ICECUBE

PINGU (and MICA): future facilities for indirect dark matter searches

Darren R. Grant
Centre for Particle Physics
University of Alberta

SNOWMASS - Cosmic Frontier Workshop
SLAC
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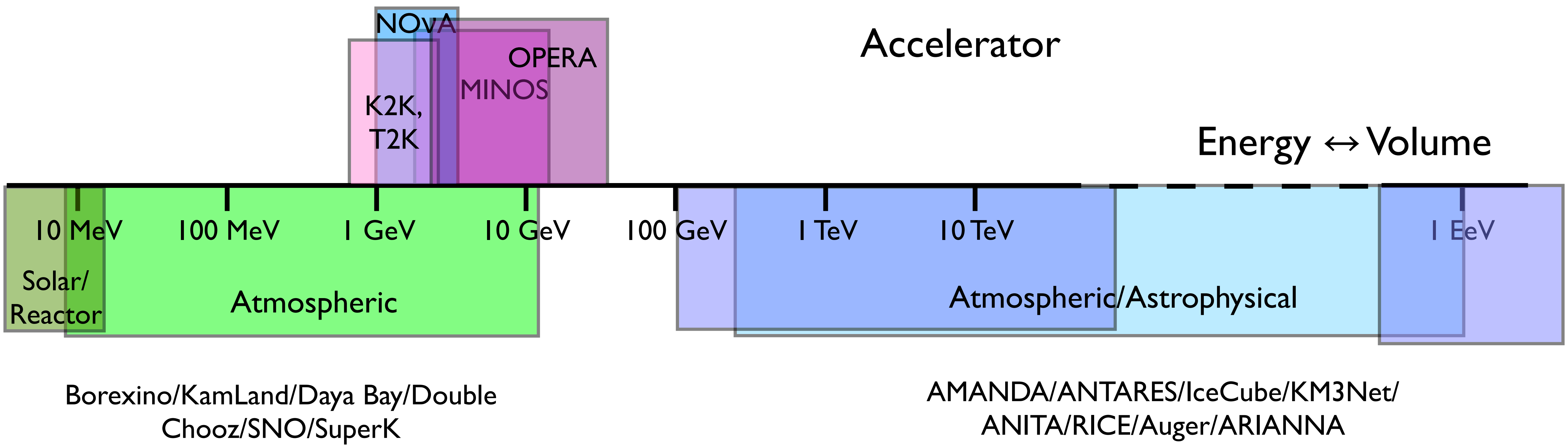
UNIVERSITY OF ALBERTA

The Neutrino Detector Spectrum



** boxes select primary detector physics energy regimes and are not absolute limits*

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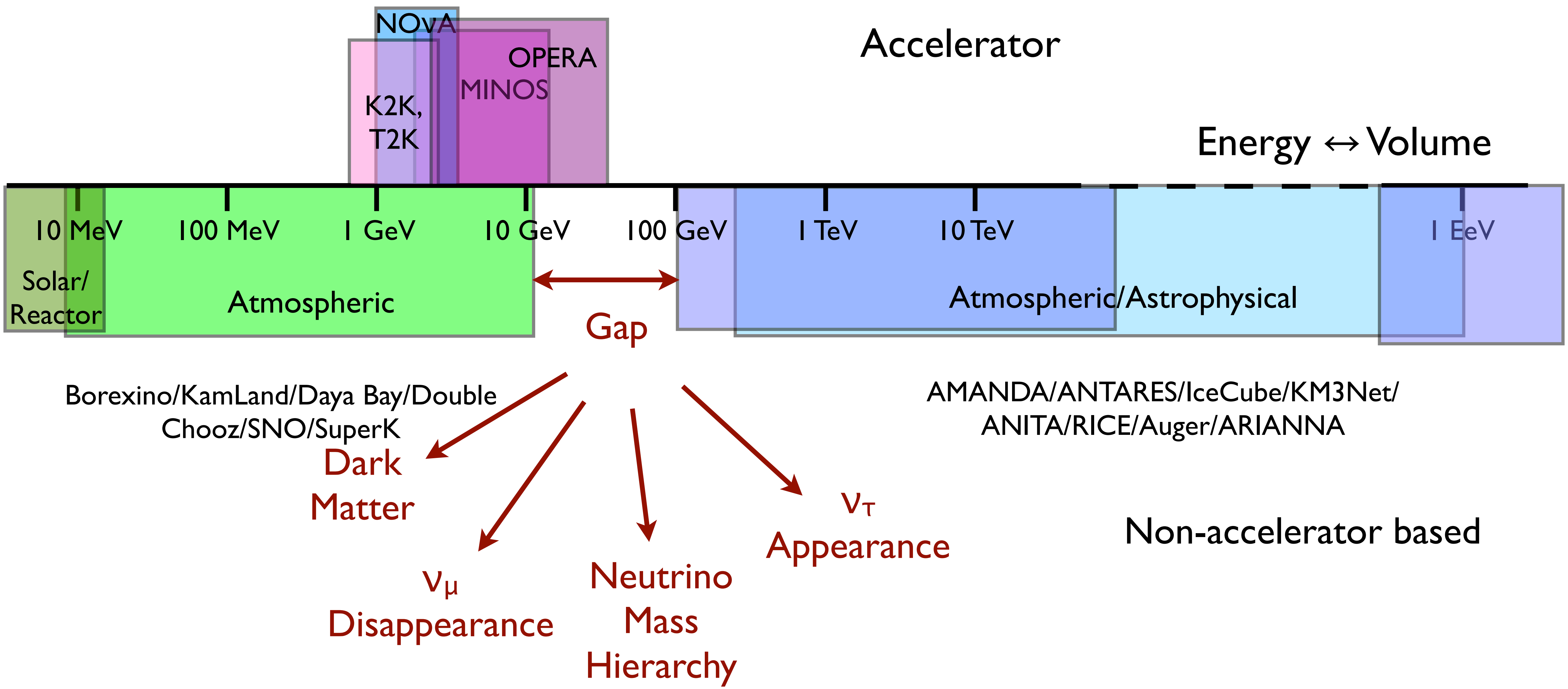

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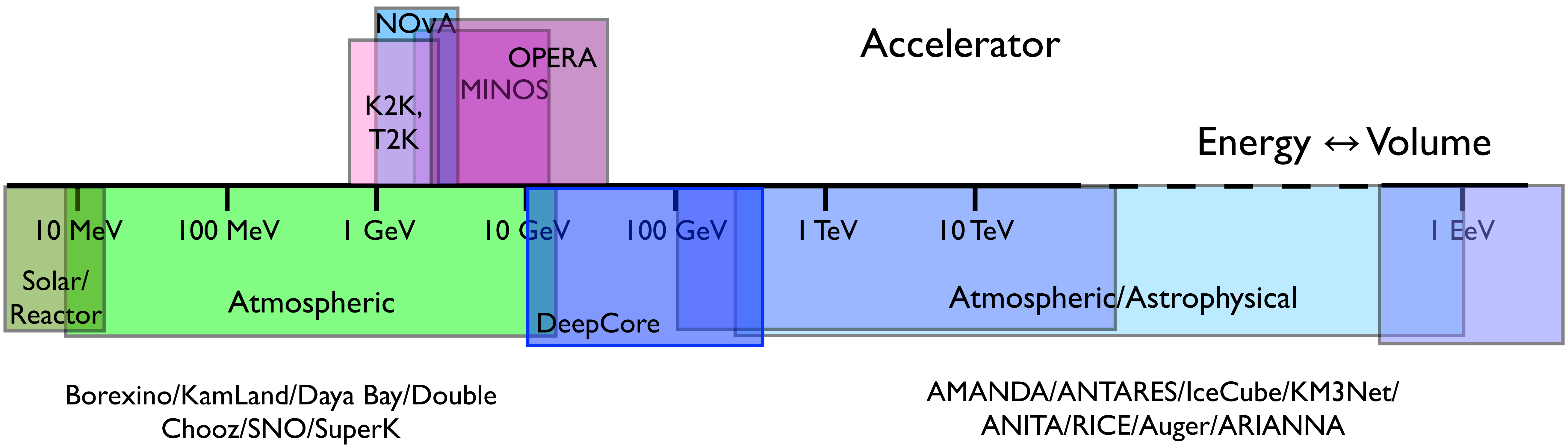

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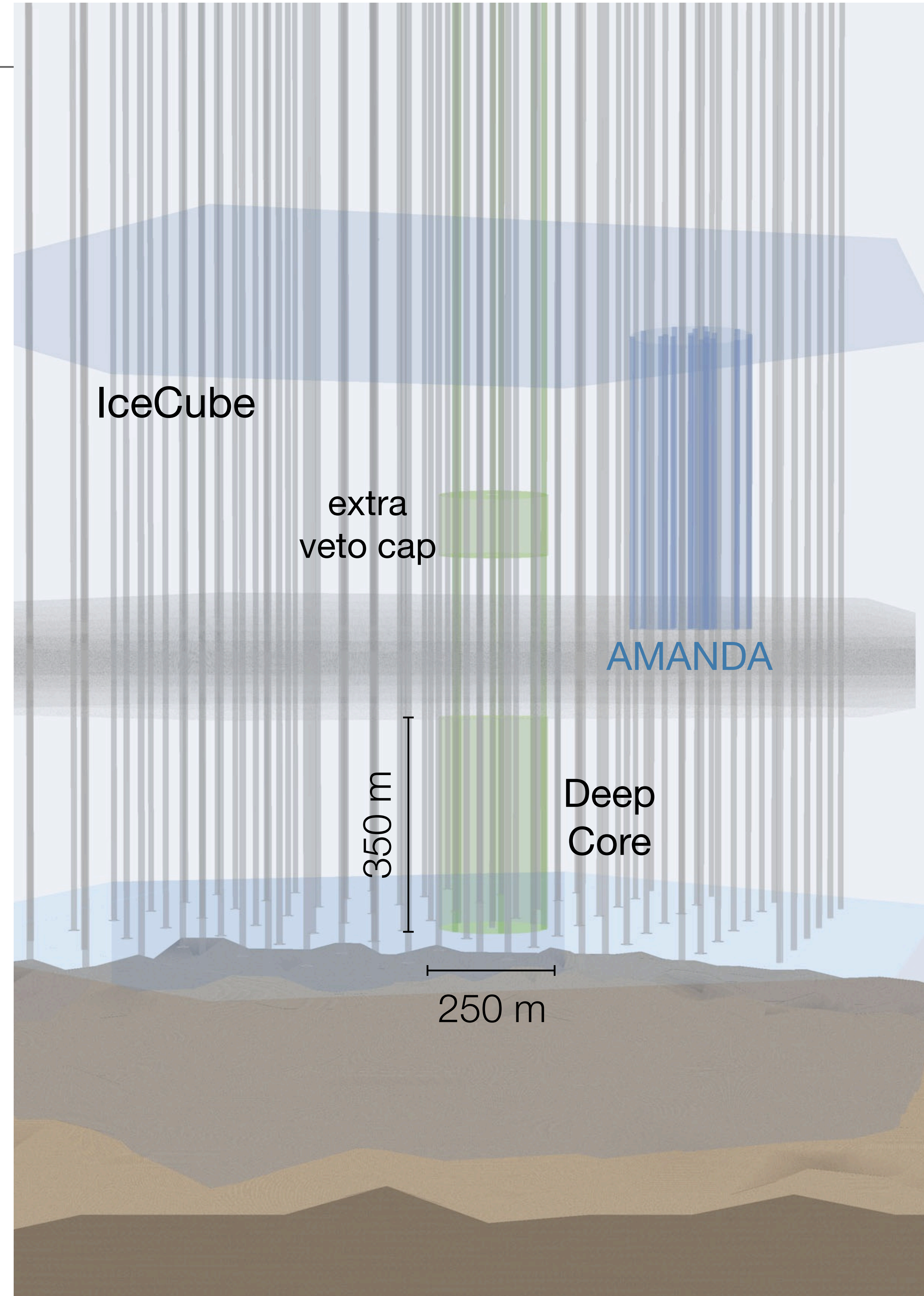
IceCube-DeepCore

- IceCube extended its "low" energy response with a densely instrumented infill array: DeepCore Astropart. Phys. Vol.35 Issue 10 (615-624)
  - Significant improvement in capabilities from ~10 GeV to ~300 GeV (ν_μ)
- Scientific Motivations:
  - primarily designed for indirect search for dark matter
  - also permits studies of particle physics with atmospheric neutrinos (Neutrino oscillations that possibly include ν_τ appearance)
  - opens a window to neutrino astronomy at low energies (southern sky galactic sources, low-energy flux from GRBs...)

IceCube-DeepCore

Astropart. Phys. Vol.35 Issue 10 (615-624)

- More densely instrumented region at the bottom centre of IceCube
  - Eight special strings plus 12 nearest standard strings (72 m inter-string horizontal spacing (six with 42 m spacing)
  - ~35% higher Q.E. PMTs
  - ~5x higher effective photocathode density



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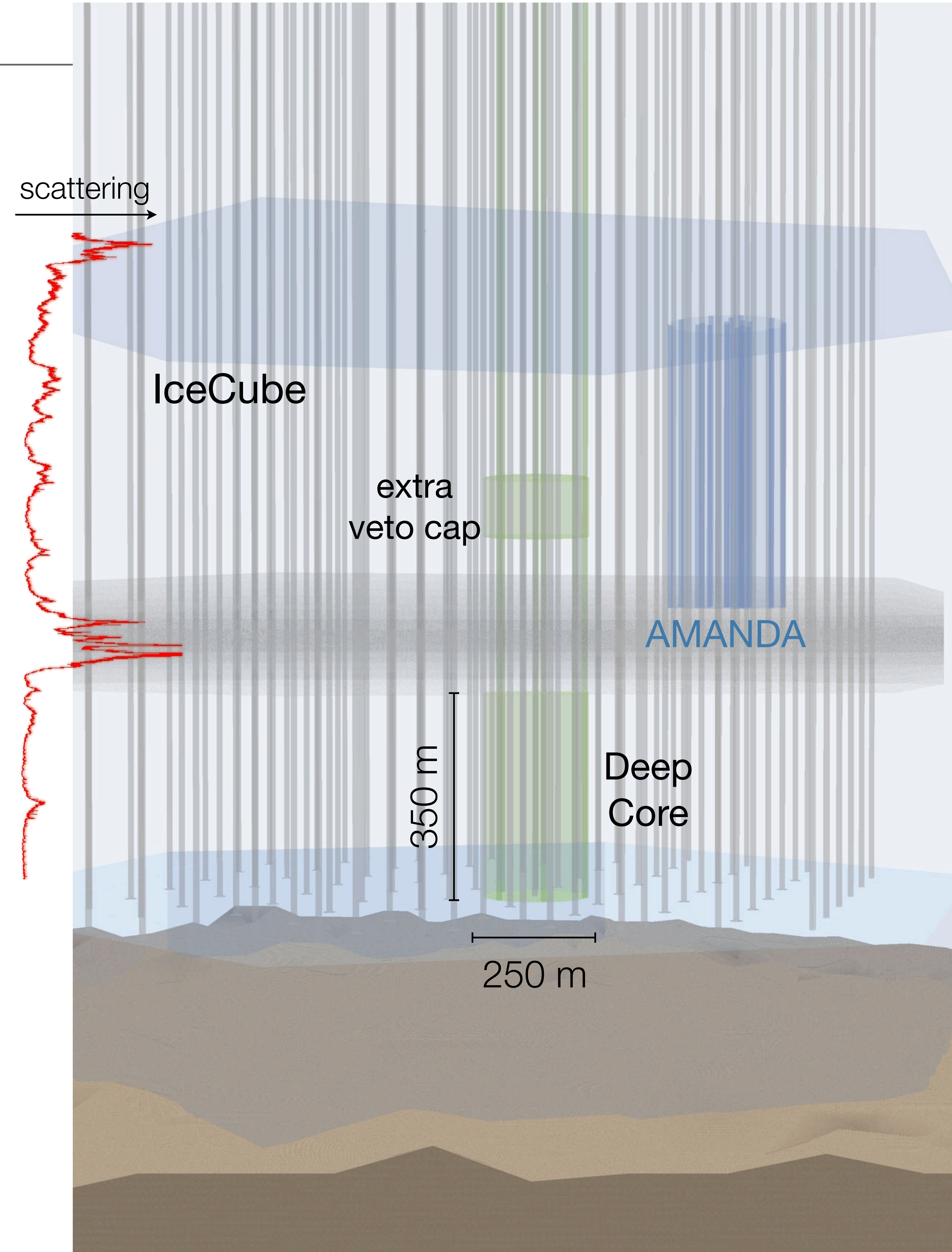
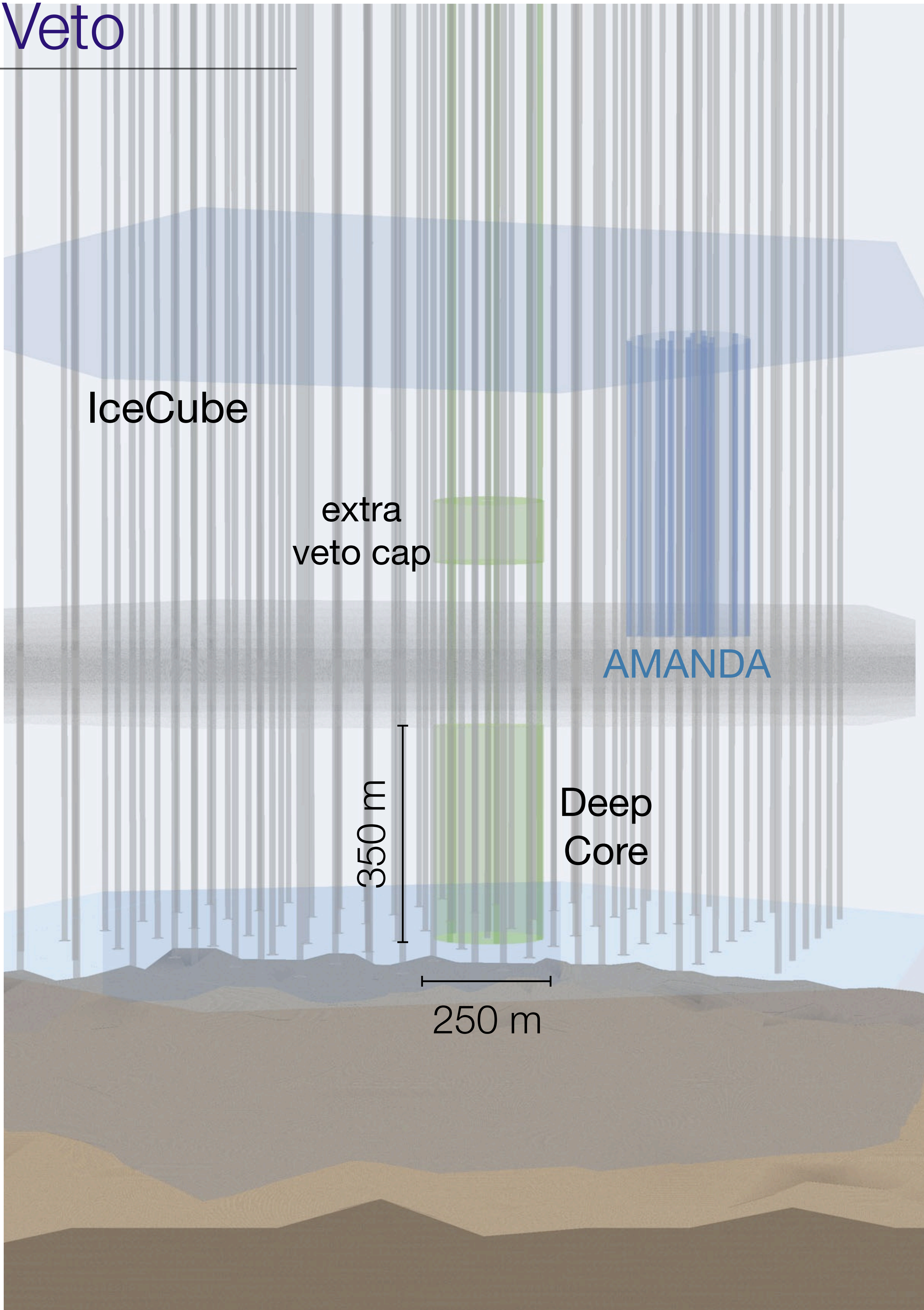
- Deployed mainly in the clearest ice, below 2100 m
  - λ_{eff} > ~45-50 m



DeepCore Atmospheric Muon Veto

- The cosmic ray muon background (around 10^6 times the atmospheric neutrino rate)
- Overburden of 2.1 km water-equivalent is substantial, but not as large as at deep underground labs



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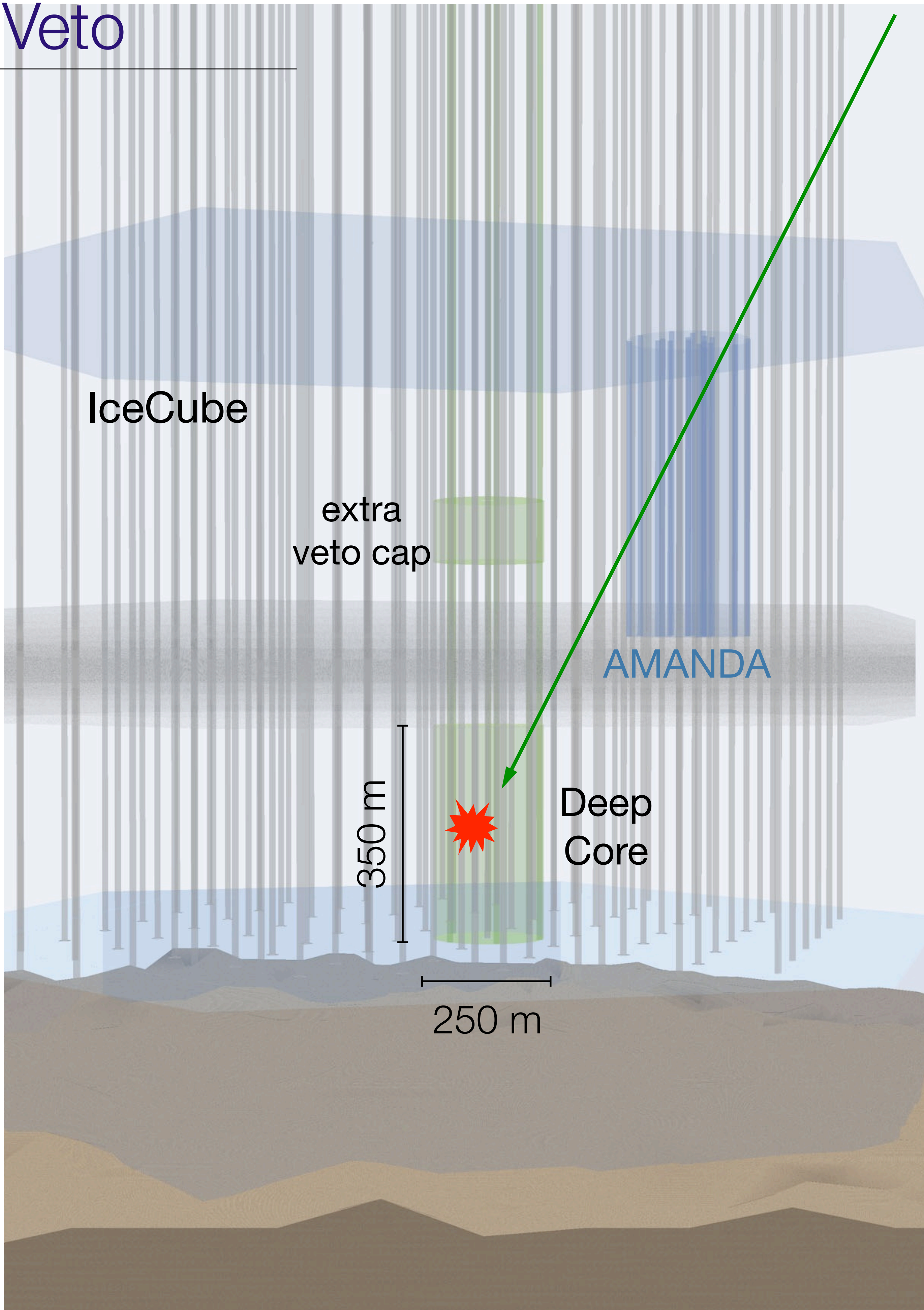
  - ~40 horizontal layers of modules above; 3 rings of strings on all sides
  - Effective μ-free depth much greater



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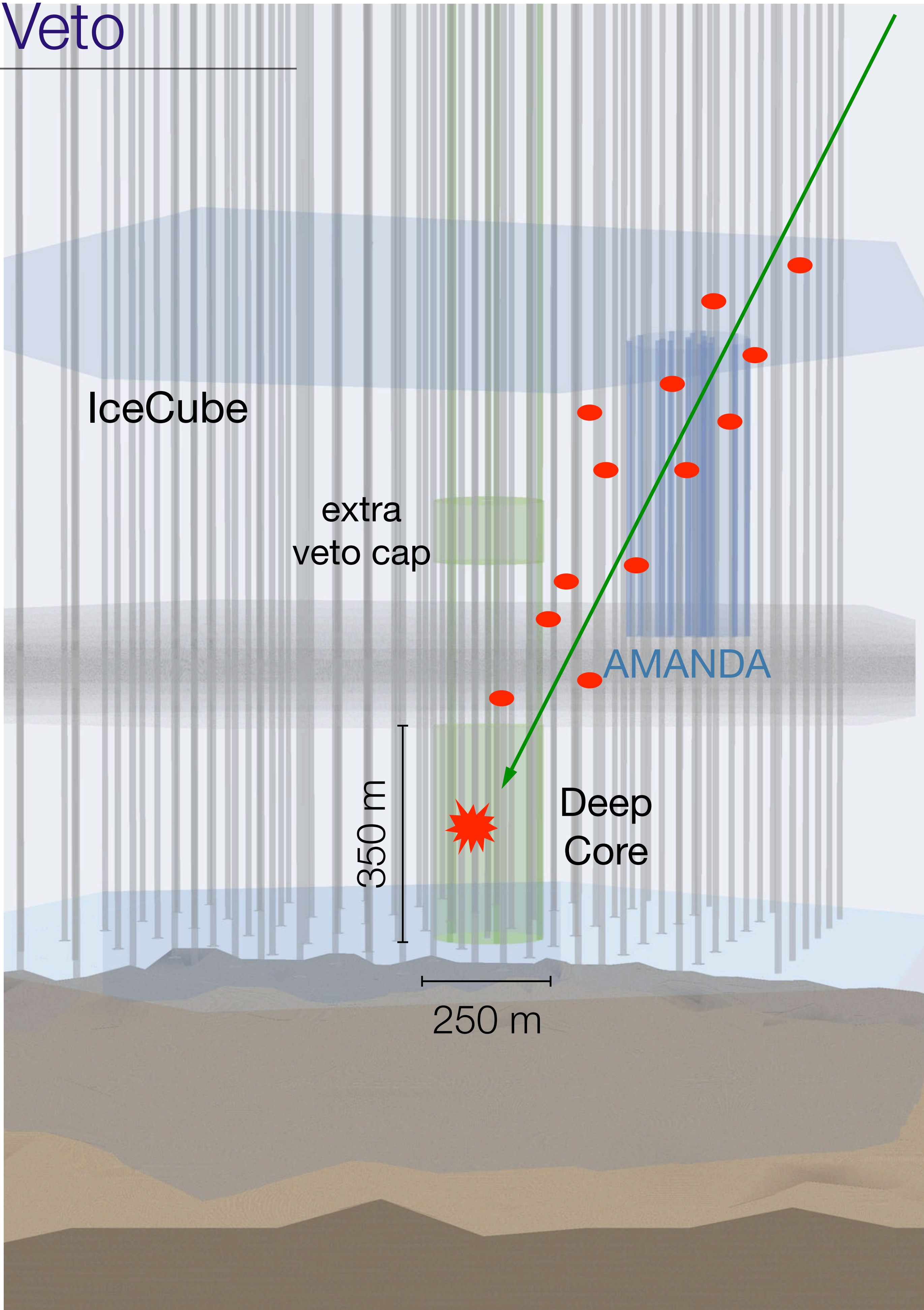

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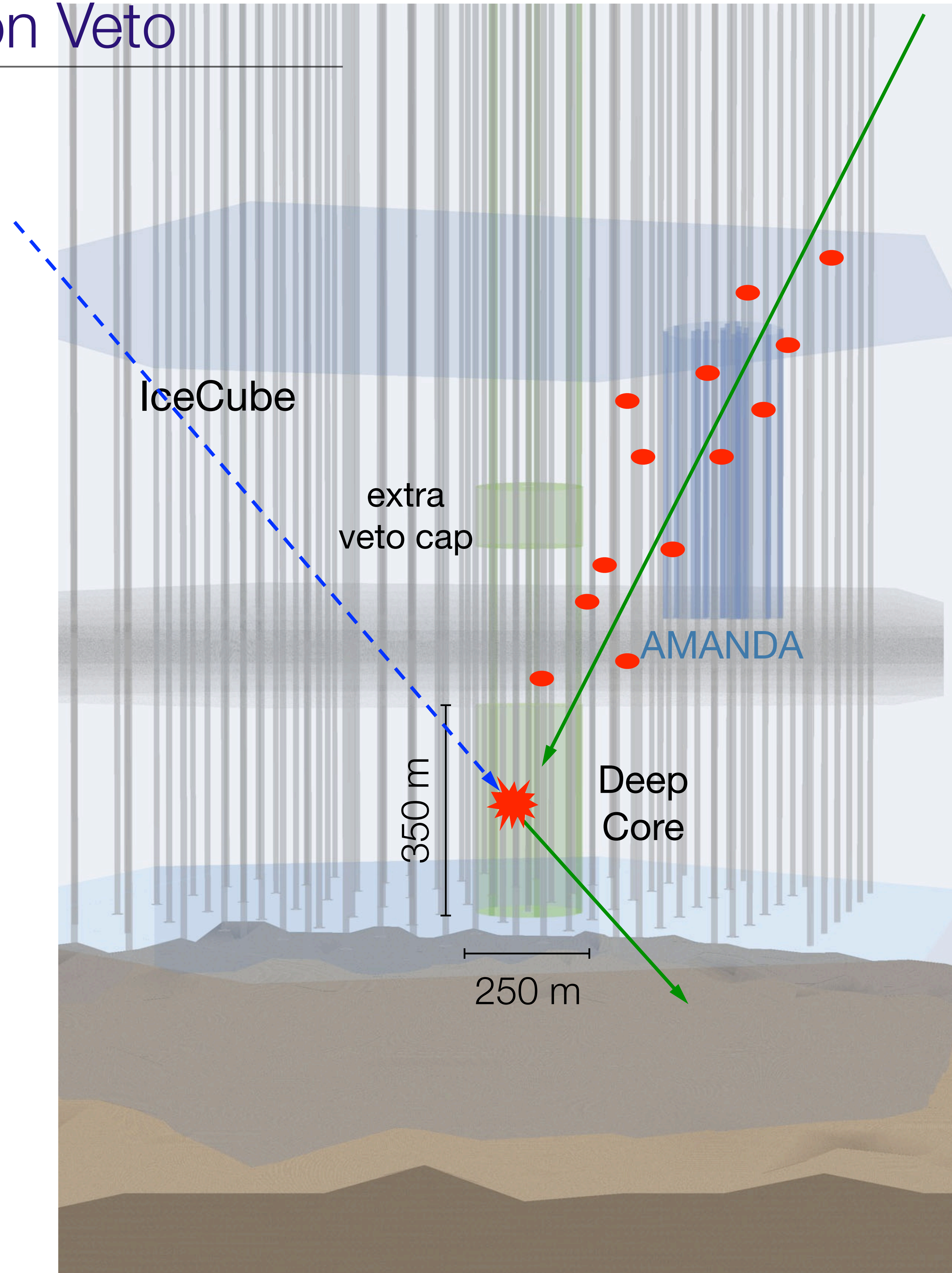

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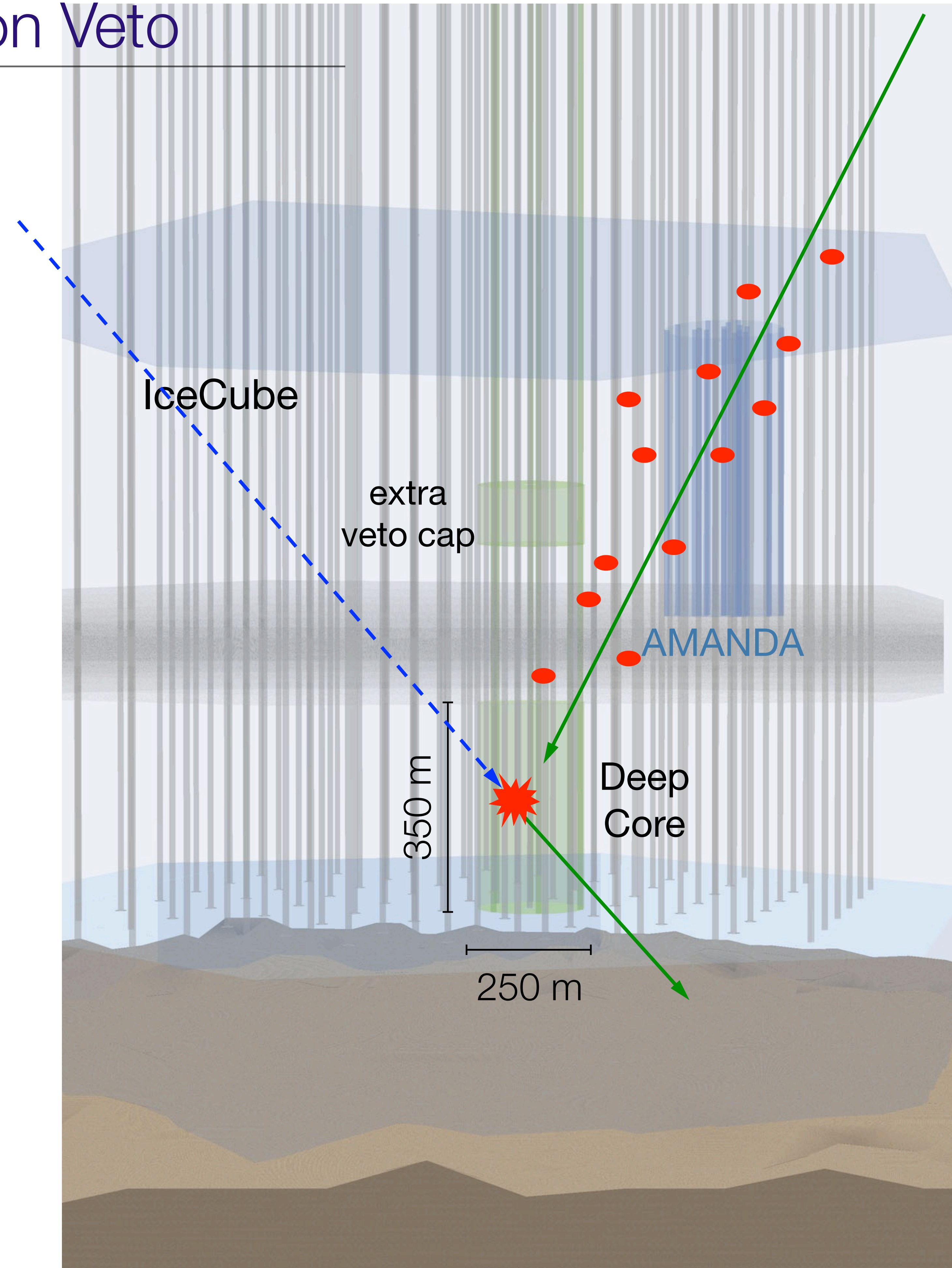
- However, top and outer layers of IceCube provide an active veto shield for DeepCore
    - ~40 horizontal layers of modules above; 3 rings of strings on all sides
    - Effective μ-free depth much greater
- Can use to distinguish atmospheric μ from atmospheric or cosmological ν (access to the Southern Hemisphere sky!)
- Vetoing algorithms surpass the required 10^6 level of background rejection

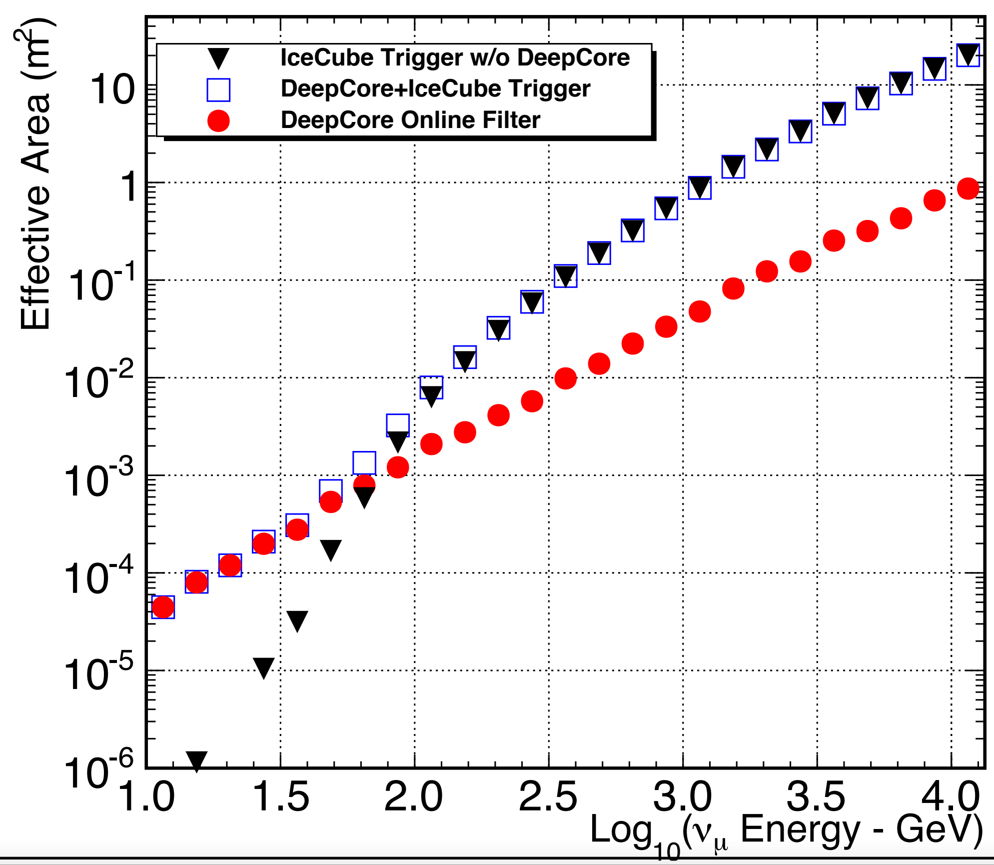


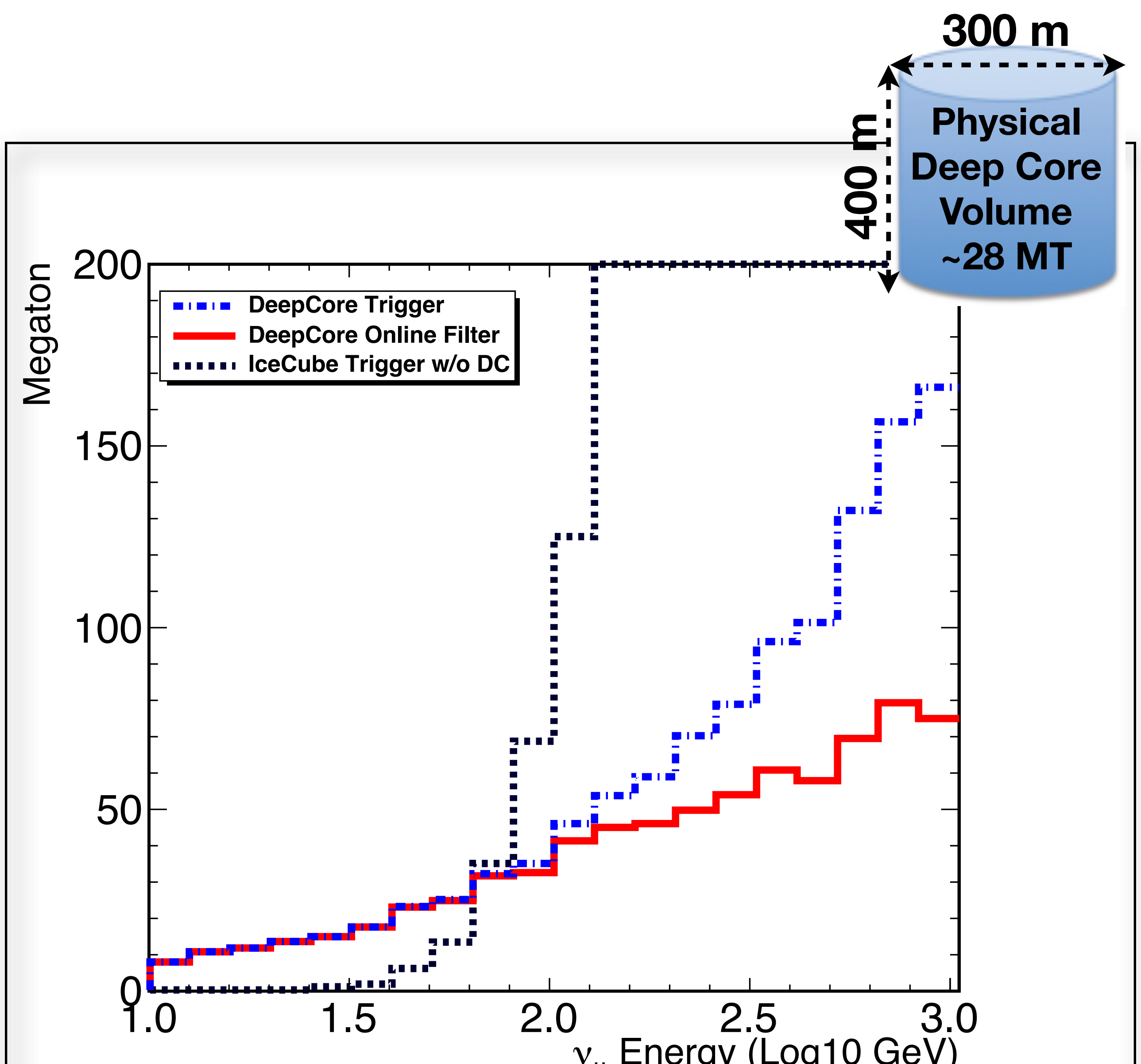
DeepCore Effective Area and Volume

DeepCore provides an ~25MTon volume with a lower energy threshold that results in O(10^5) neutrino triggers per year

Effective area for ν_μ at trigger level

Reconstruction efficiencies not included yet – relative effect likely to increase





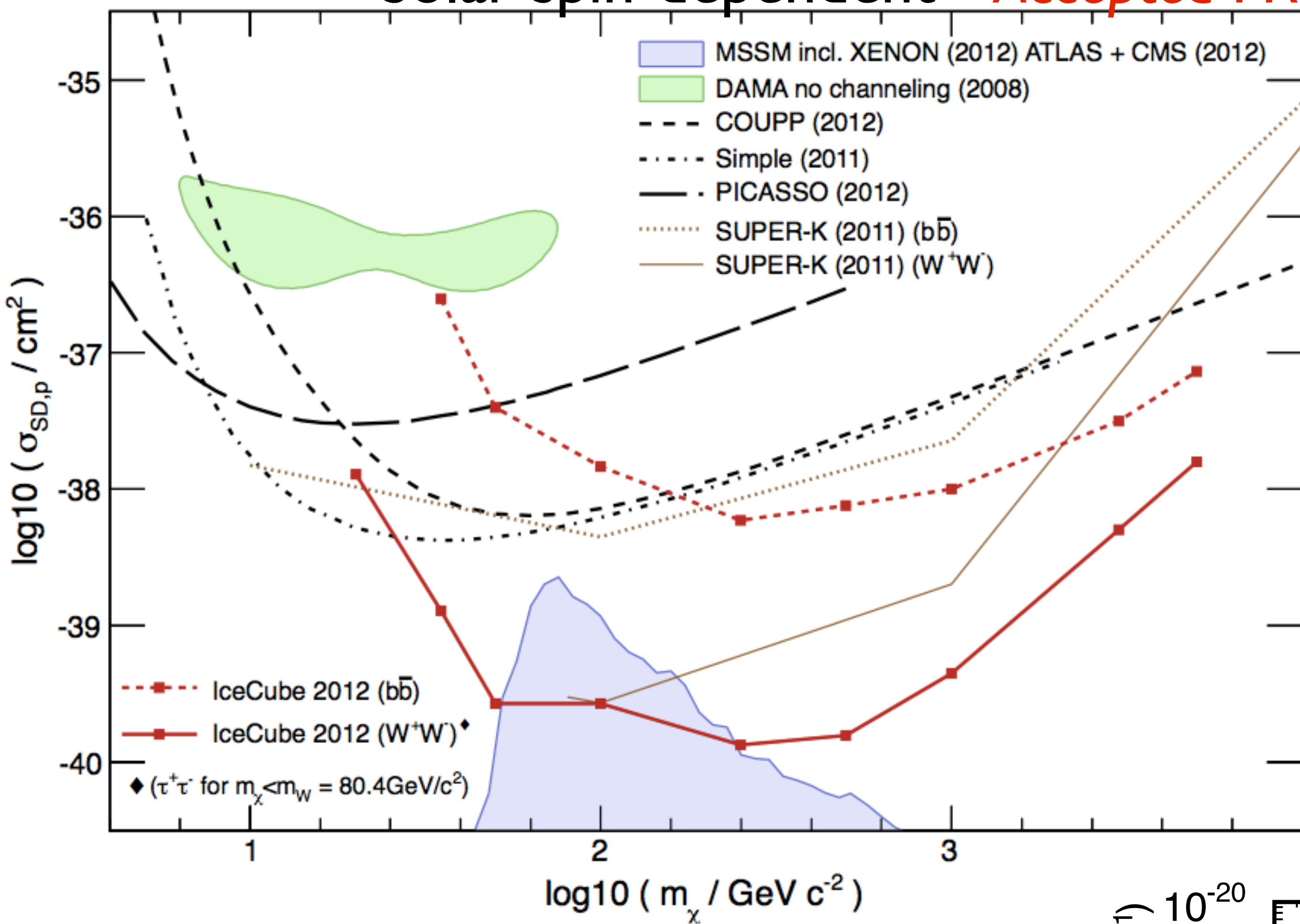
Effective volume for muons from ν_μ interacting in Deep Core

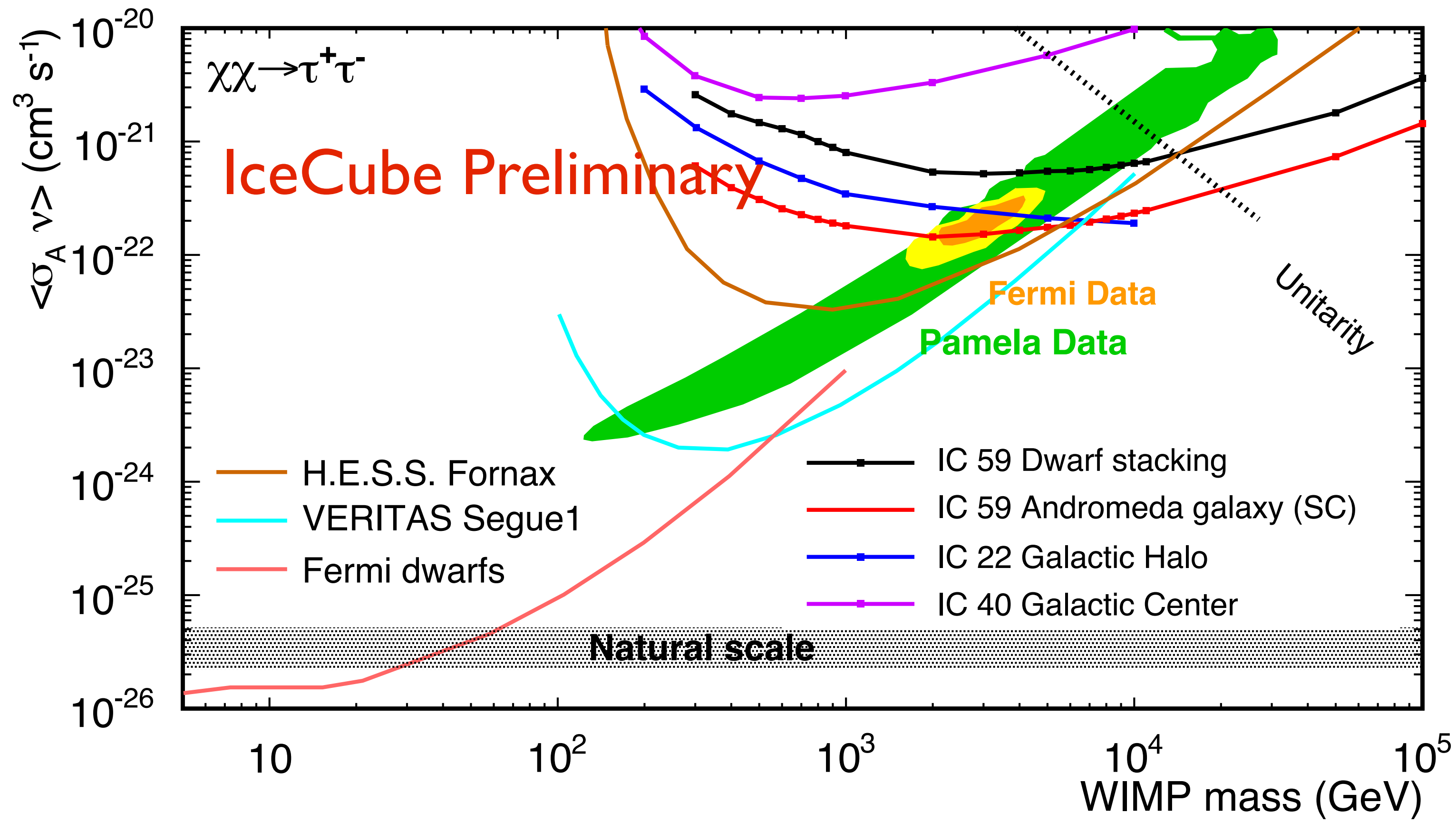
NB: full analysis efficiency *not* included yet

Trigger: $\geq$3 DOMs hit in 2.5μs;
Online Veto: No hits consistent with muons outside DeepCore volume

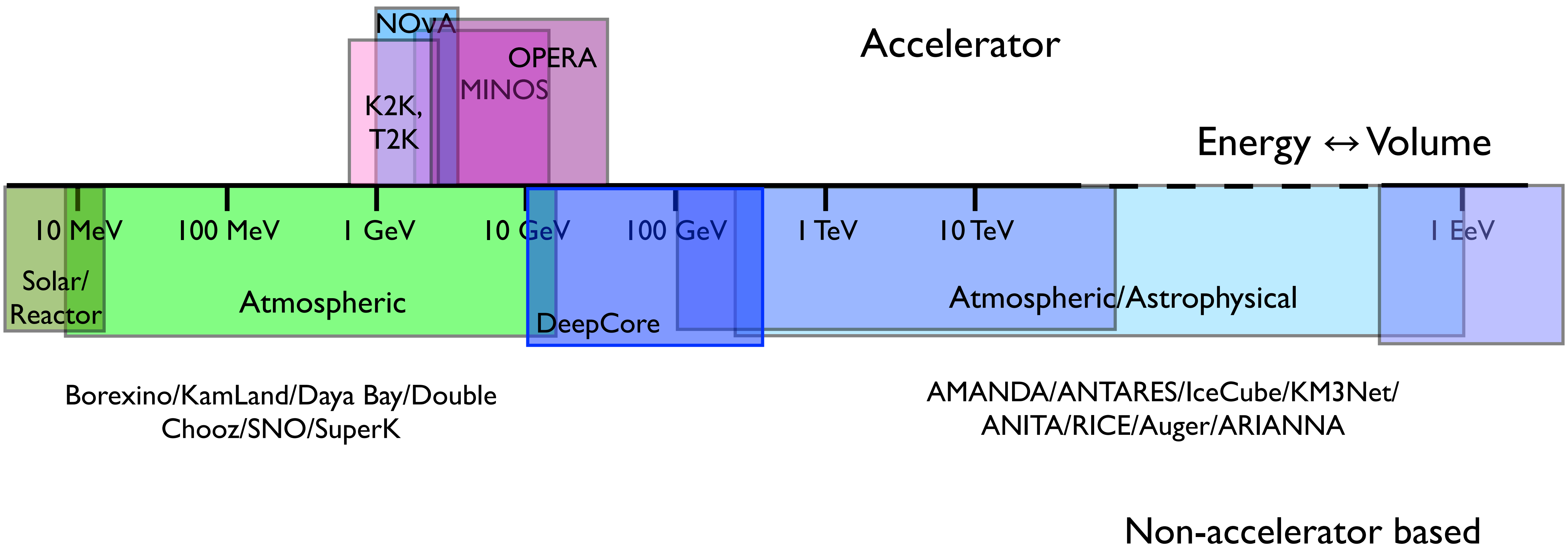
IceCube-DeepCore indirect WIMP searches

Solar spin-dependent *Accepted PRL*





The Neutrino Detector Spectrum



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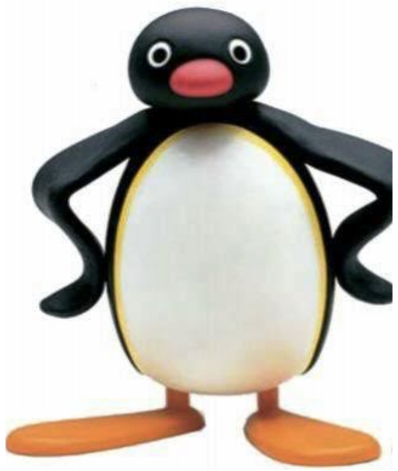
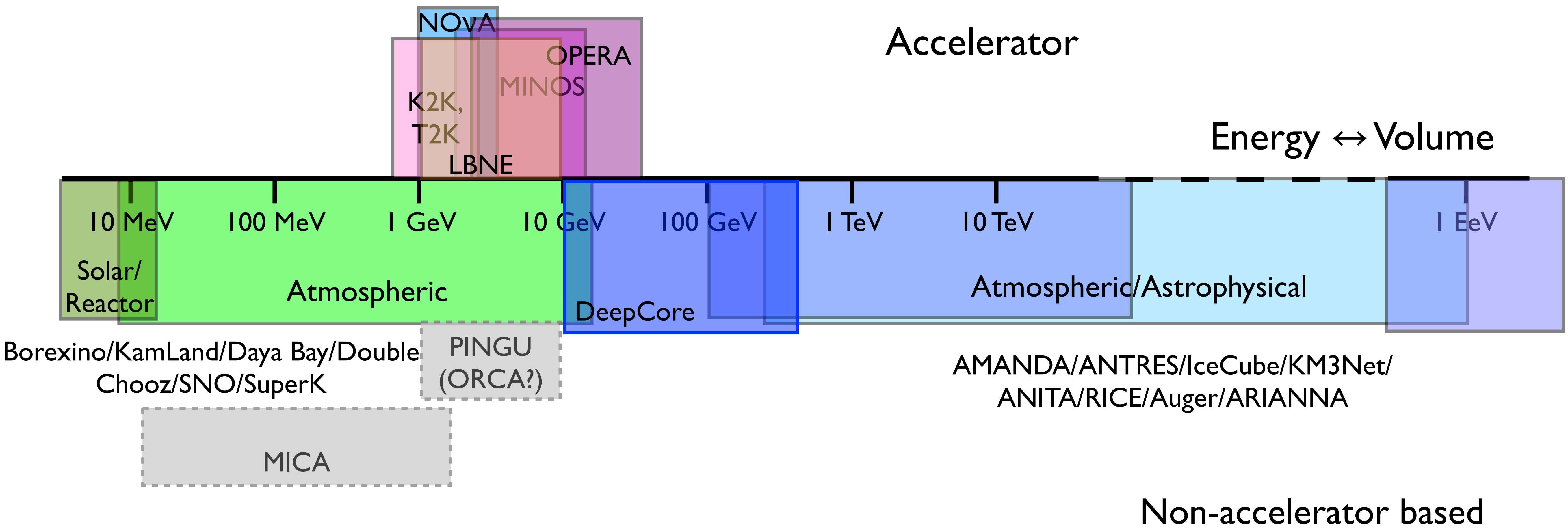
PINGU/MICA

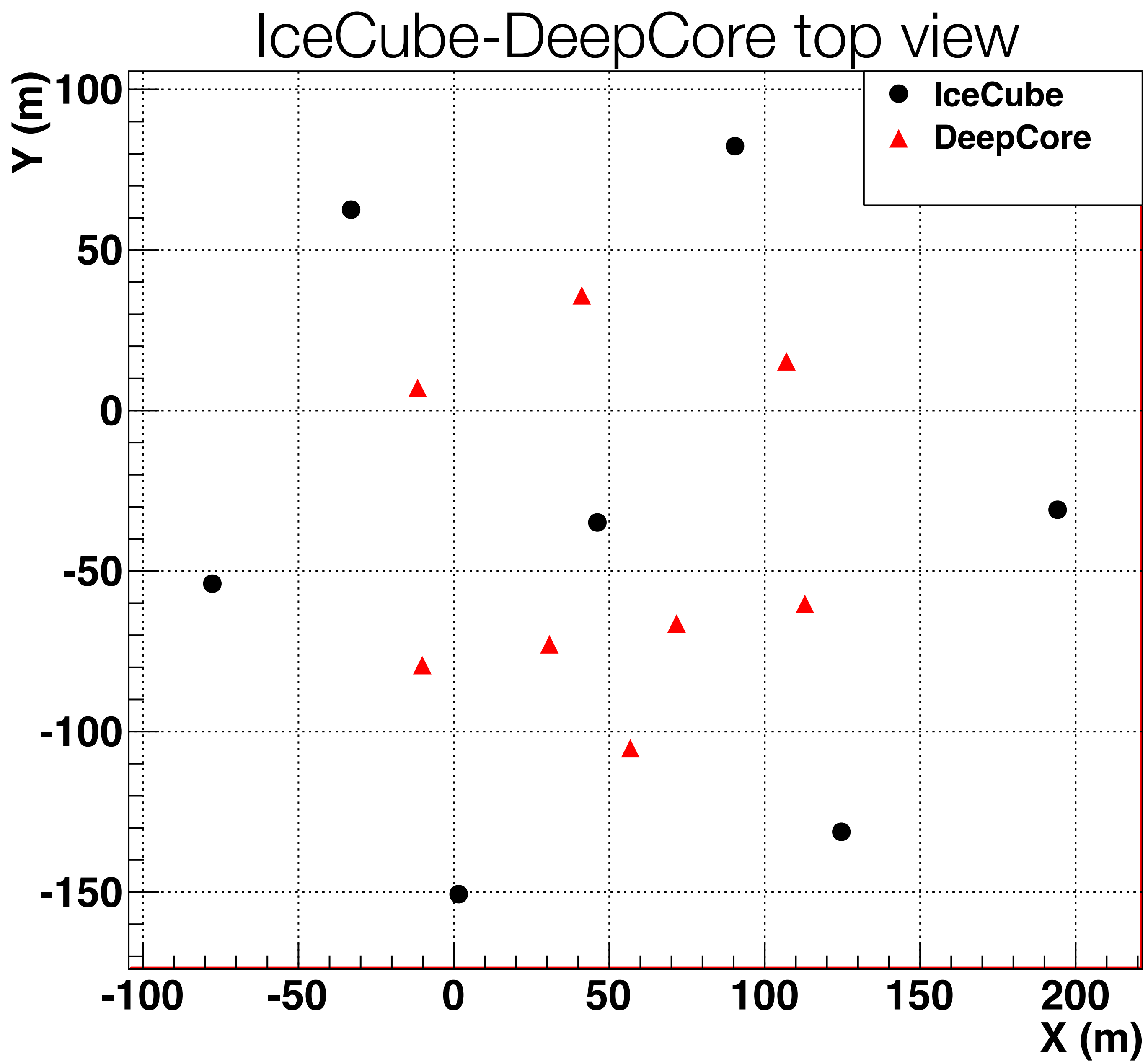
(Precision IceCube Next Generation Upgrade/Multimegaton Ice Cherenkov Array)





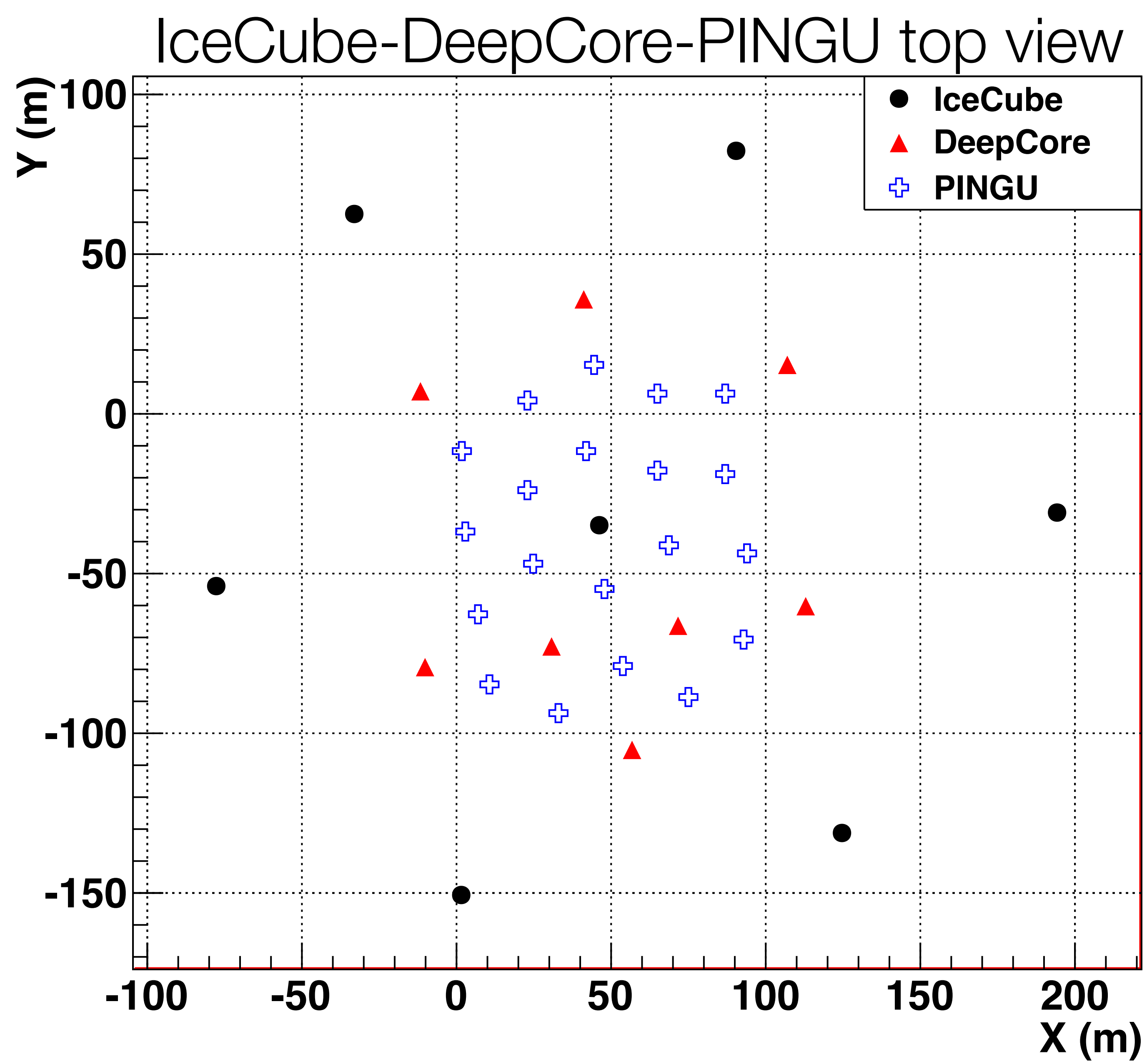
The PINGU detector design

- 78 Strings
  - 125m string spacing
  - 17m DOM spacing
- Add 8 strings
  - 75m string spacing
  - 7m DOM spacing

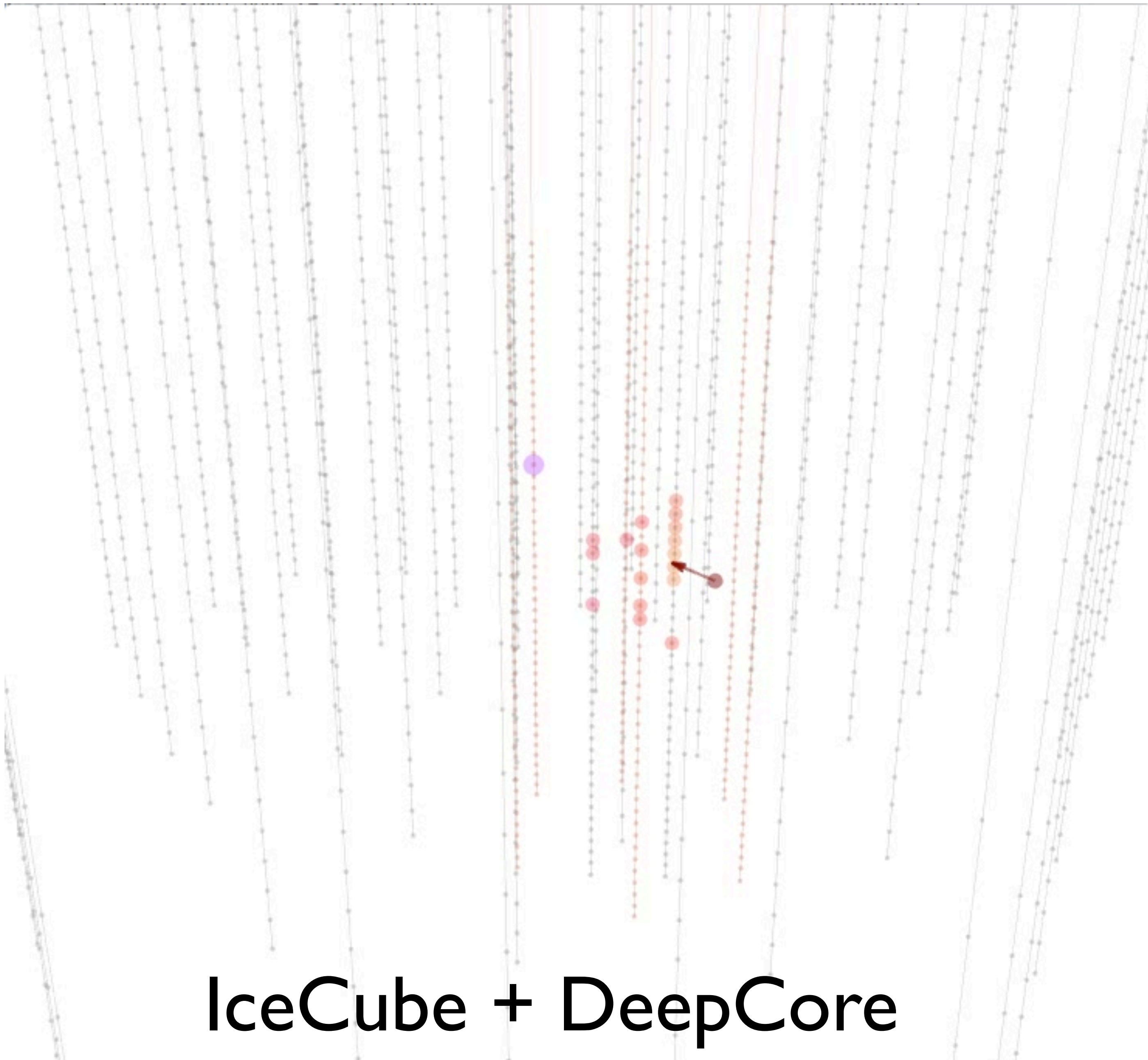


The PINGU detector design

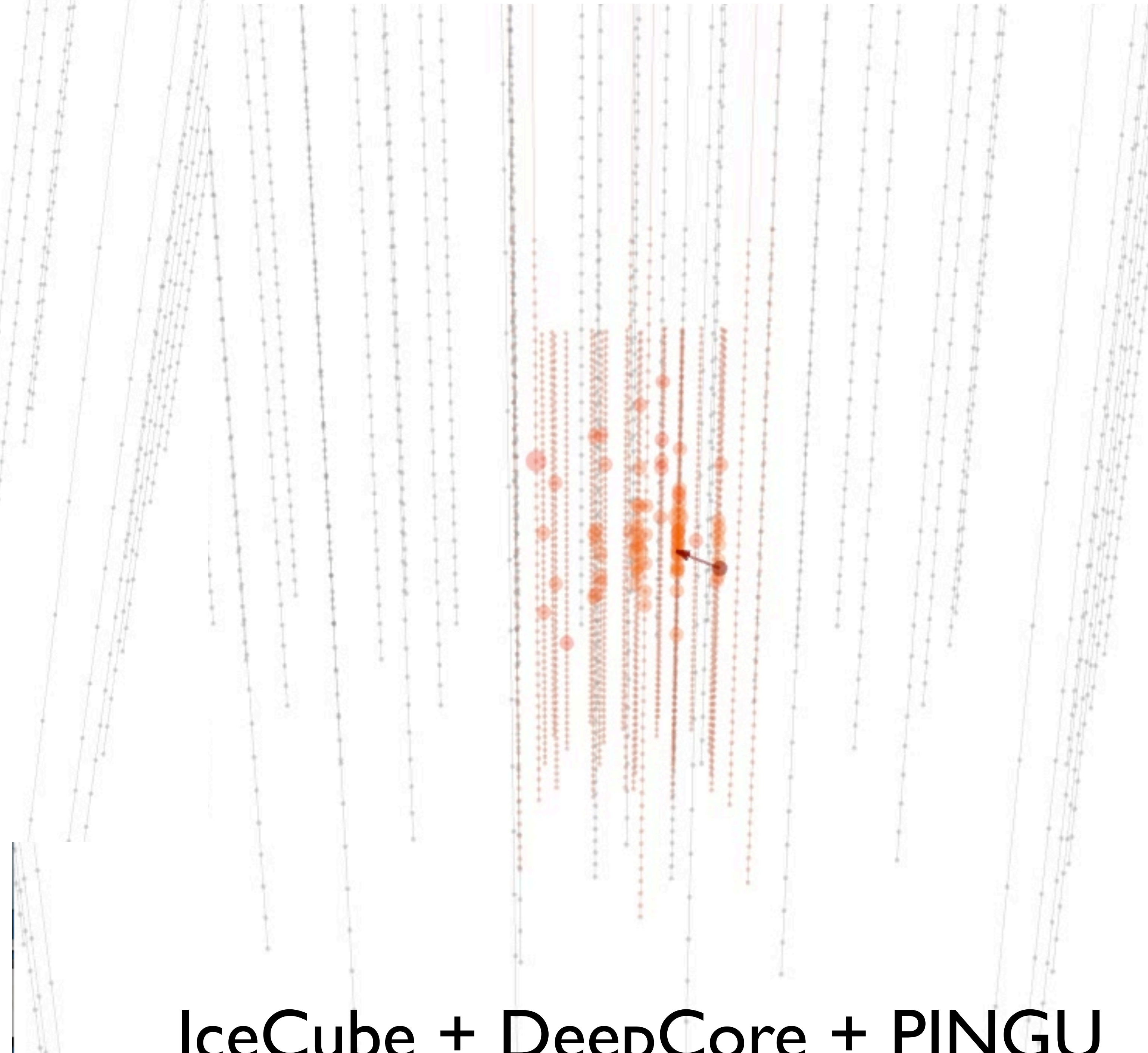
- 78 Strings
  - 125m string spacing
  - 17m DOM spacing
- Add 8 strings
  - 75m string spacing
  - 7m DOM spacing
- One possible extension is to add 20 strings
  - 26m string spacing
  - 5m DOM spacing
  - detector geometry is currently under optimization for the physics output



DeepCore and PINGU events



- 9.28 GeV Neutrino, 4.9 GeV muon, 4.5 GeV cascade



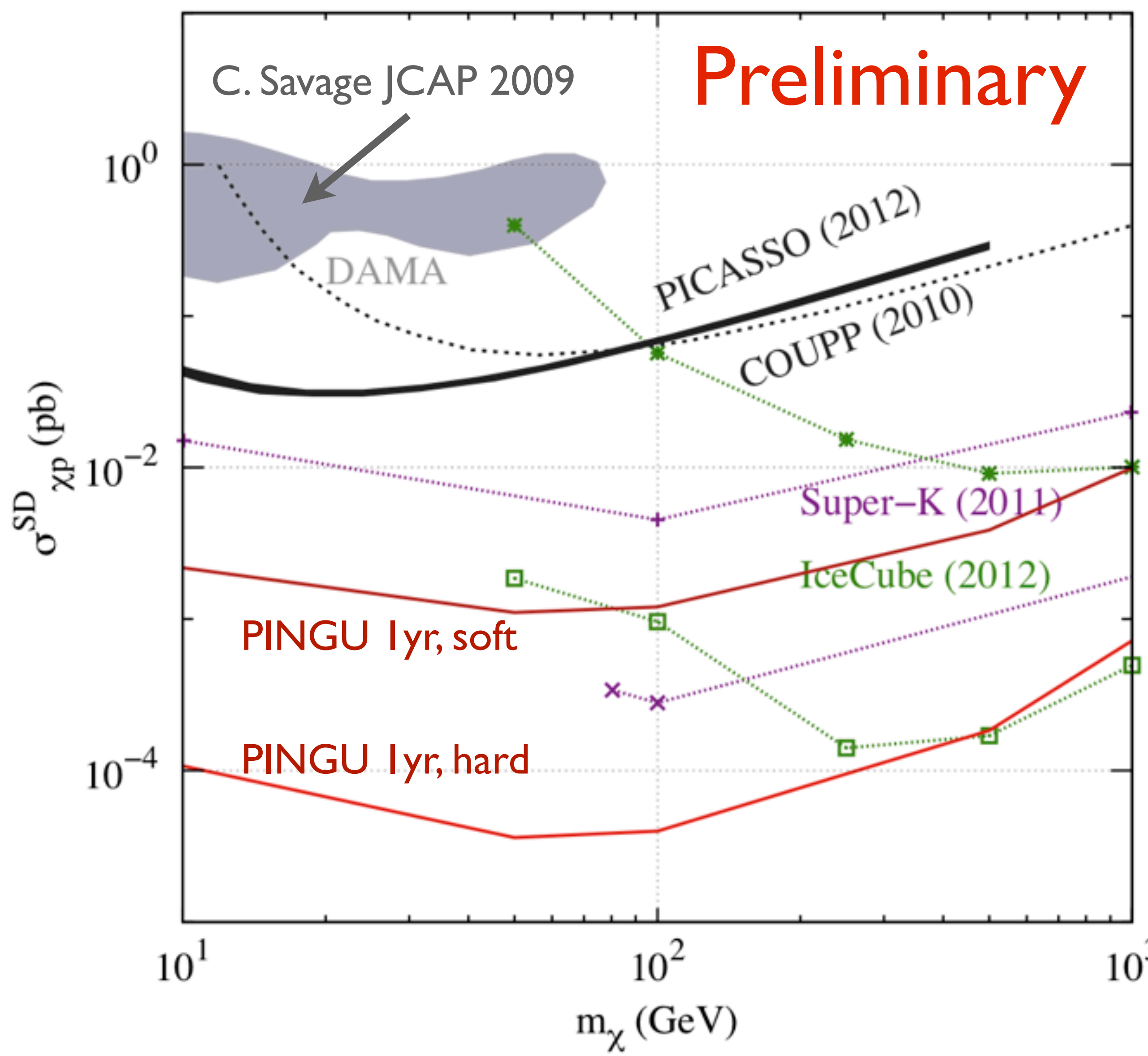
PINGU indirect WIMP searches

- Probe lower mass WIMPs
- Gain sensitivity to second oscillation peak/trough
  - will help pin down $(\Delta m_{23})^2$
  - **definitive measurement of the neutrino mass hierarchy**
- Gain increased sensitivity to supernova neutrino bursts
  - Extension of current search for coherent increase in singles rate across entire detector volume
  - Only 2±1 core collapse SN/century in Milky Way
    - need to reach out to our neighboring galaxies
    - Gain depends strongly on noise reduction via coincident photon detection (e.g., in neighbor DOMs)
- Initiate an extensive calibration program
- Pathfinder technological R&D for MICA

PINGU indirect WIMP searches

- Low-mass WIMP scenarios well testable at trigger level
- Next steps:
  - Detailed study with full PINGU simulation
  - More sophisticated event reconstruction
  - Check atmospheric muon background

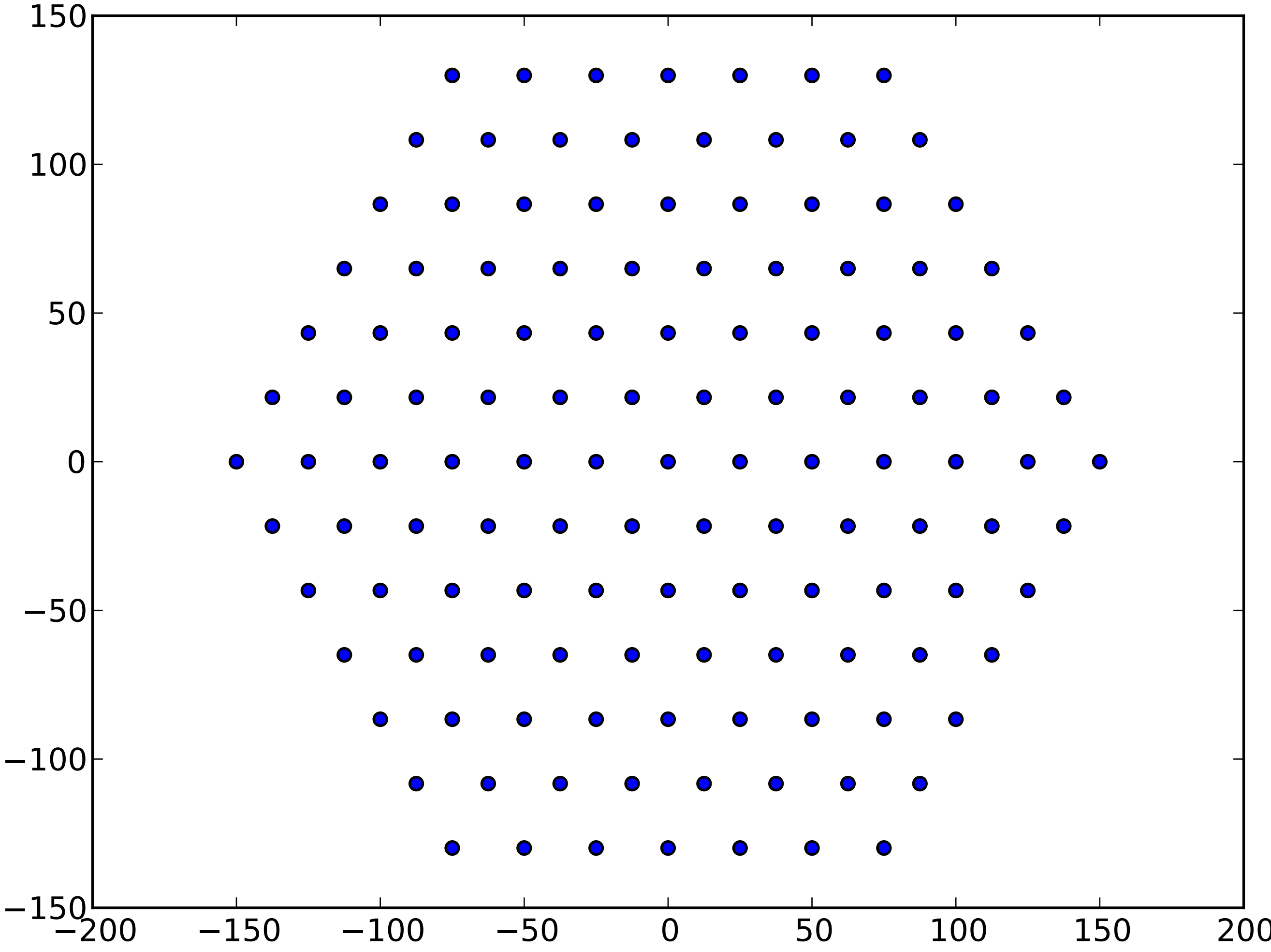
Adapted Rott, Tanaka, Itow JCAP09(2011)029 to PINGU.



MICA Conceptual Detector

"Anything worth doing is worth overdoing" M. Jagger

- Up to a few hundred strings of "linear" detectors within DeepCore fiducial volume
- Goals: ~5 MTon scale with energy sensitivity of:
    - O(10 MeV) for bursts
    - O(50MeV) for single events
- Physics extraction from Cherenkov ring imaging in the ice
- Annual supernovae neutrinos to 10 MPc; New MeV detection channels for Solar WIMPs become available; potential proton decay sensitivity
- IceCube and DeepCore provide the active veto
- No excavation necessary: detection medium is the support structure (melting ice is more cost effective than moving rock)



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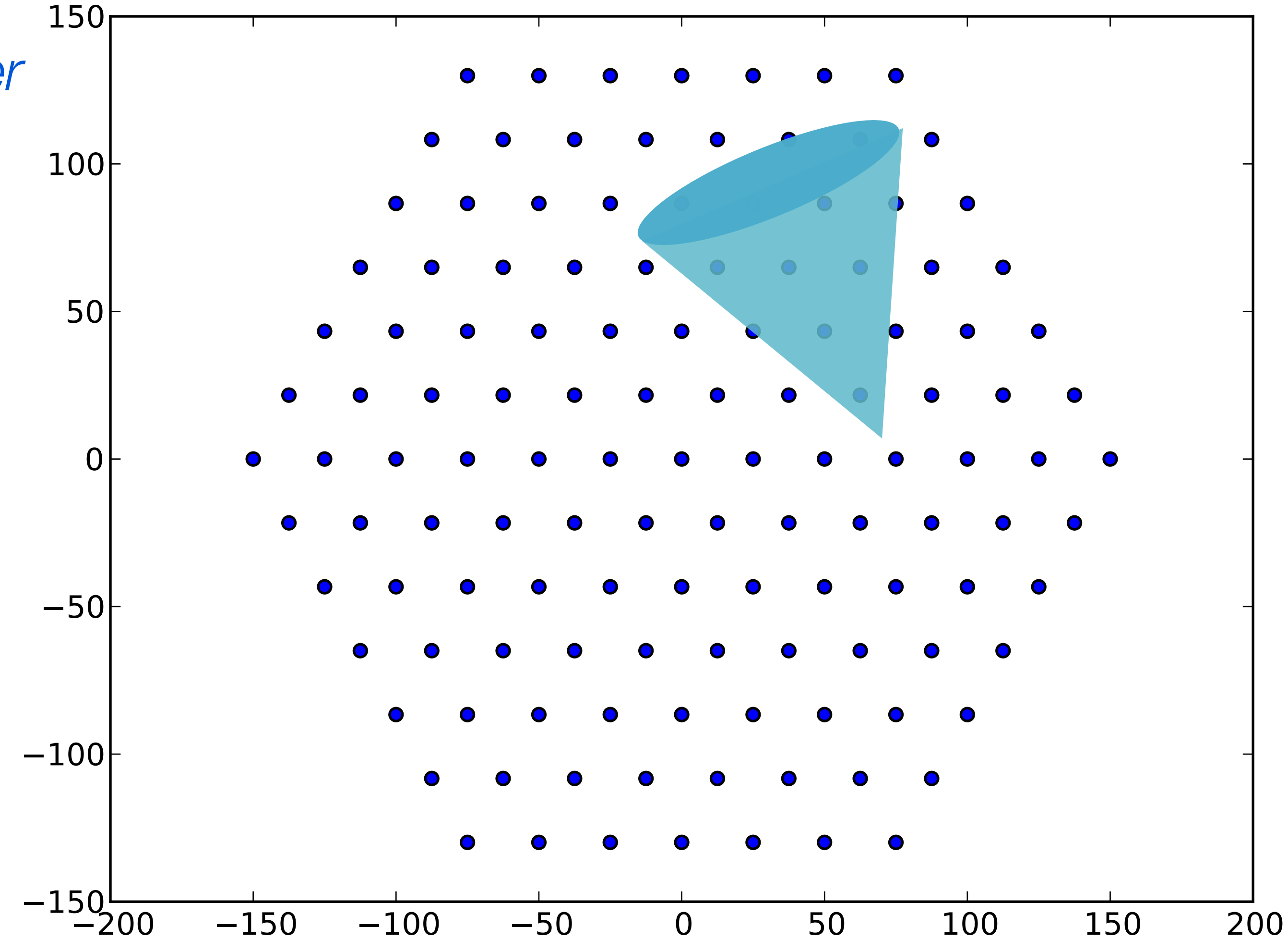

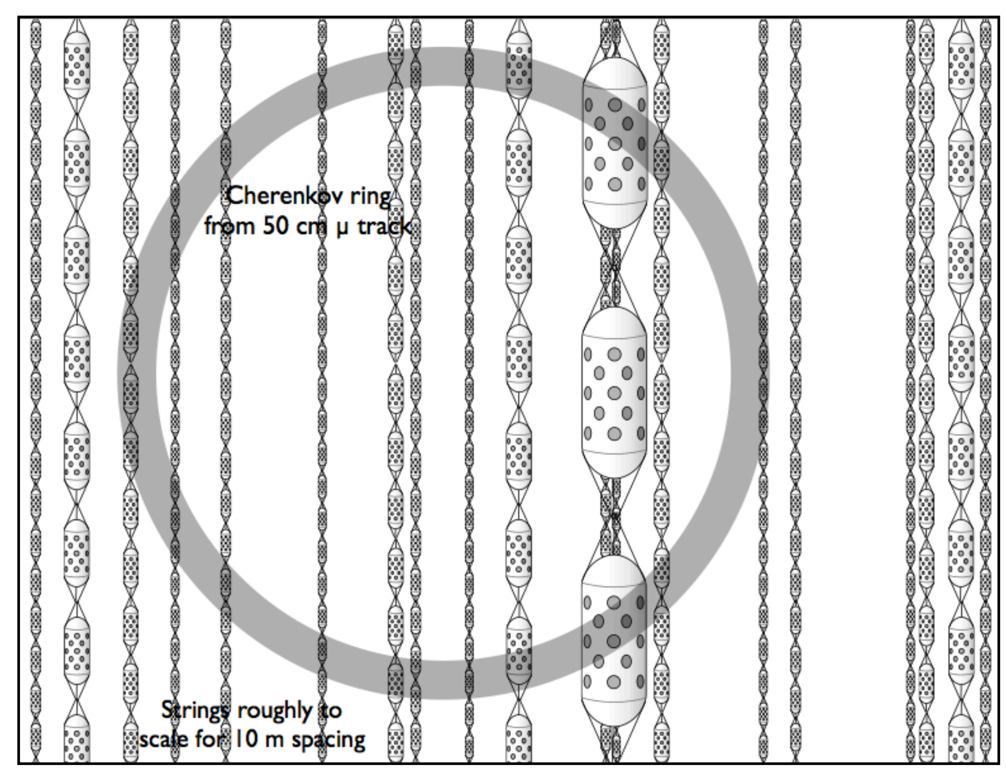

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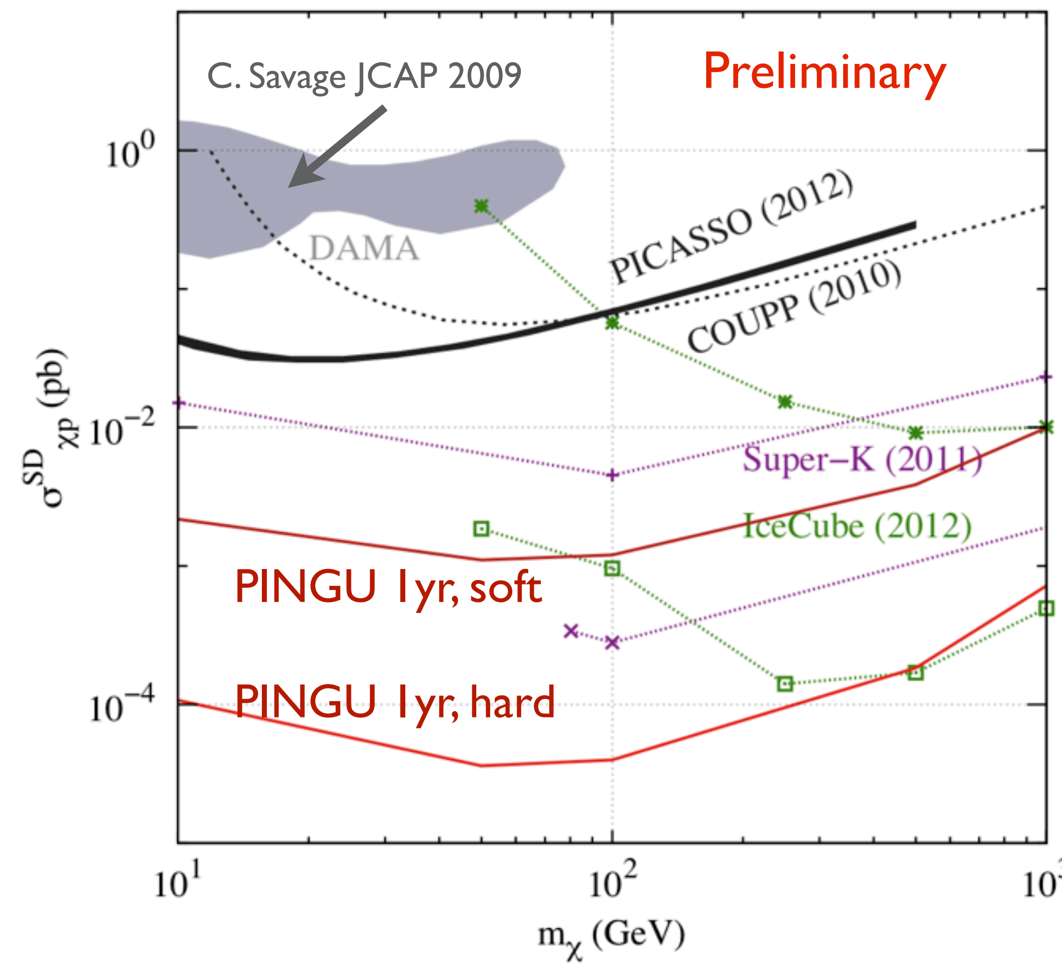
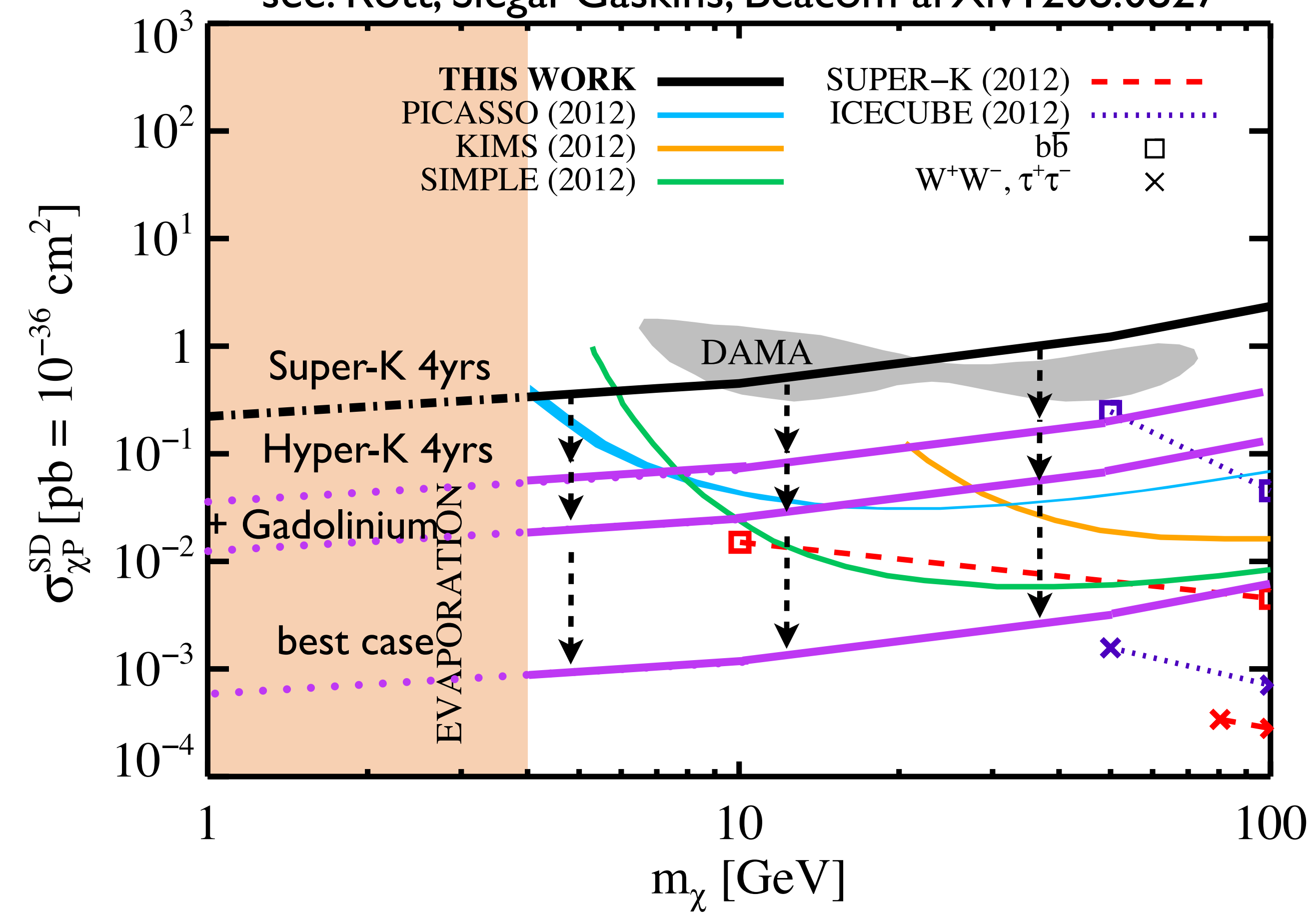


see: Rott, Siegal-Gaskins, Beacom arXiv1208.0827



Very Rough PINGU Timeline

Spring 2013
Letter of Intent

Summer/ Fall 2013
Submit proposals to international agencies

April 2014
Proposal results. Begin pre-spending on critical path items (cables, mainboards, drill refurbishment).

Austral Summer 2015/16
Drill half-crew on ice to begin drill preparation. DOM production and testing underway

Austral Summer 2016/17
Drill operational with full crew. Deploy 8 strings.

Austral Summer 2017/18
Drill operational with full crew. Deploy 12 strings. Re-pack drill

PINGU complete

physics data taking

February 2018

Today

Current Status

- Detailed Monte Carlo simulations nearing completion
- Low energy reconstruction algorithms from DeepCore being applied to PINGU events
- Estimation of sensitivity to neutrino mass hierarchy with full reconstruction underway
- Letter of Intent in preparation

Summary

- DeepCore has demonstrated the viability of low-energy neutrino physics in the Antarctic ice and is augmenting the indirect dark matter search and atmospheric neutrino oscillation programs of IceCube.
- The PINGU extension, being optimized for a first measurement of the neutrino mass hierarchy, will enhance the low-mass WIMP sensitivity for indirect searches via neutrinos.
- PINGU advantages include:
    - relatively quick (2 years of procurement and fabrication; 2-3 years of deployment)
    - cost effective (~$10M for design and startup; $1.25M/string - based on IceCube experience)
    - huge detector volumes without the need for cavern excavation
- MICA (further future) could provide measurements of supernova neutrinos 1-2 times per year, very low-mass WIMP searches and (potentially) proton decay. PINGU would be used for a testbed of future MICA detector modules

Solar WIMP searches - Past, Present, Future