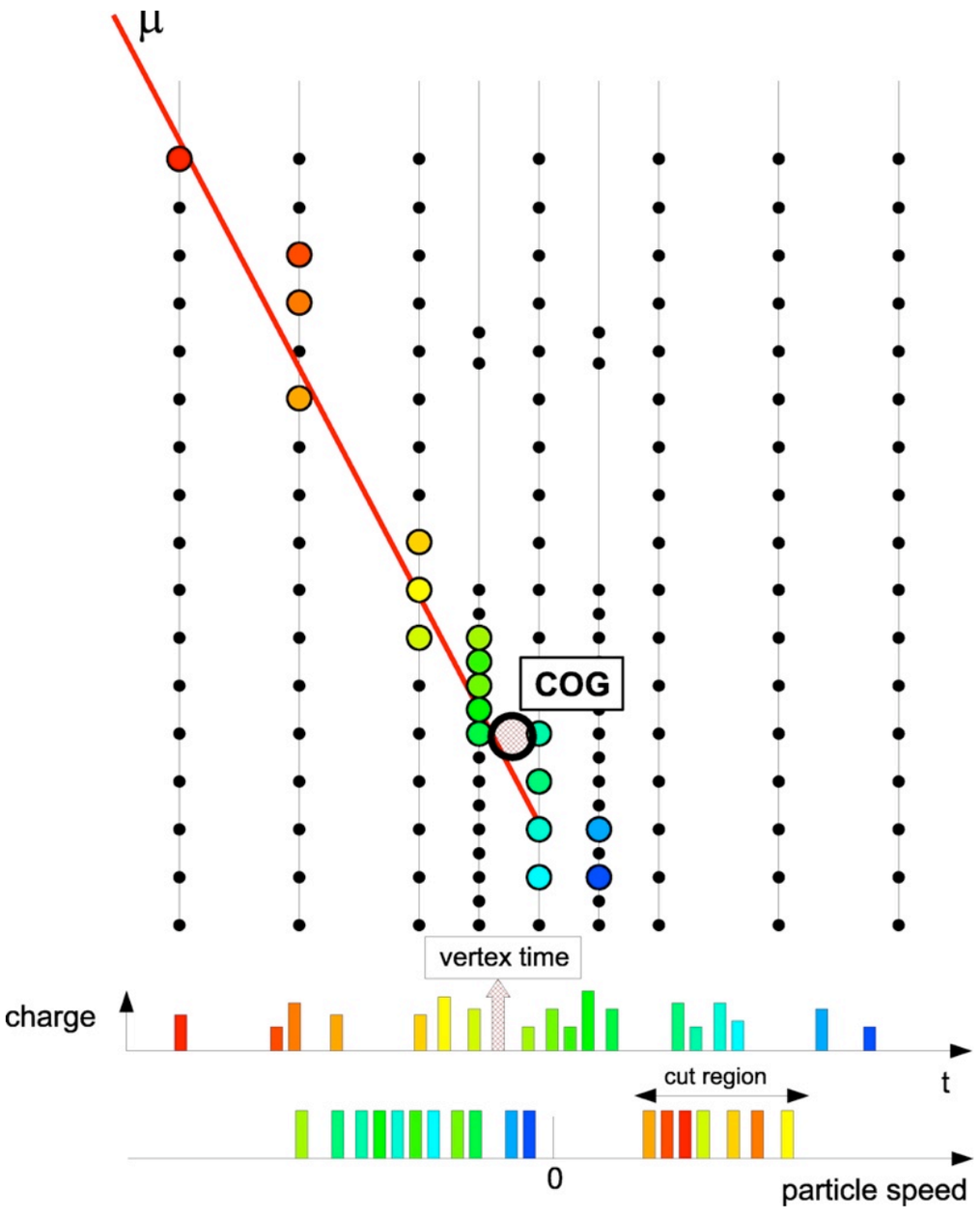
IceCube DeepCore

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

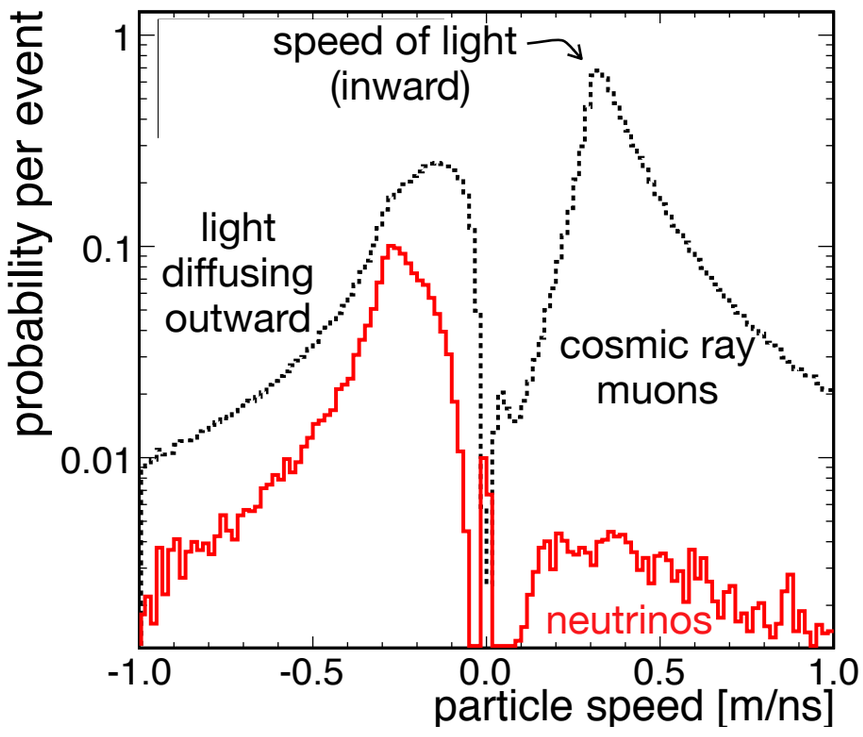




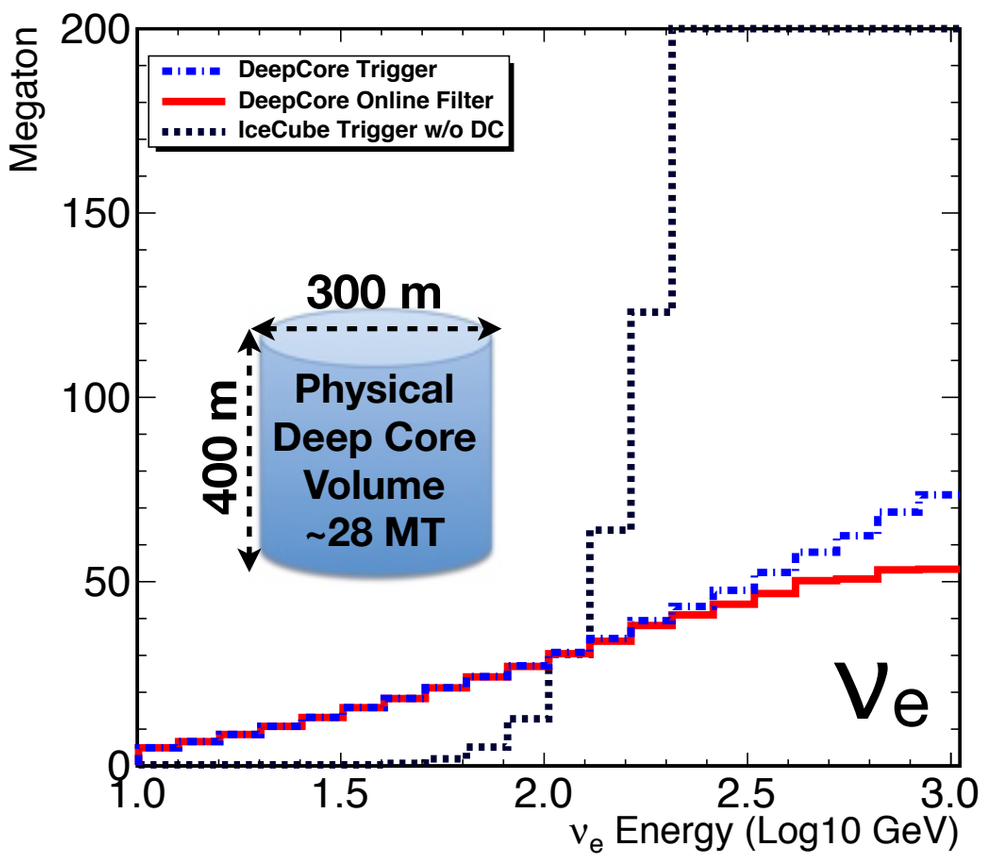
Online Atmospheric Muon Veto

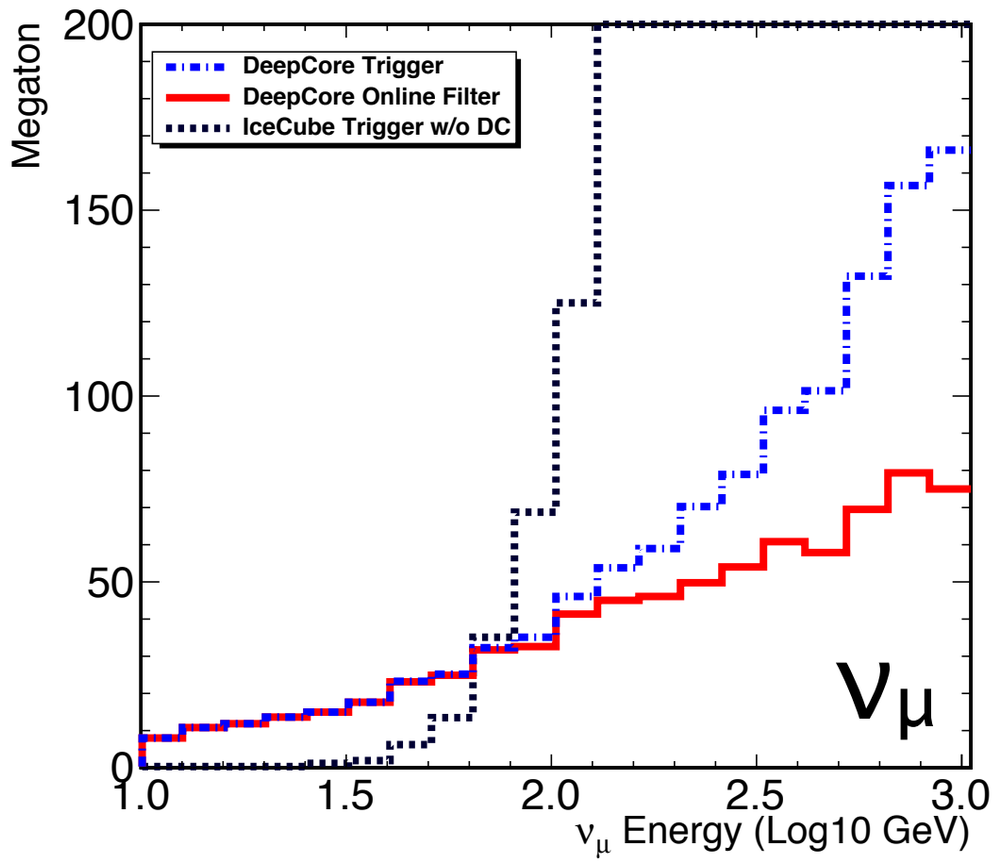


- Look for hits in veto region consistent with speed-of-light travel time to hits in DeepCore
  - Achieves 7 x 10^{-3} rejection of cosmic ray muon background with 99% efficiency for neutrinos interacting within DeepCore
- More sophisticated versions used offline



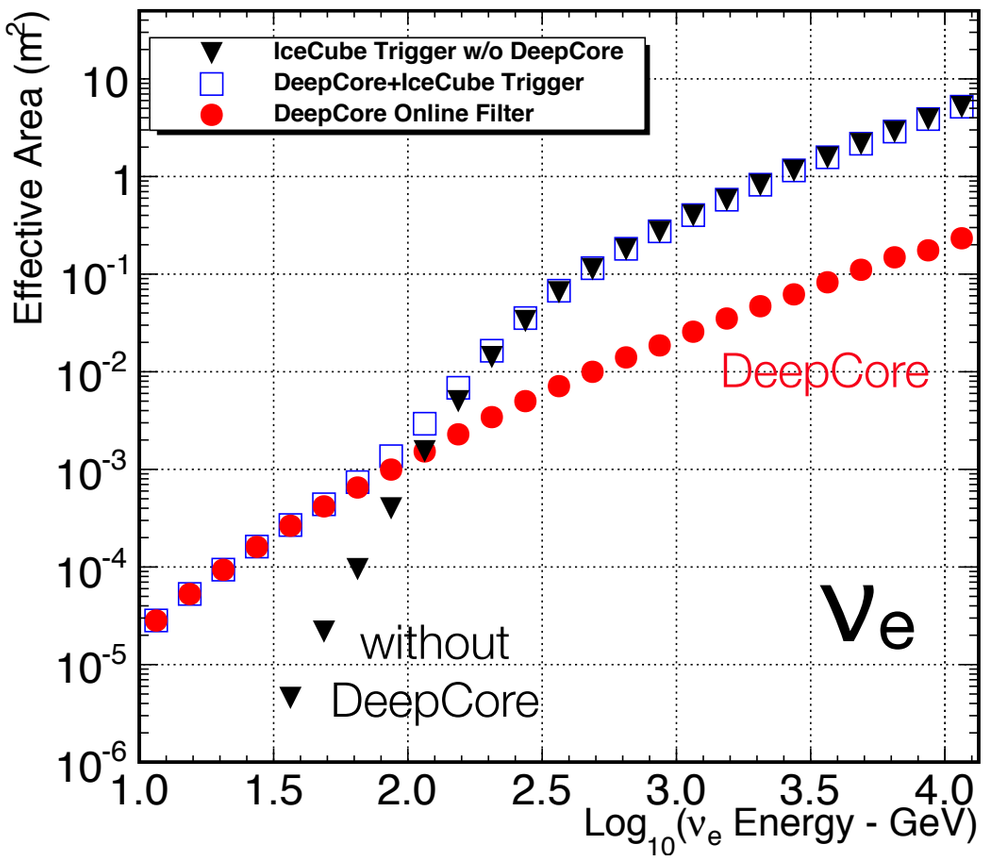
DeepCore Lepton Effective Volume

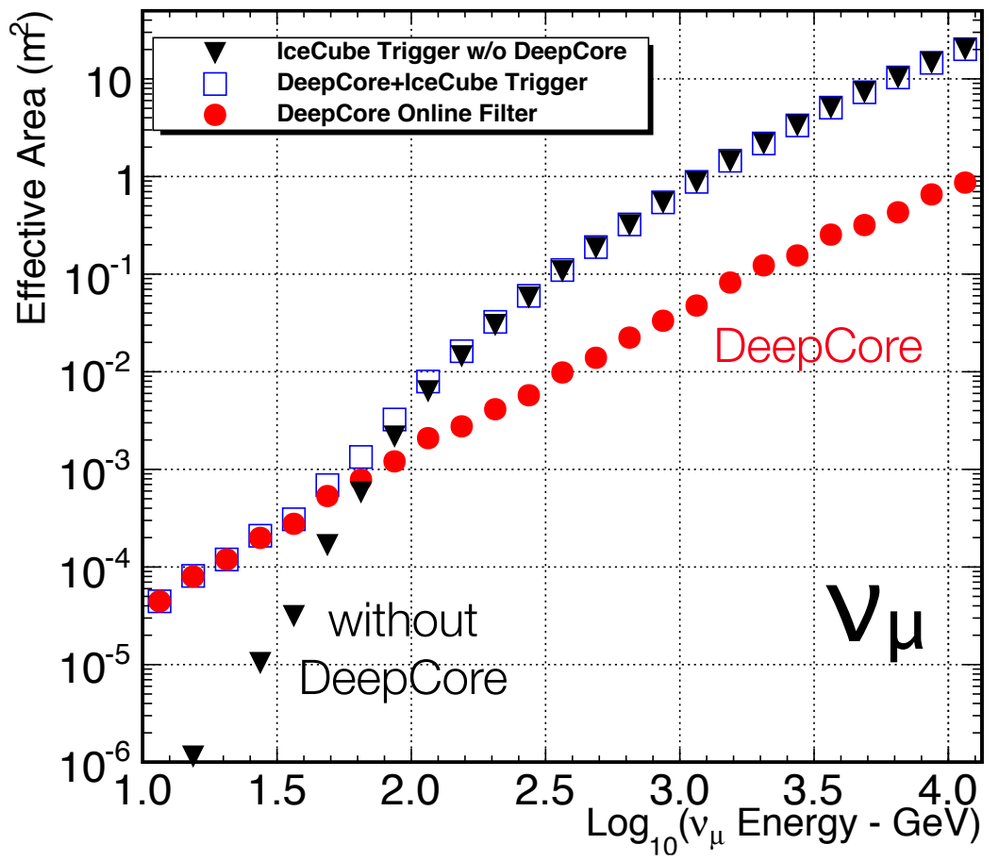




- Many DeepCore triggers are events occurring in the rest of IceCube
  - These events are rejected by the online veto algorithm
  - Online efficiency for neutrinos interacting in the DeepCore volume is >98%
  - Efficiency in final analysis will be significantly lower; losses to reconstruction efficiency,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

DeepCore Neutrino Effective Area





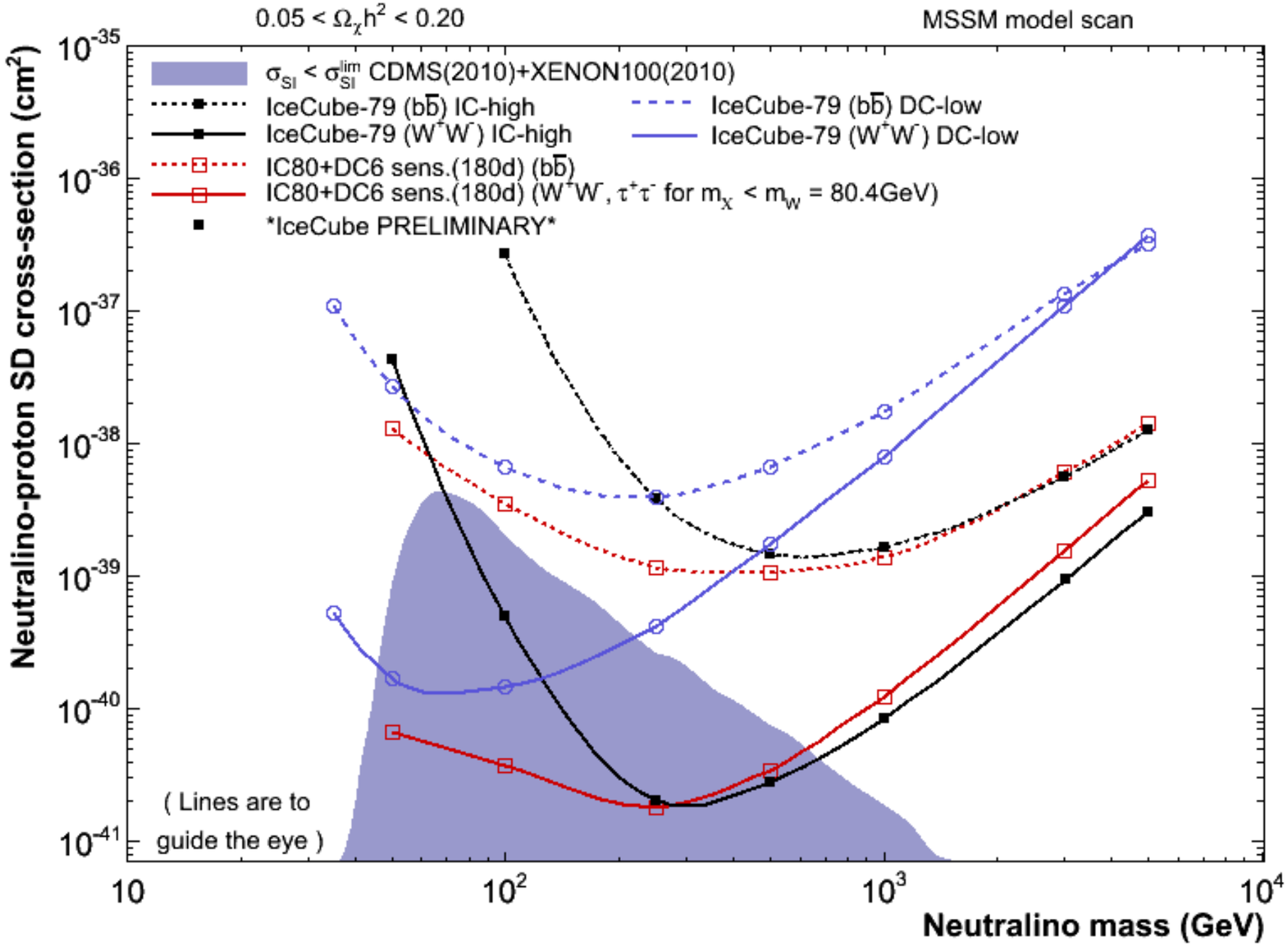
- DeepCore dominates total response for E_ν below ~100 GeV, depending on flavor
  - Improved trigger efficiency overcomes much smaller volume
  - Linear growth at high energies reflects neutrino interaction cross section, not detector efficiency

Search for Solar Dark Matter

M. Danninger, TAUP 2011

- Solar WIMP dark matter searches probe SD scattering cross section
  - SI cross section constrained well by direct search experiments
- DeepCore is essential to low mass WIMPs
- For non-SUSY DM, even lower energies are of interest

Preliminary sensitivities

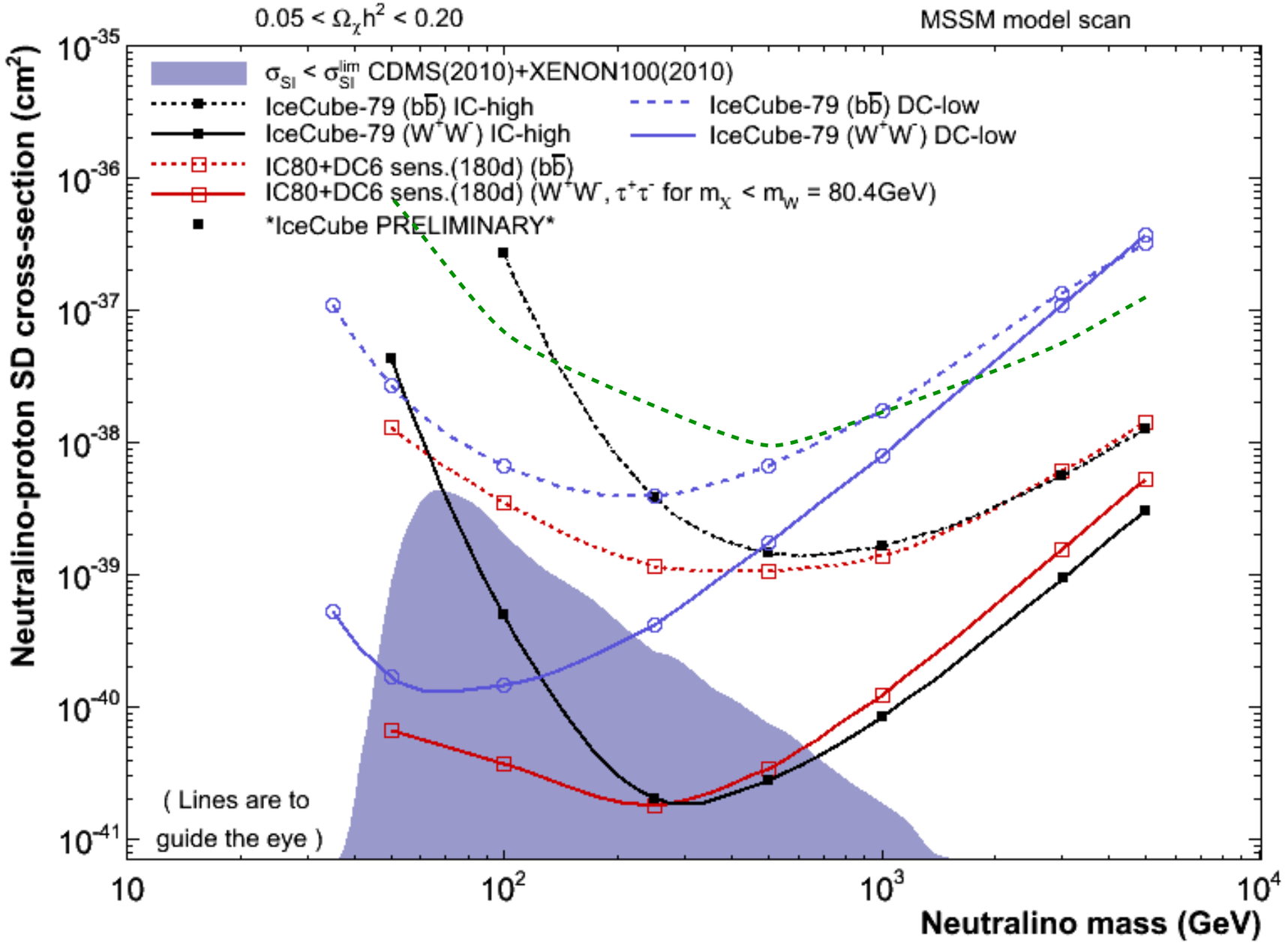


Search for Solar Dark Matter

M. Danninger, TAUP 2011

- Solar WIMP dark matter searches probe SD scattering cross section
  - SI cross section constrained well by direct search experiments
- DeepCore is essential to low mass WIMPs
- For non-SUSY DM, even lower energies are of interest

Preliminary sensitivities

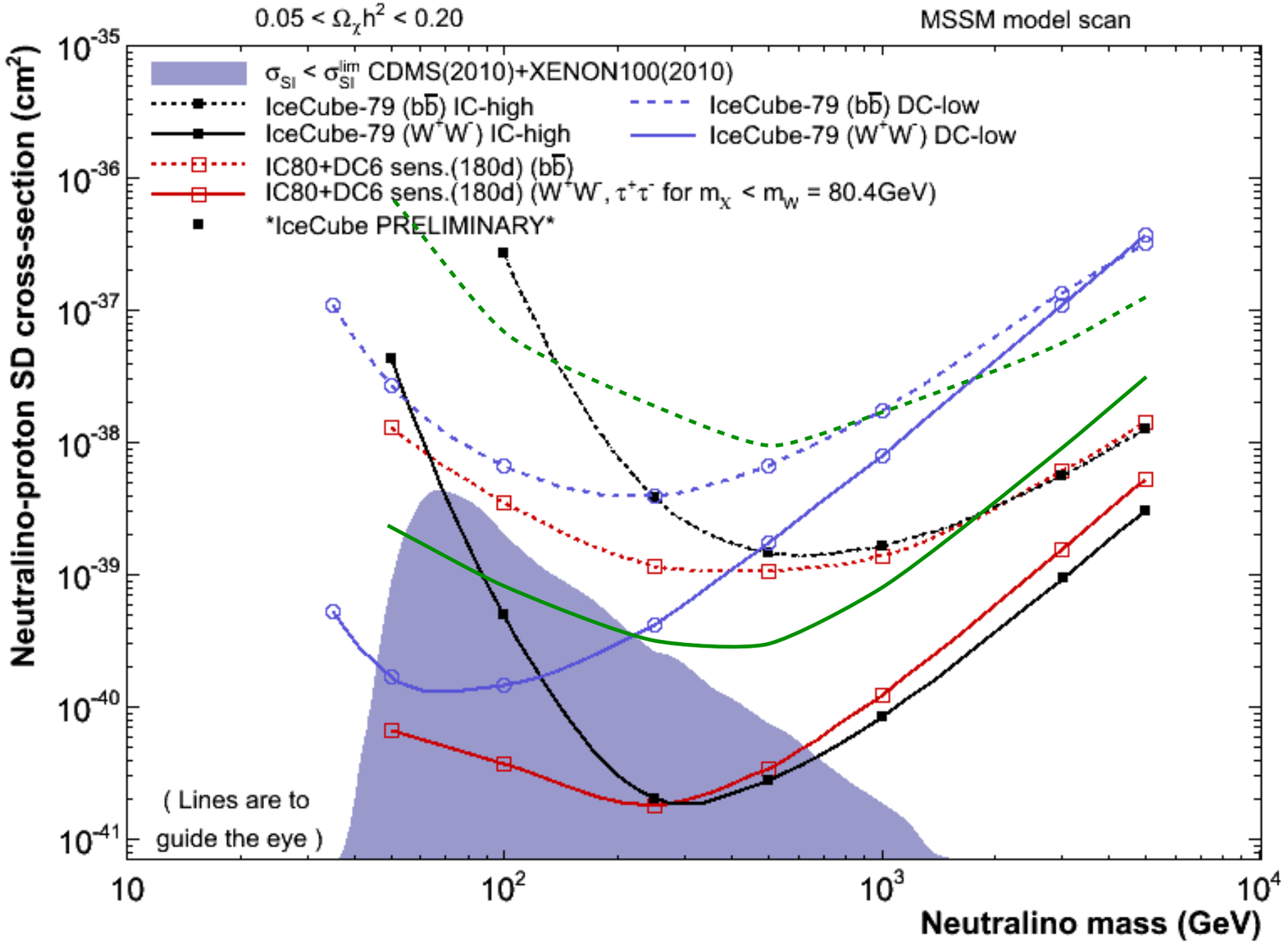


Search for Solar Dark Matter

M. Danninger, TAUP 2011

- Solar WIMP dark matter searches probe SD scattering cross section
  - SI cross section constrained well by direct search experiments
- DeepCore is essential to low mass WIMPs
- For non-SUSY DM, even lower energies are of interest

Preliminary sensitivities

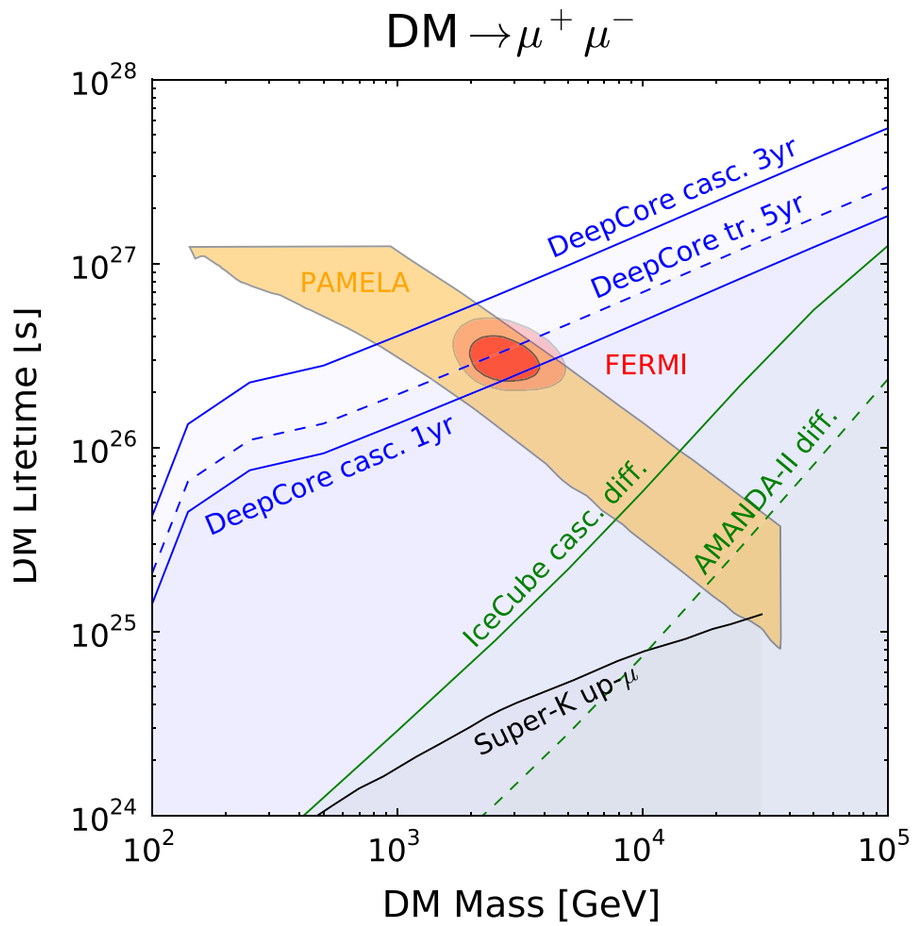


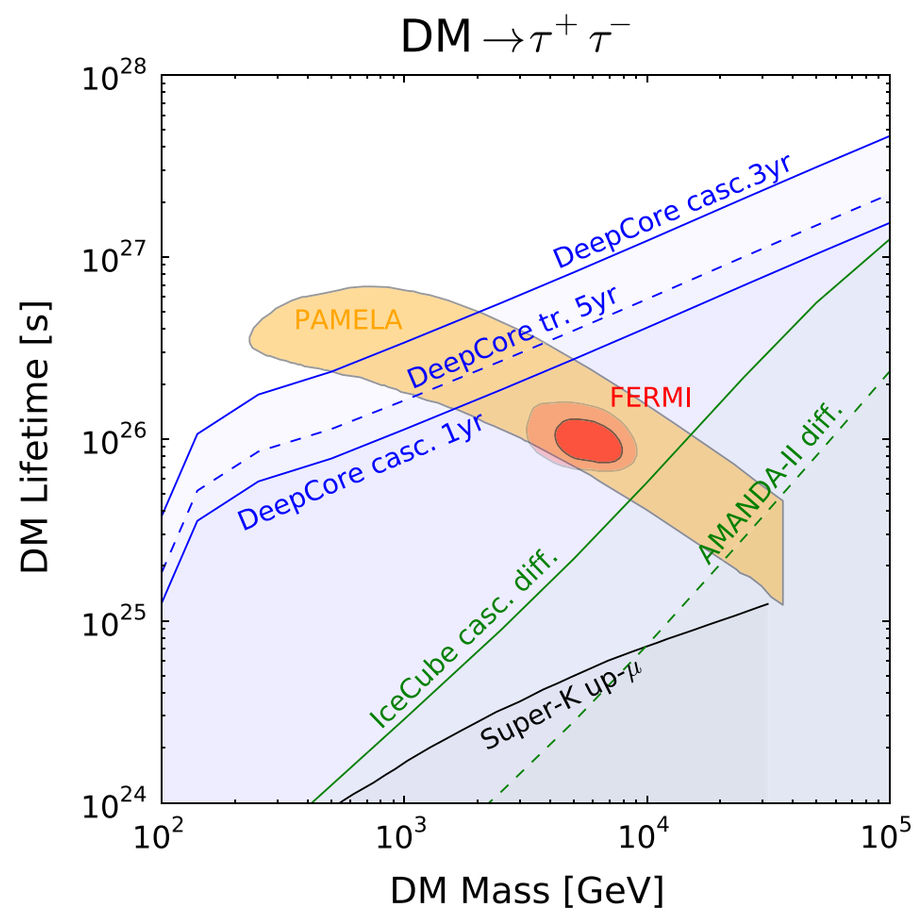
Non-Standard Dark Matter Searches

- As a general-purpose detector, IceCube-DeepCore will soon be able to probe new theories using archival data sets

- E.g., interpretations of PAMELA positron fraction in terms of decaying or boosted leptophilic dark matter

- Will have the world's largest neutrino set – many things we can use it for

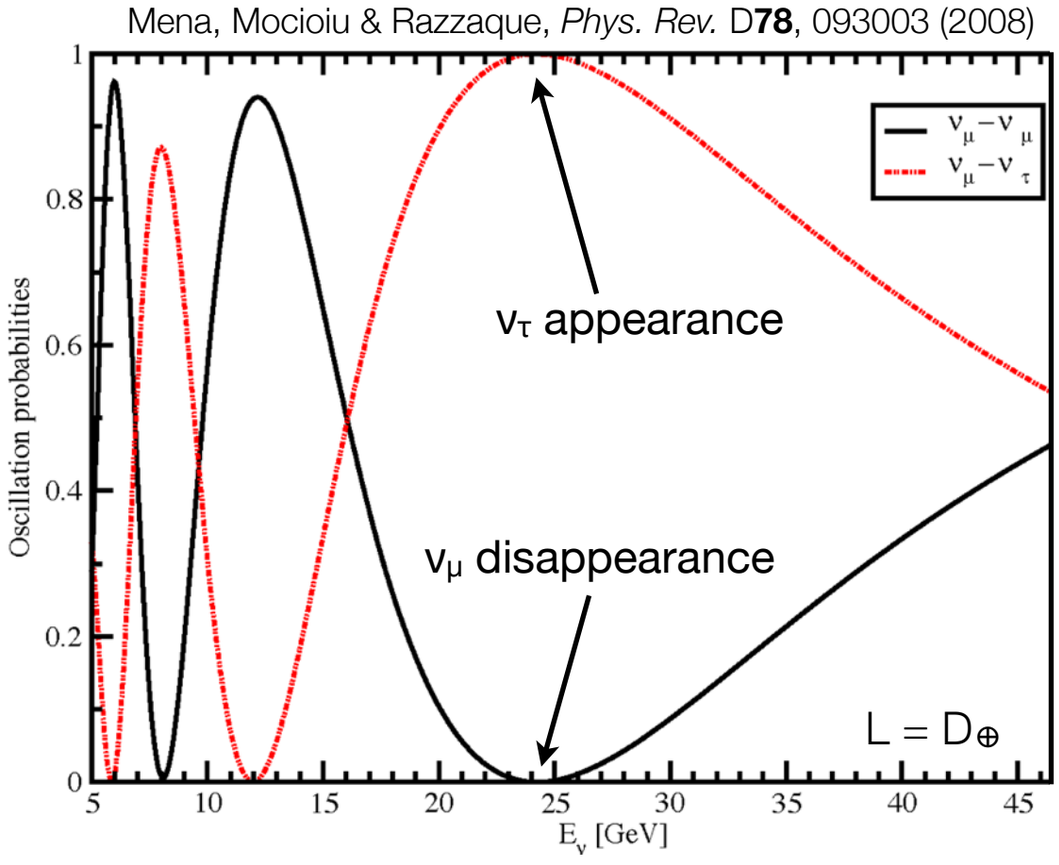




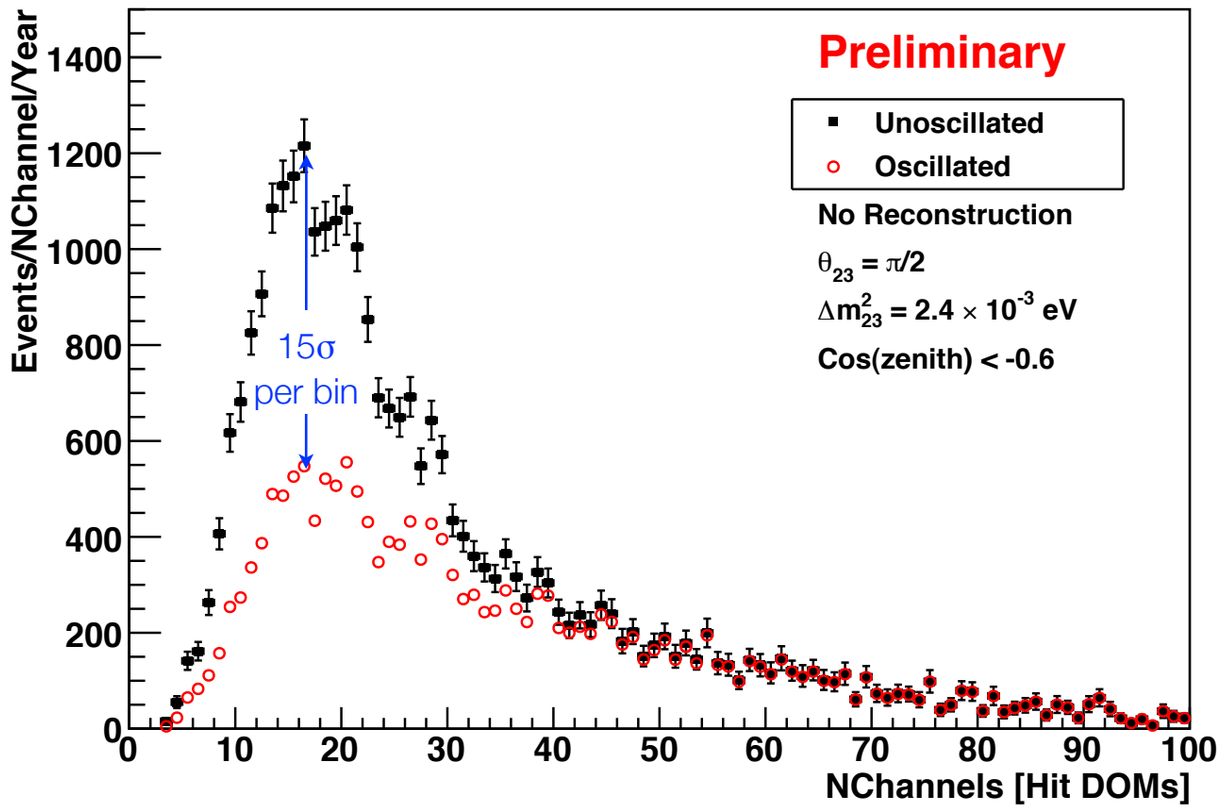
Mandal, Buckley, Freese, Spolyar, & Murayama, PRD **81**, 043508 (2010)

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

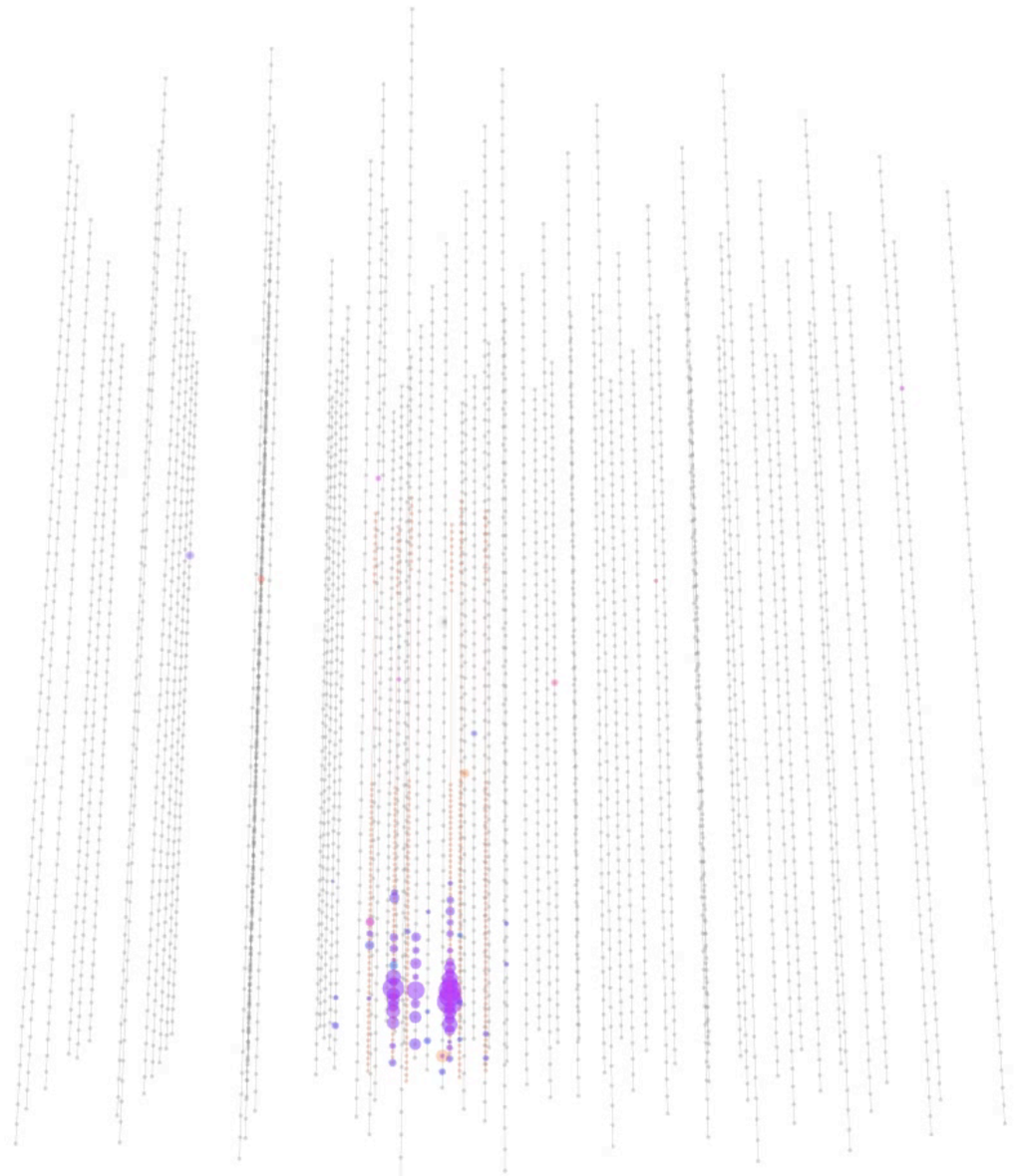


- Plot of ν_μ disappearance shows only simulated signal, rough energy estimator
  - Analysis efficiencies not included yet – work ongoing
  - Promising work on a track length reconstruction, zenith-only reconstruction inspired by ANTARES (J.-P. Yánez, J. Brunner)



Observation of Neutrino Cascades (Preliminary)

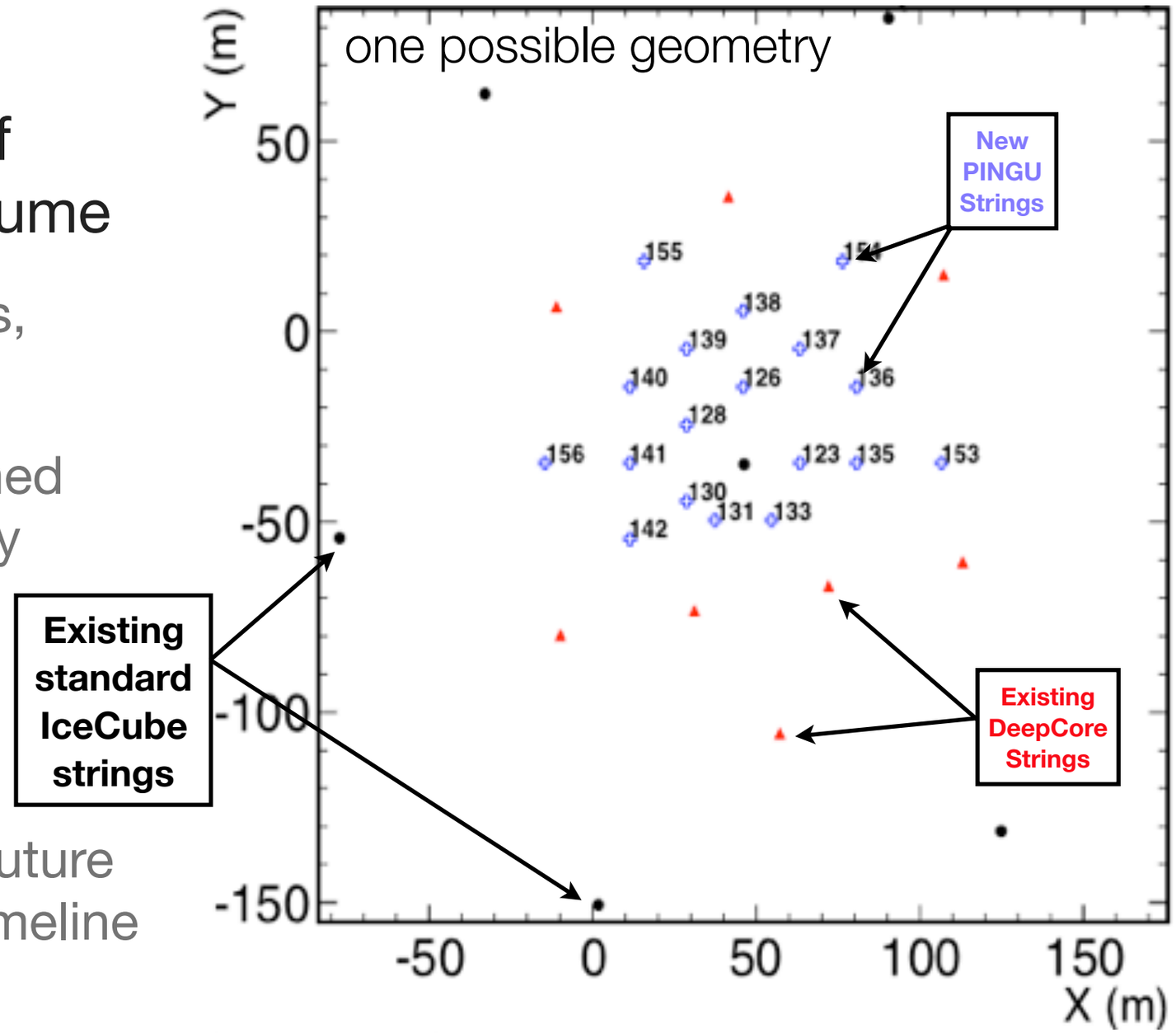
- Disappearing ν_μ should appear in IceCube as ν_τ cascades
  - Effectively identical to neutral current or ν_e CC events
  - Could observe ν_τ appearance as a distortion of the energy spectrum, if cascades can be separated from muon background
- We believe we see neutrino cascade events for the first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



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

Beyond DeepCore: PINGU

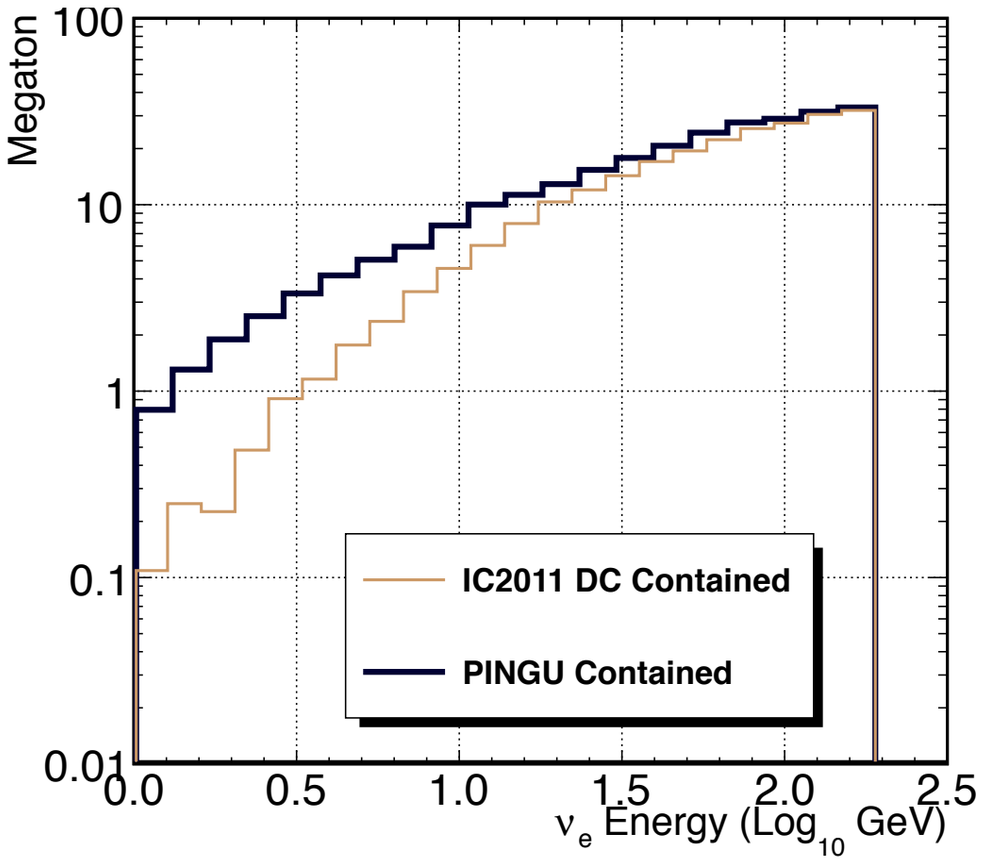
- Developing a proposal to further increase density of instrumentation in DC volume
  - An additional 18-20 strings, 1000-1200 DOMs
  - Make use of well-established IceCube drilling technology
  - Might get to a threshold of ~1 GeV in a ~10 MTon volume
  - Also an R&D platform for future detectors on a ~decade timeline

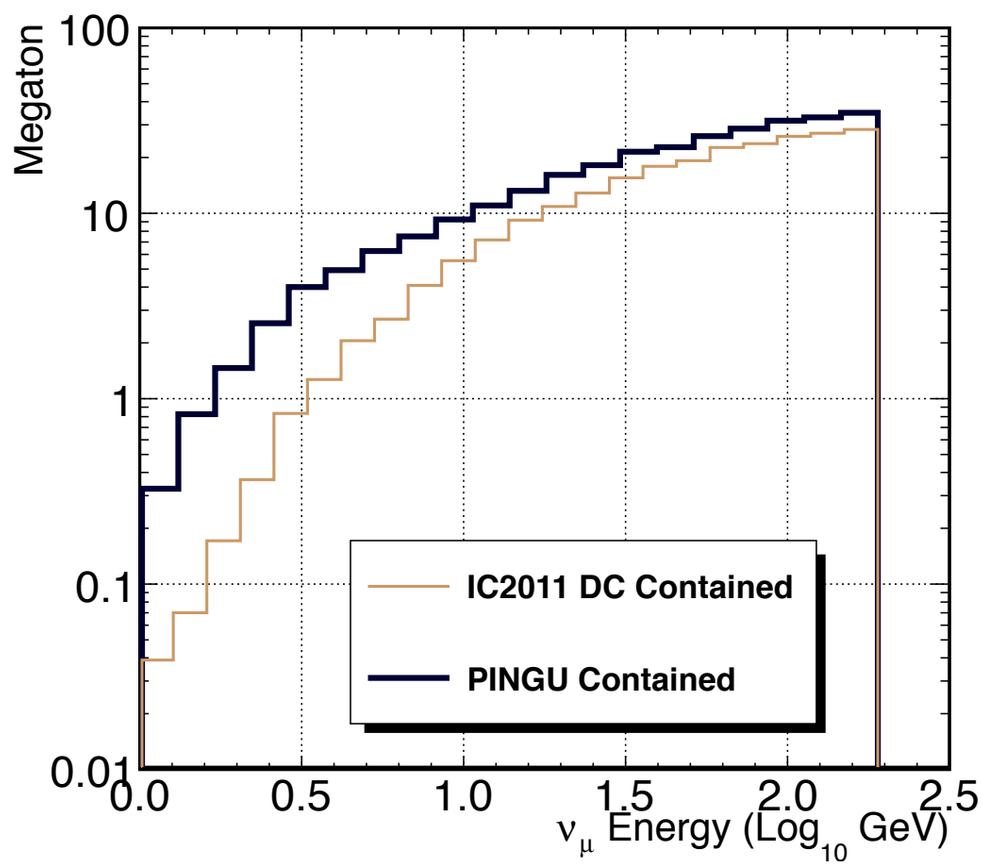


- Price tag expected to be around $25M – $30M

PINGU Effective Volumes

Preliminary



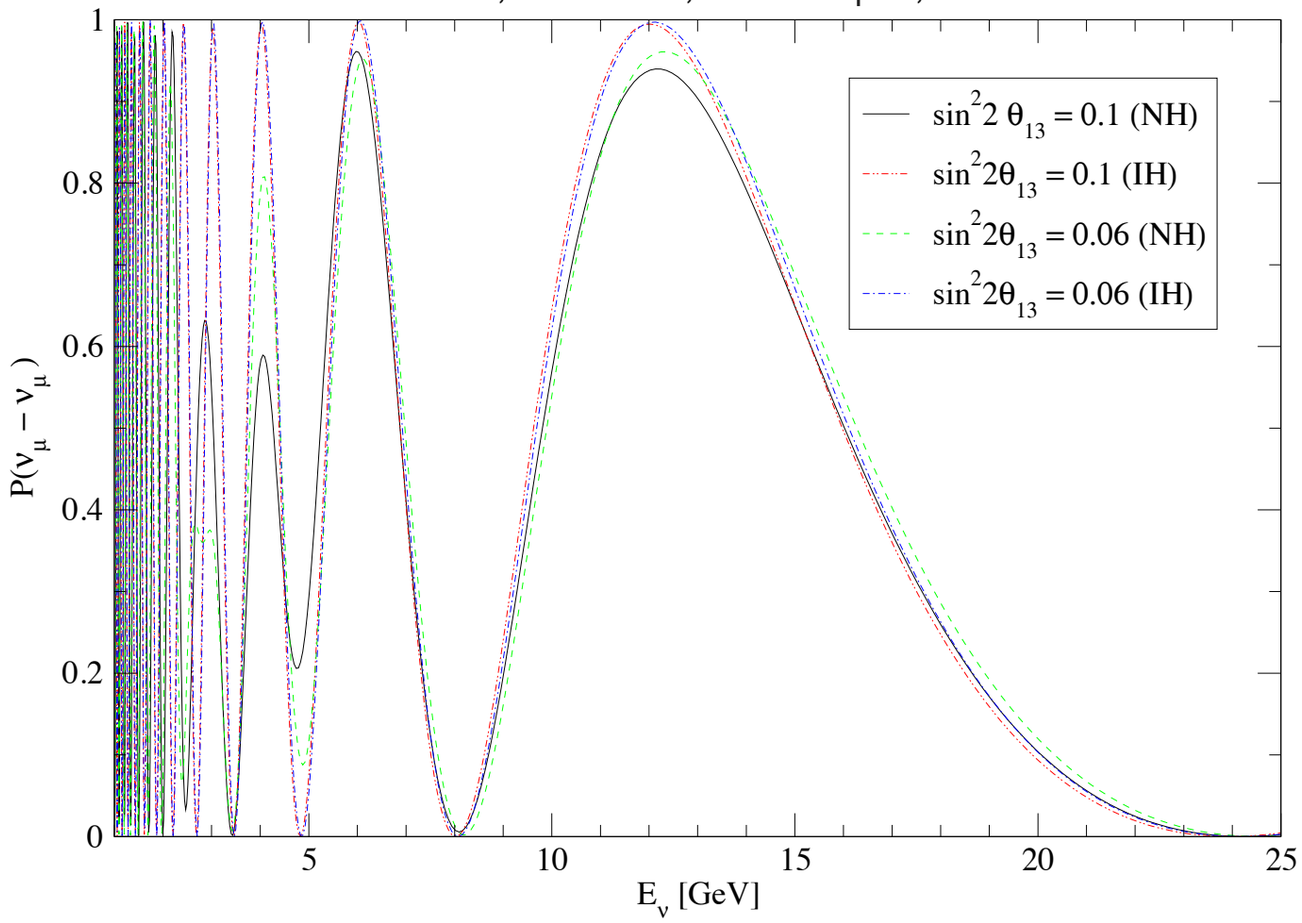


- Increased effective volume for energies below ~15 GeV
- Nearly an order of magnitude increase at 1 GeV (100's of kton)
- Does not include analysis efficiencies, reconstruction precision
  - Absolute scale lower, but improvement over DeepCore likely >10x

PINGU Neutrino Physics

- Lower mass WIMPs
- Increased sensitivity to supernova neutrinos
- Sensitivity to 2nd oscillation peak/trough
- Possible sensitivity to neutrino mass hierarchy via matter effects if θ_{13} is large
  - Exploit asymmetries in ν / $\bar{\nu}$ cross section, kinematics
  - Control of systematics crucial
- Plan for a robust calibration program to understand systematics

Mena, Mocioiu, Razzaque, arXiv:0803.3044

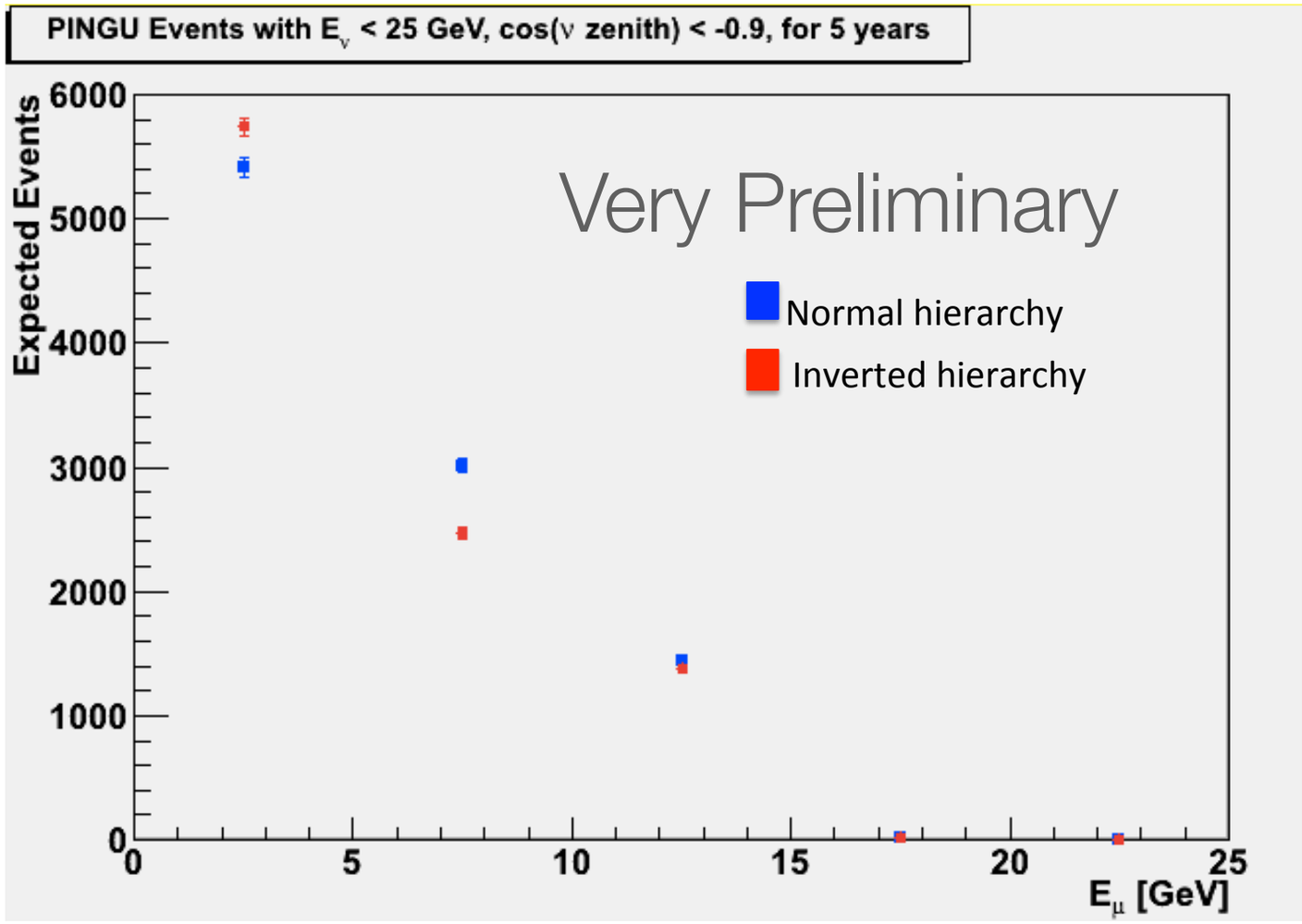


PINGU Hierarchy Measurement?

- Simulations of 20-string PINGU for 5 years with large θ_{13}

- Assumes perfect background rejection, select events within 25° of vertical

  - 5 GeV muon energy bins – ~25 m length resolution



- Up to 20% (=10σ) effects in several energy/angle bins

  - Signal is potentially there, if systematics can be controlled

R&D: Multi-PMT Digital Optical Module

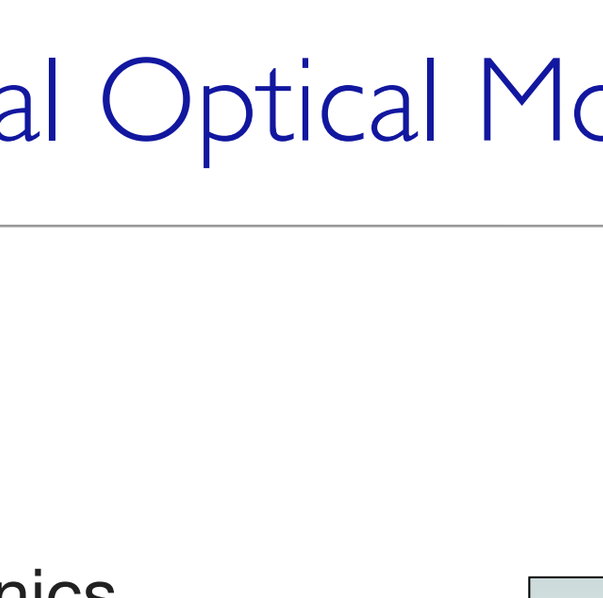
P. Kooijman &
E. de Wolf

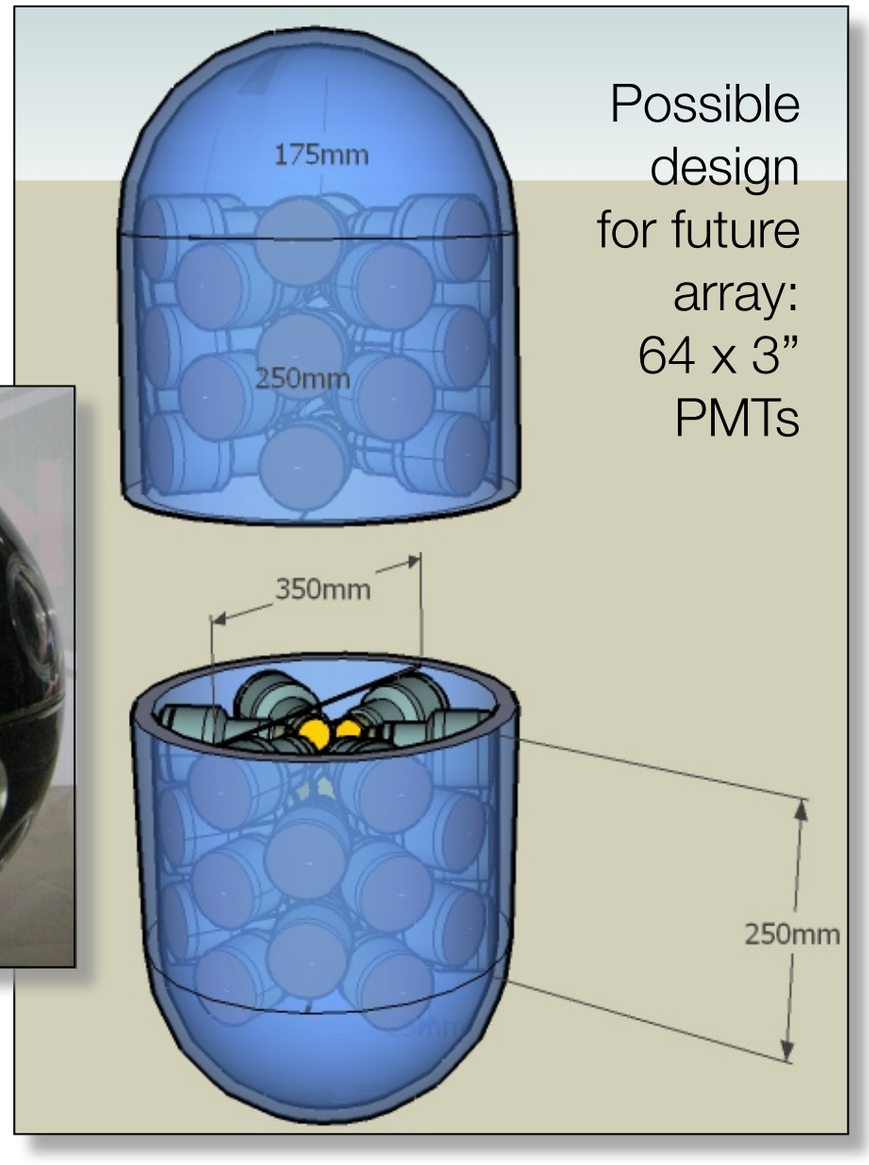
- Based on a KM3NeT design

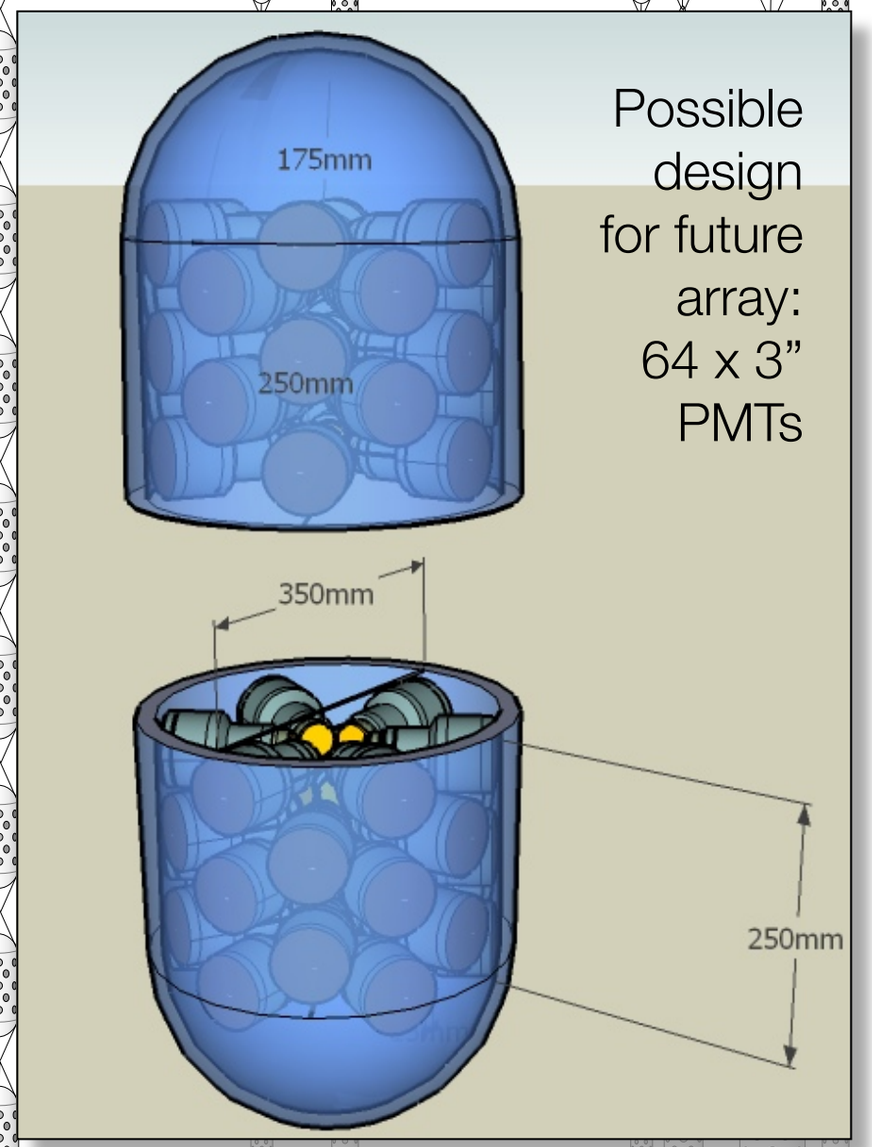
- Glass cylinder containing 64 3” PMTs and associated electronics
  - Effective photocathode area >6x that of a standard IceCube 10” PMT
  - Diameter similar to IceCube DOM, single connector

- 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?

- R&D beginning (U. Katz/P. Kooijman)







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
  - Reduces energy threshold to ~10 GeV
- Particle physics in the ice: significant improvement in sensitivity to dark matter, potential for measurements of neutrino oscillations
  - Initial progress is encouraging, but much remains to be done
- Thinking about a future upgrade of IceCube to further extend its particle physics capabilities – PINGU and possibly beyond
  - Potential for significant contributions to fundamental particle physics, but requires a level of precision better than we have achieved so far