IceCube Neutrino Telescope

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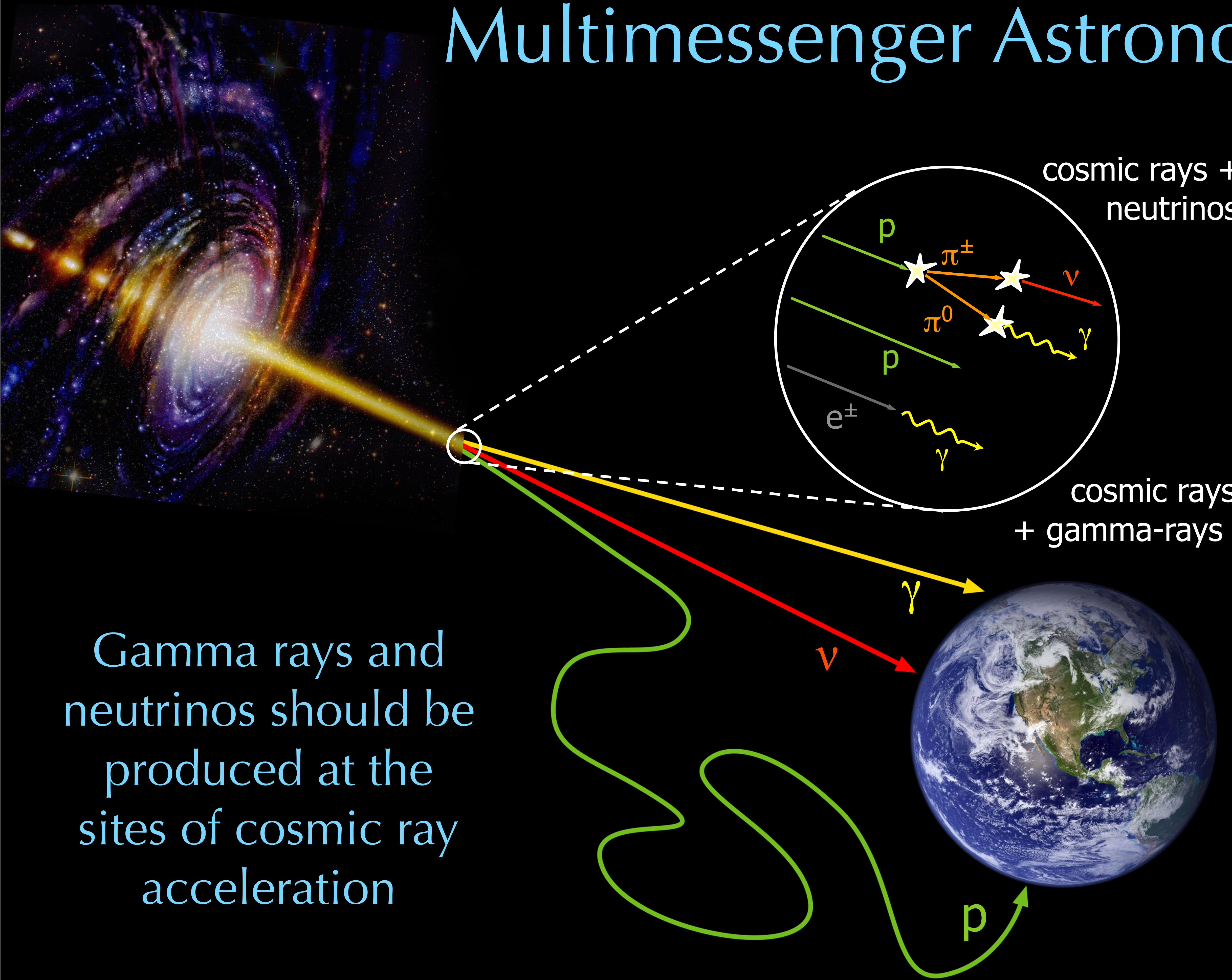
Breakdown

- Particle Astrophysics
  - Use high energy astrophysical neutrinos to learn about the cosmos
  - Point Source, Gamma Ray Burst and Diffuse Astrophysical Flux results
- Astroparticle physics
  - Use particles from the cosmos to learn about the smallest bits of our universe
  - DeepCore - Low energy extension to IceCube
  - Indirect Dark Matter results and neutrino oscillation prospects

- Neutrinos are long distance cosmic messengers
  - Photons interact with CMB
  - Charged cosmic rays lose directionality through magnetic deflection
- The cosmic laboratory
  - Complementarity with cosmic rays
  - Astrophysical objects and Cosmic Ray acceleration, leptonic or baryonic? (GRB, SNR, PWN)

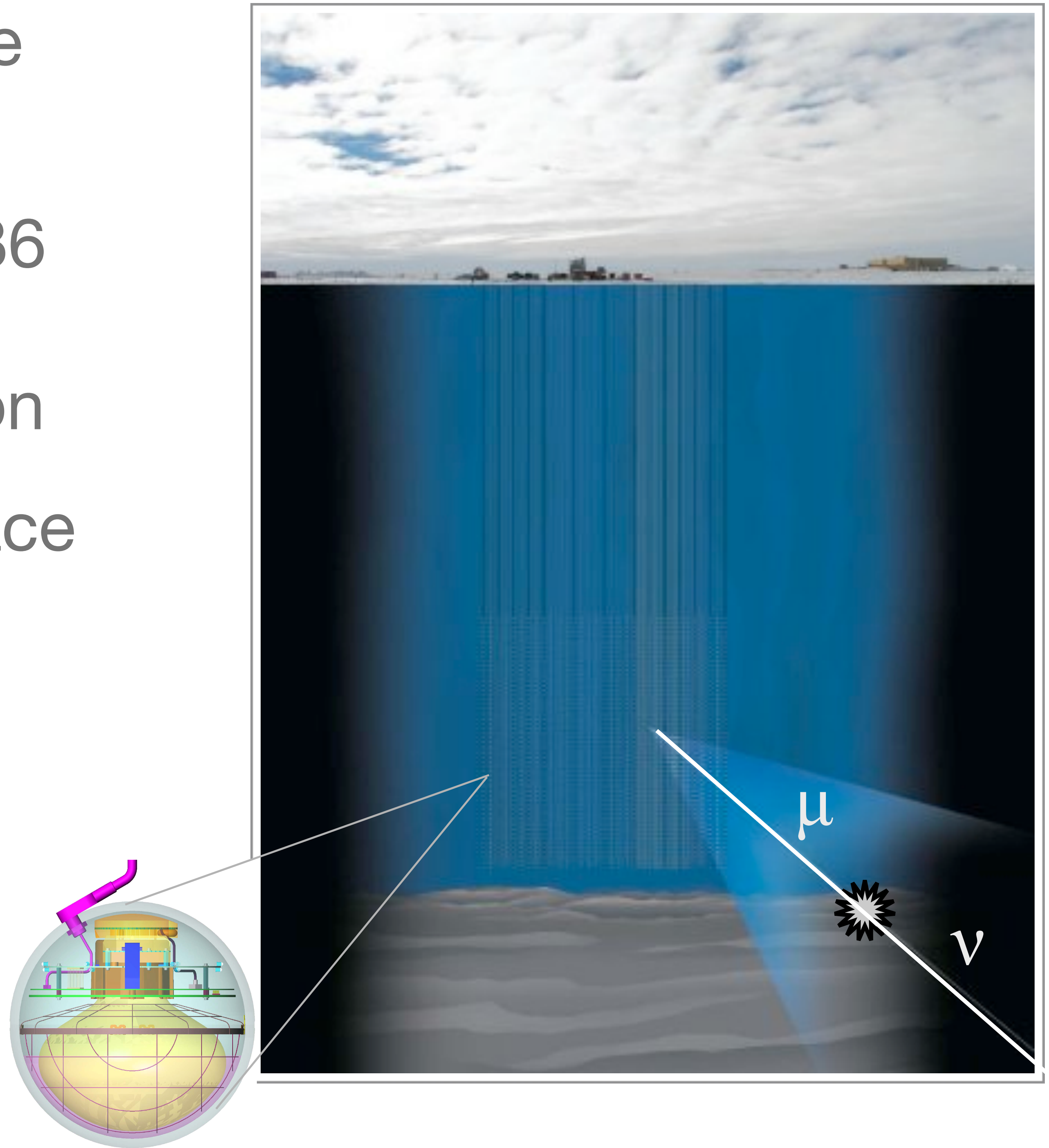
Multimessenger Astronomy



Gamma rays and neutrinos should be produced at the sites of cosmic ray acceleration

IceCube Detector

- ~1km^3 of instrumented ice
- Uses 5160 Digital Optical Modules (DOMs) across 86 strings within the ice to detect Cherenkov radiation
- 160 Cherenkov tank surface array (IceTop)
- Completed Dec. 18, 2010



IceCube DOM

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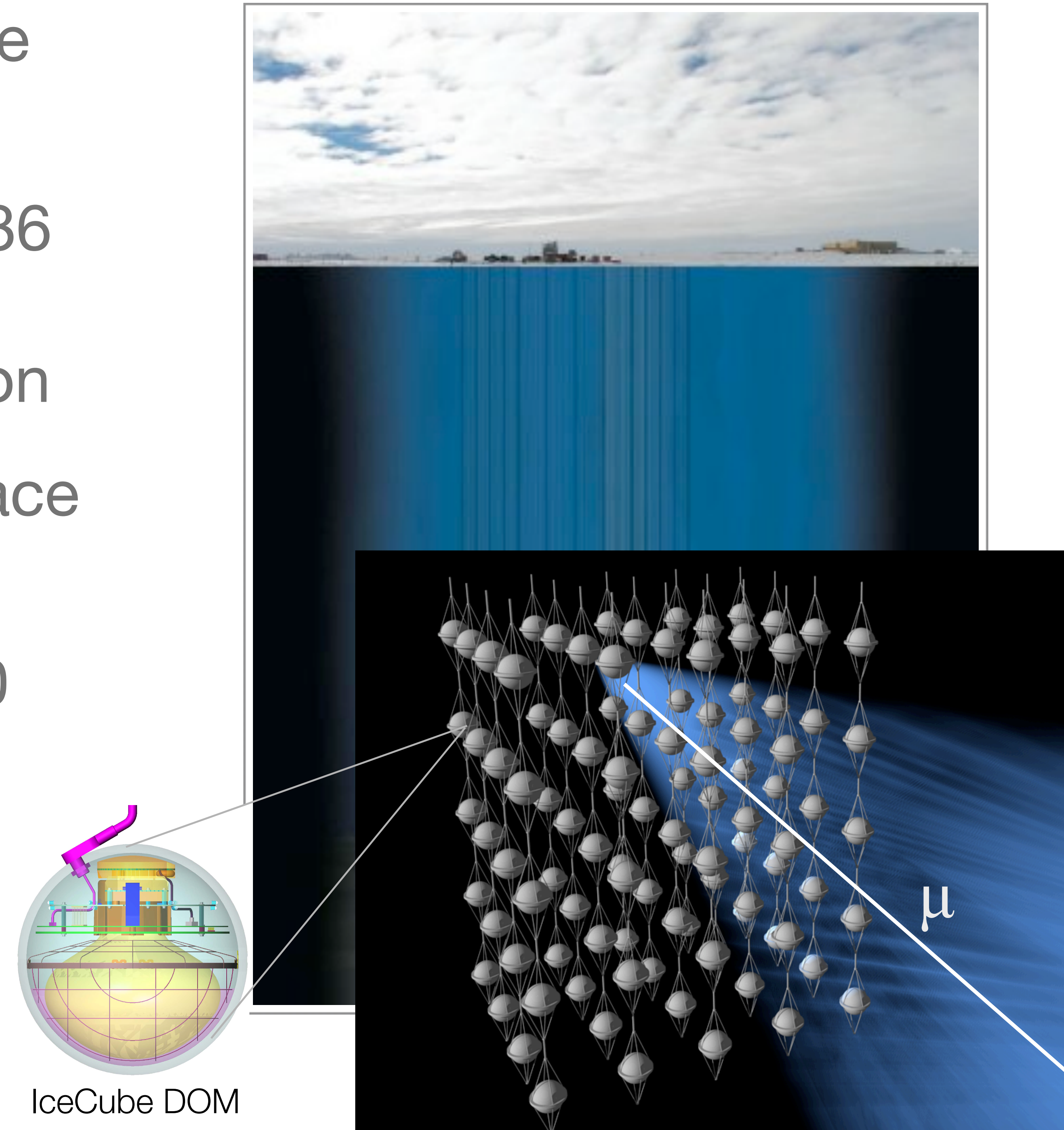


Collaboration

The IceCube Collaboration

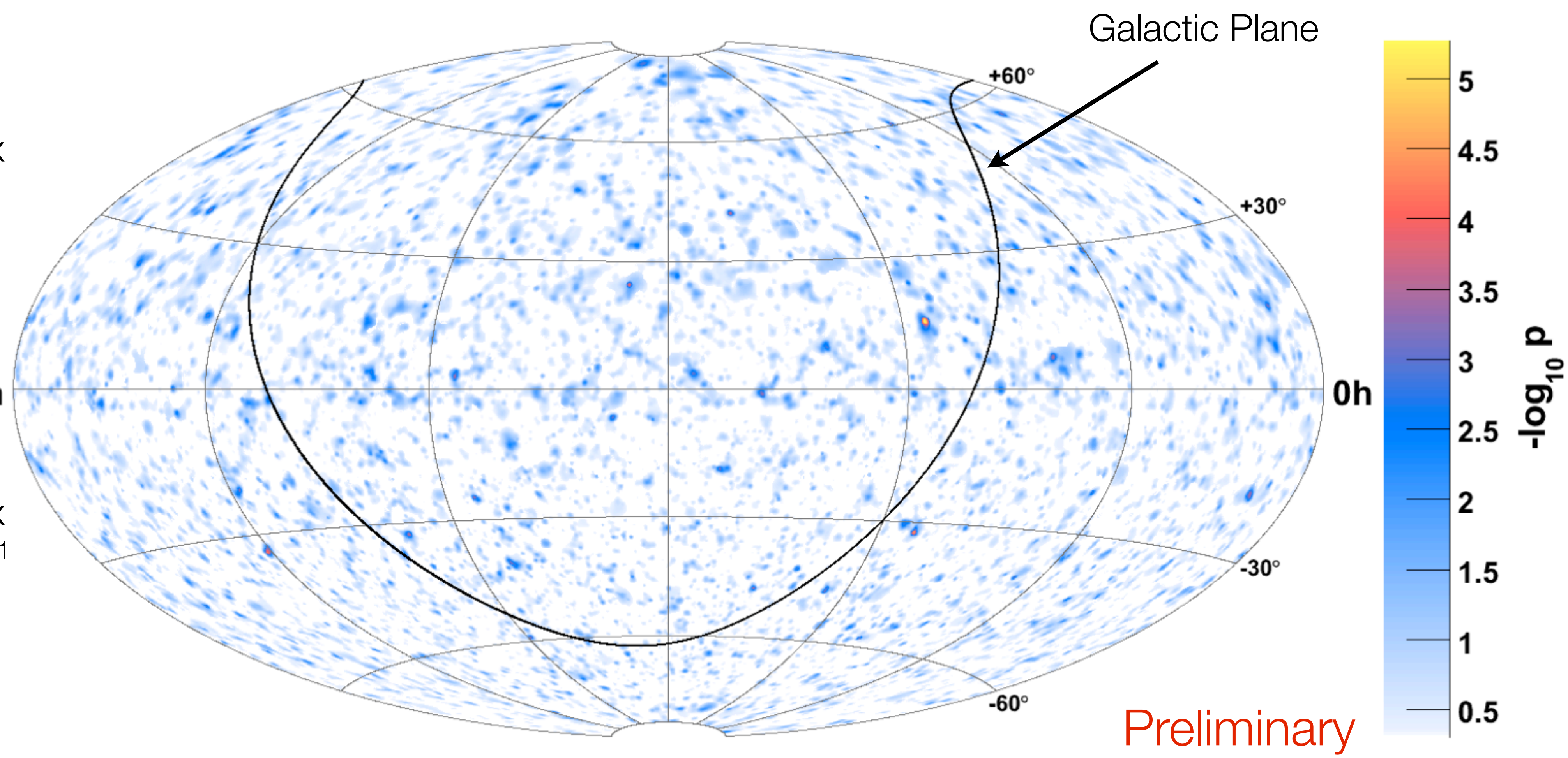
36 institutions - 4 continents - ~250 Physicists

Astrophysical Neutrino Point Souces

- 375.5 livetime days using partially constructed 40 (IC40) string array collecting 36900 events (14121 up-going Northern Sky, 22779 down-going Southern Sky)
- No evidence for neutrino source, yet

Northern Sky Limit for E^{-2} flux
$\Phi^{90} = 2\text{-}20 \times 10^{-12}$ TeV cm^{-2} s^{-1}
TeV-PeV sensitivity

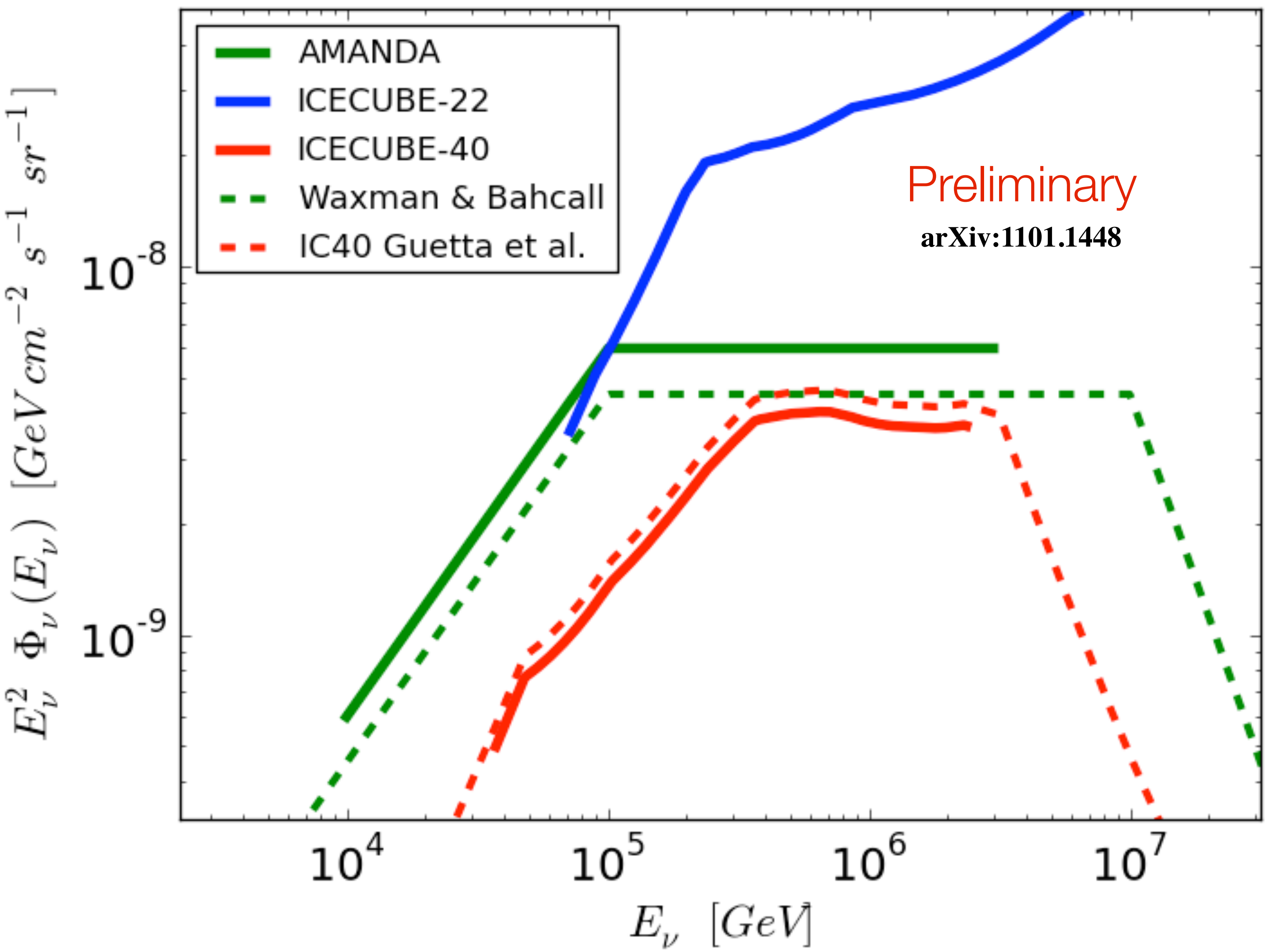
Southern Sky Limit for E^{-2} flux
$\Phi^{90} = 3\text{-}700 \times 10^{-12}$ TeV cm^{-2} s^{-1}
1 PeV < sensitivity



arXiv:1012.2137

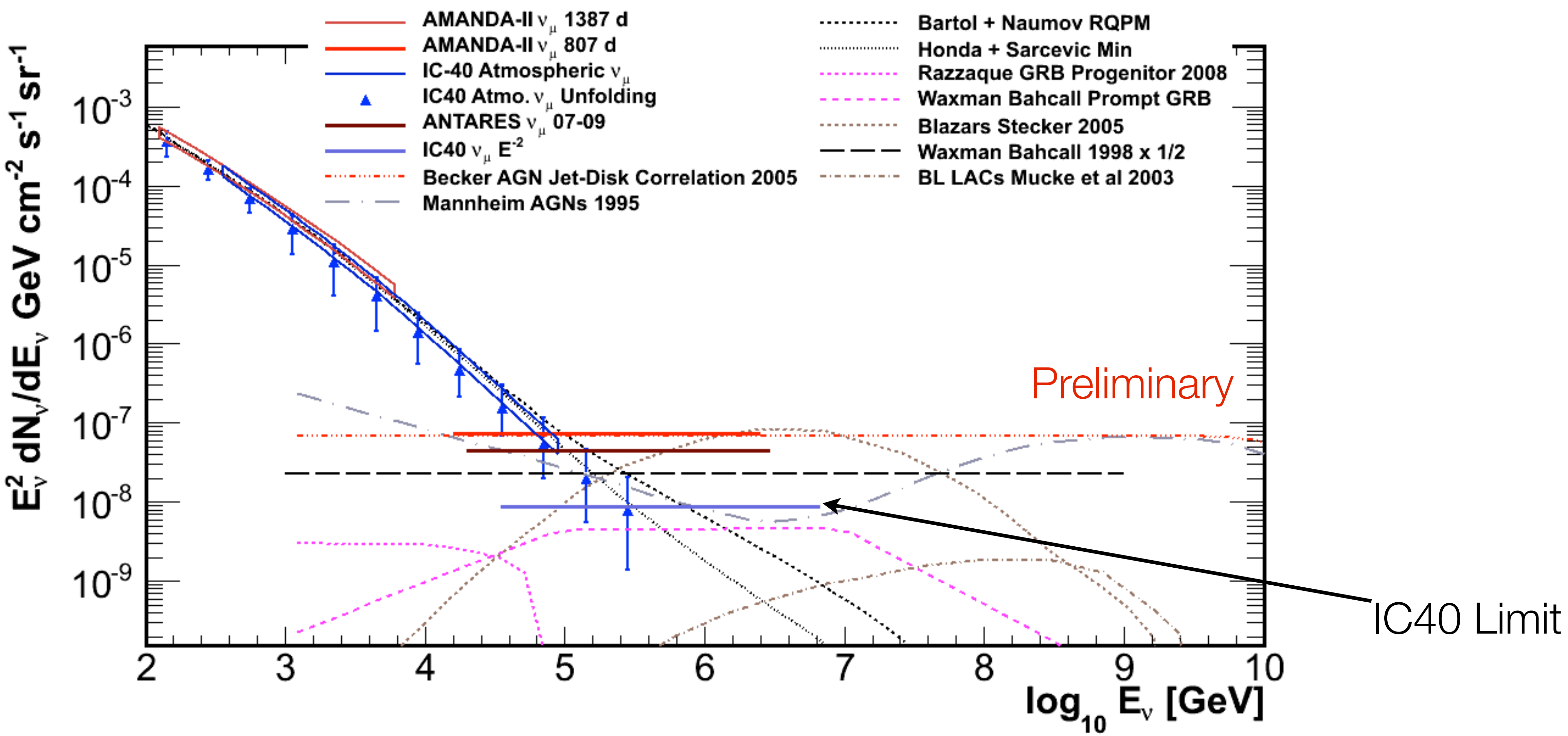
Gamma Ray Bursts

- Searches for neutrinos produced by p+γ interactions during the primary fireball using IC40 partial array
- 117 GRBs using IC40 detector exclude the Waxman & Bahcall and Guetta et al. at 90% C.L.

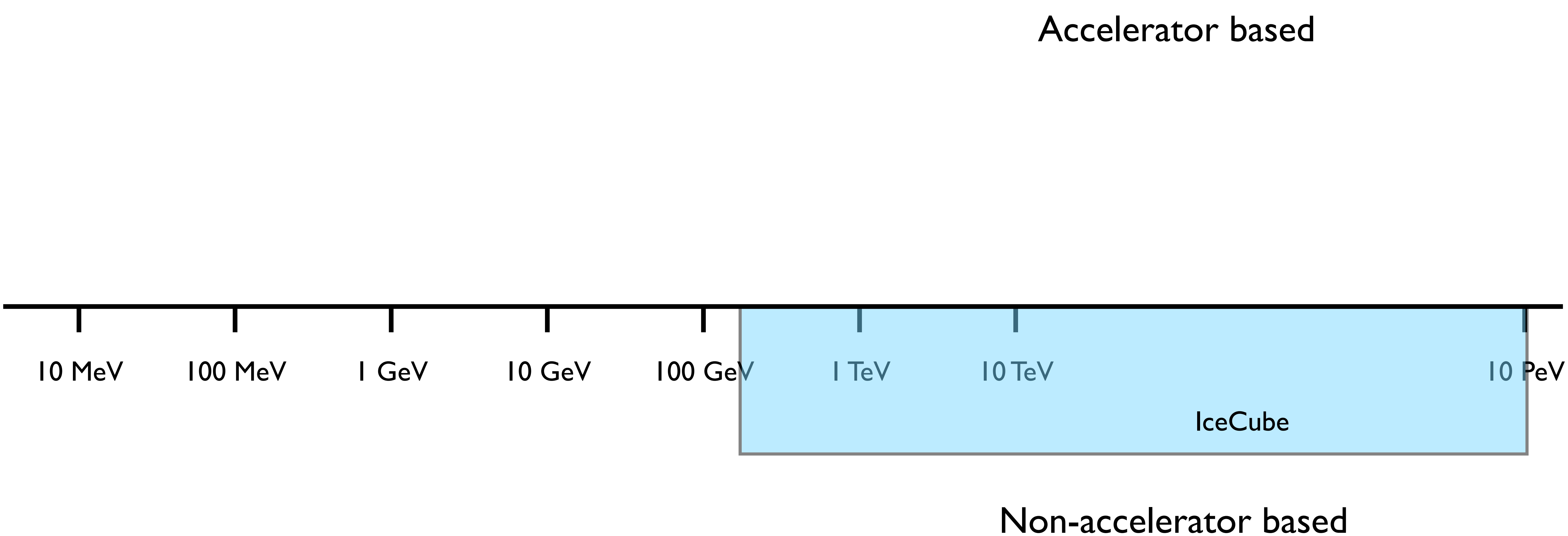


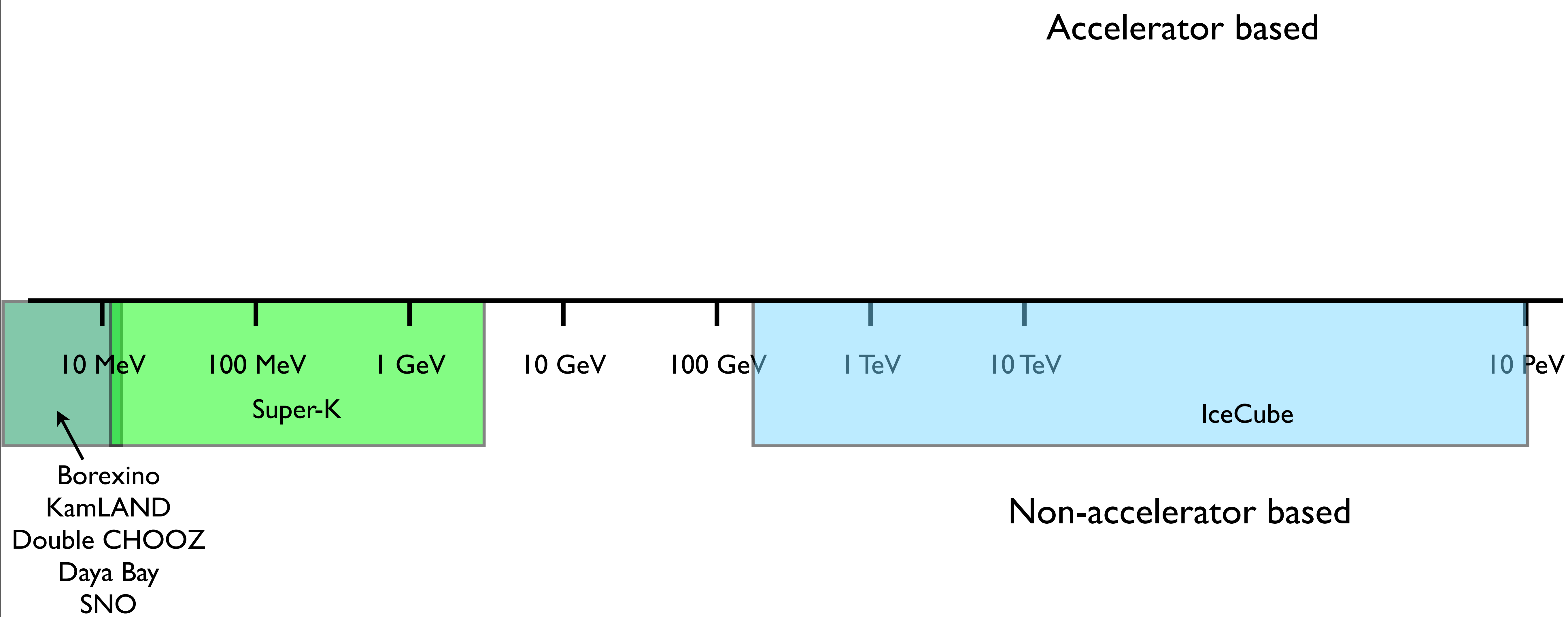
Astrophysical Diffuse Flux

- In addition to cosmic rays, Fermi acceleration is theorized to produce neutrinos at a flux$\propto E_\nu^{-2}$
- IC40 analysis places new limits on diffuse E_ν^{-2} flux of astrophysical muon neutrinos



Experimental Neutrino Landscape




Accelerator based
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
1 TeV
10 TeV
10 PeV
Super-K
IceCube
Borexino
KamLAND
Double CHOOZ
Daya Bay
SNO
Non-accelerator based

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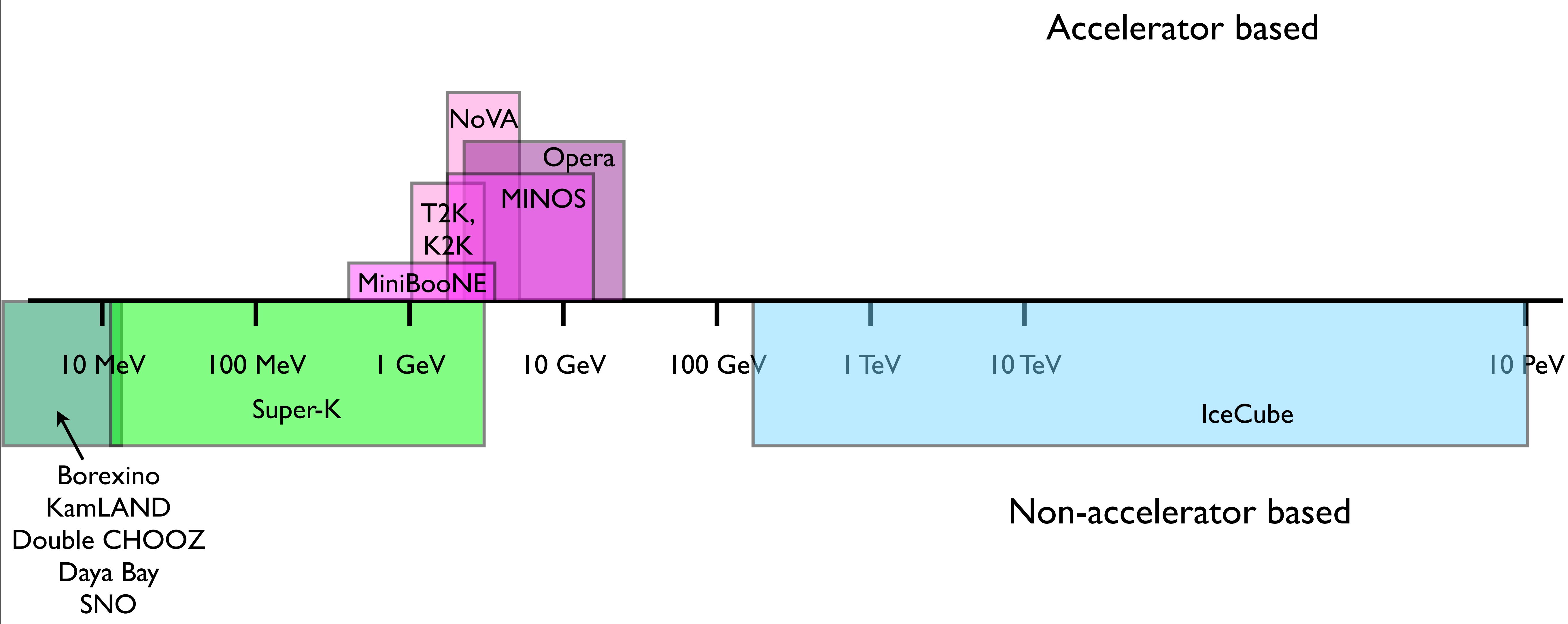

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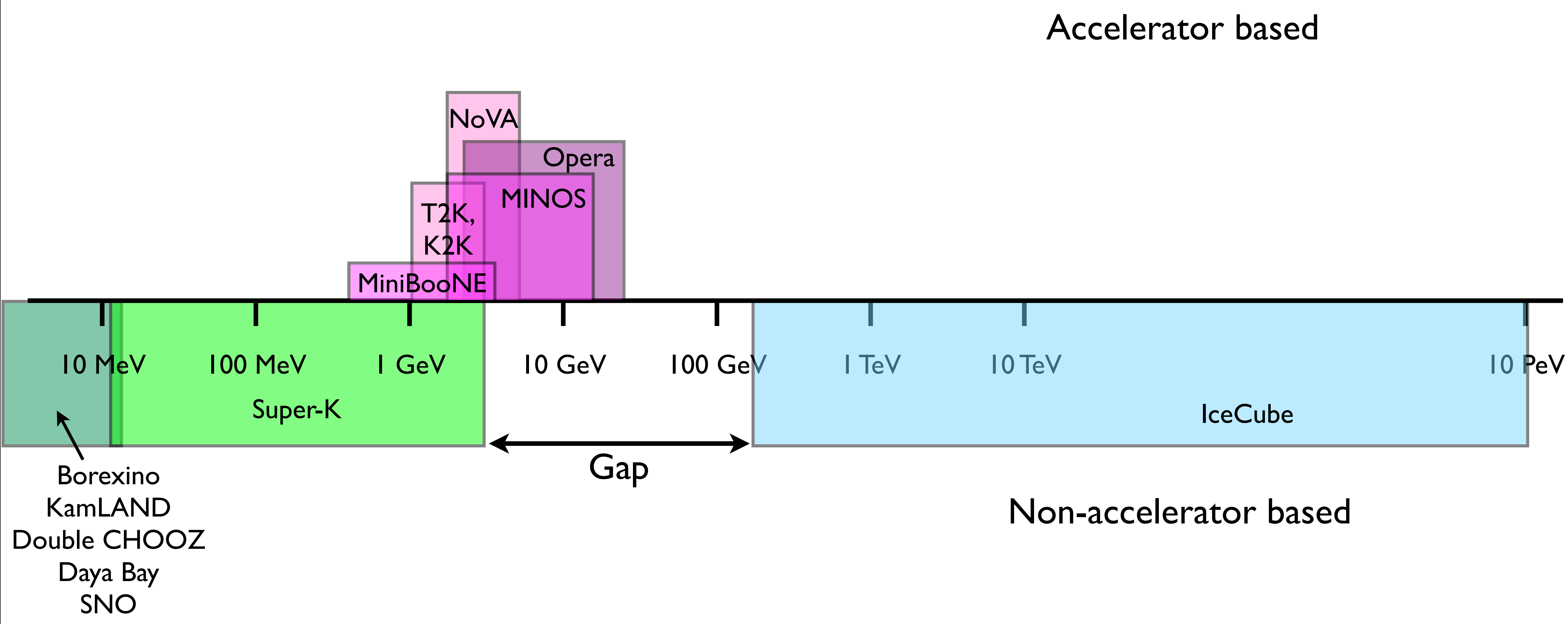

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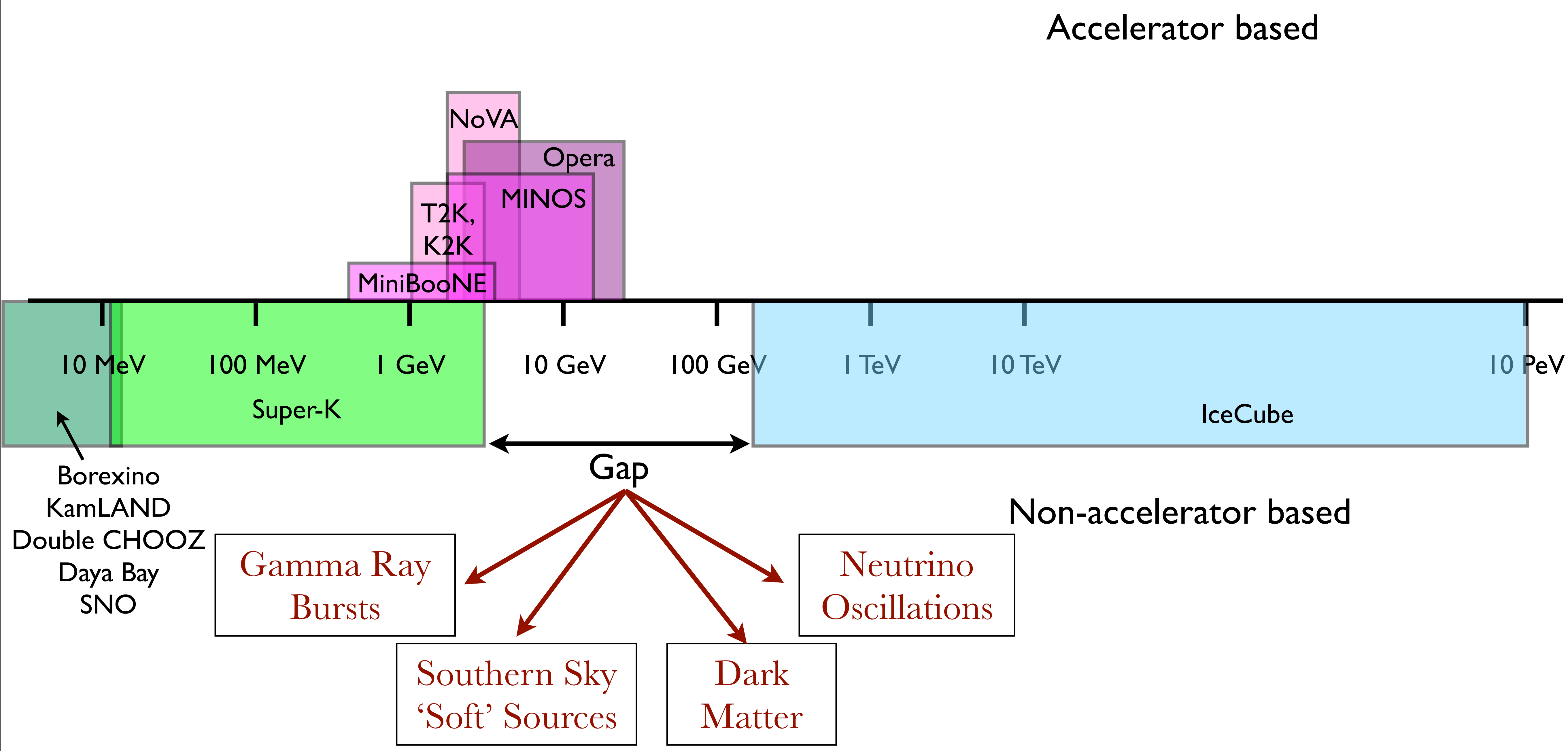

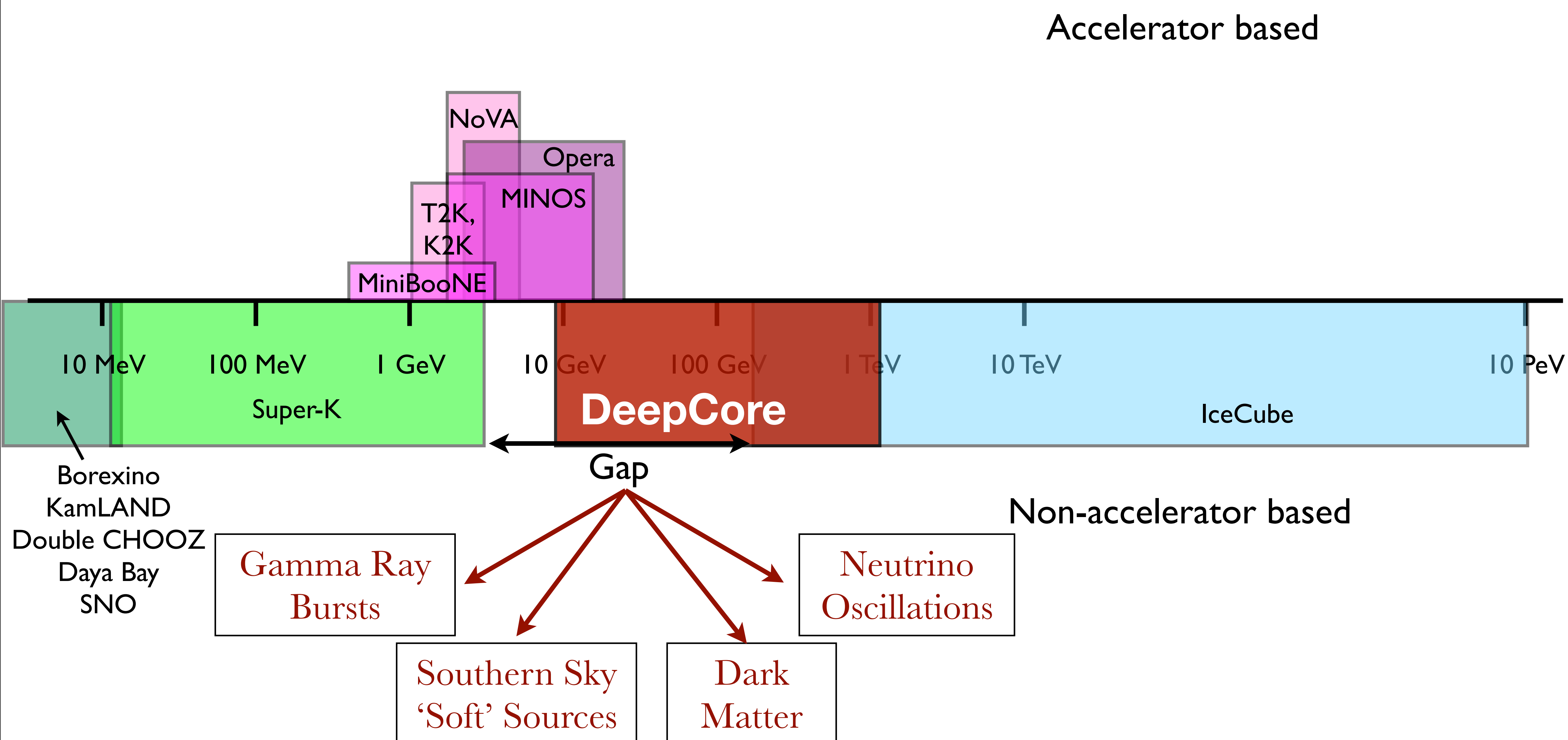
Accelerator based
NoVA
Opera
MINOS
T2K,
K2K
MiniBooNE
10 MeV
100 MeV
1 GeV
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DeepCore
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Gap
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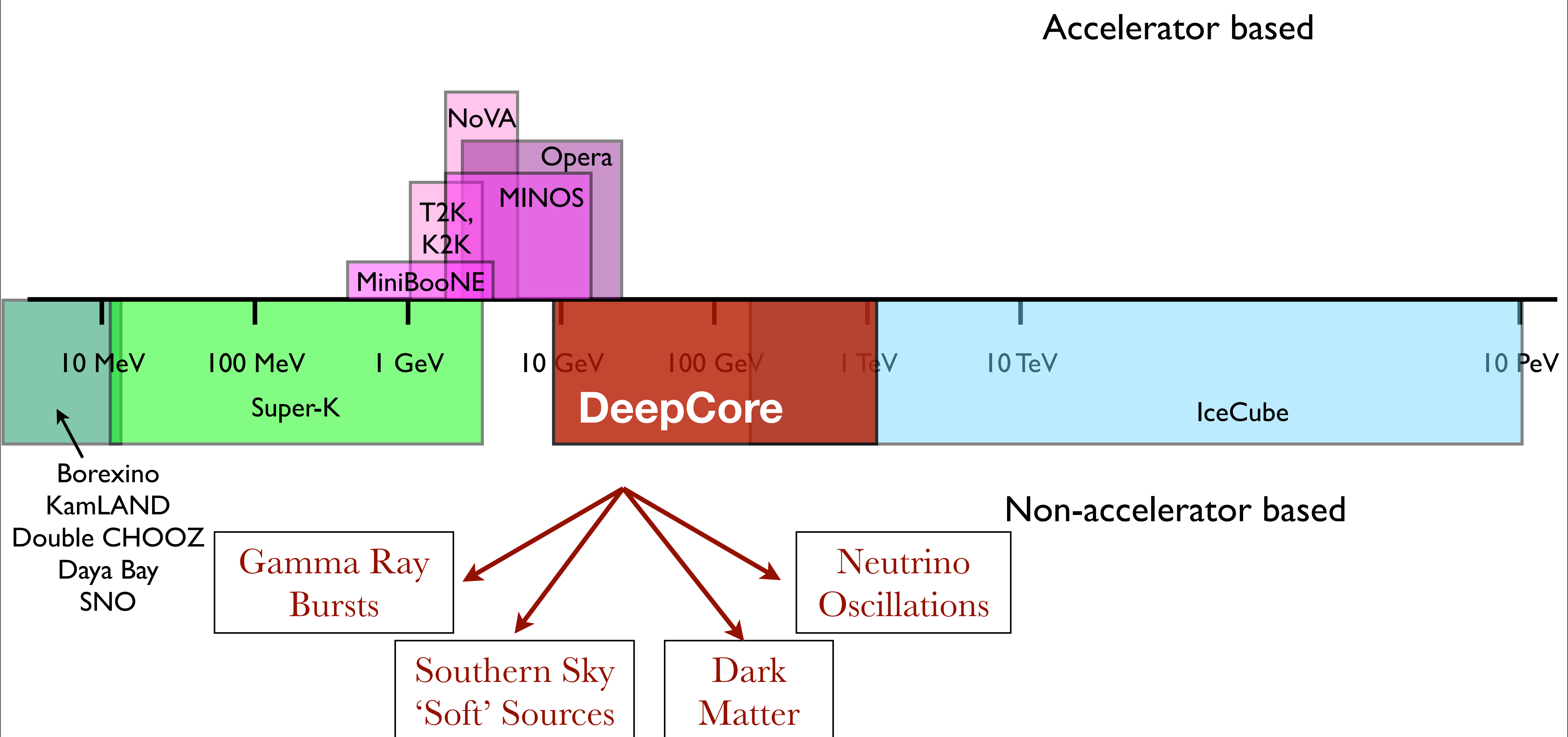
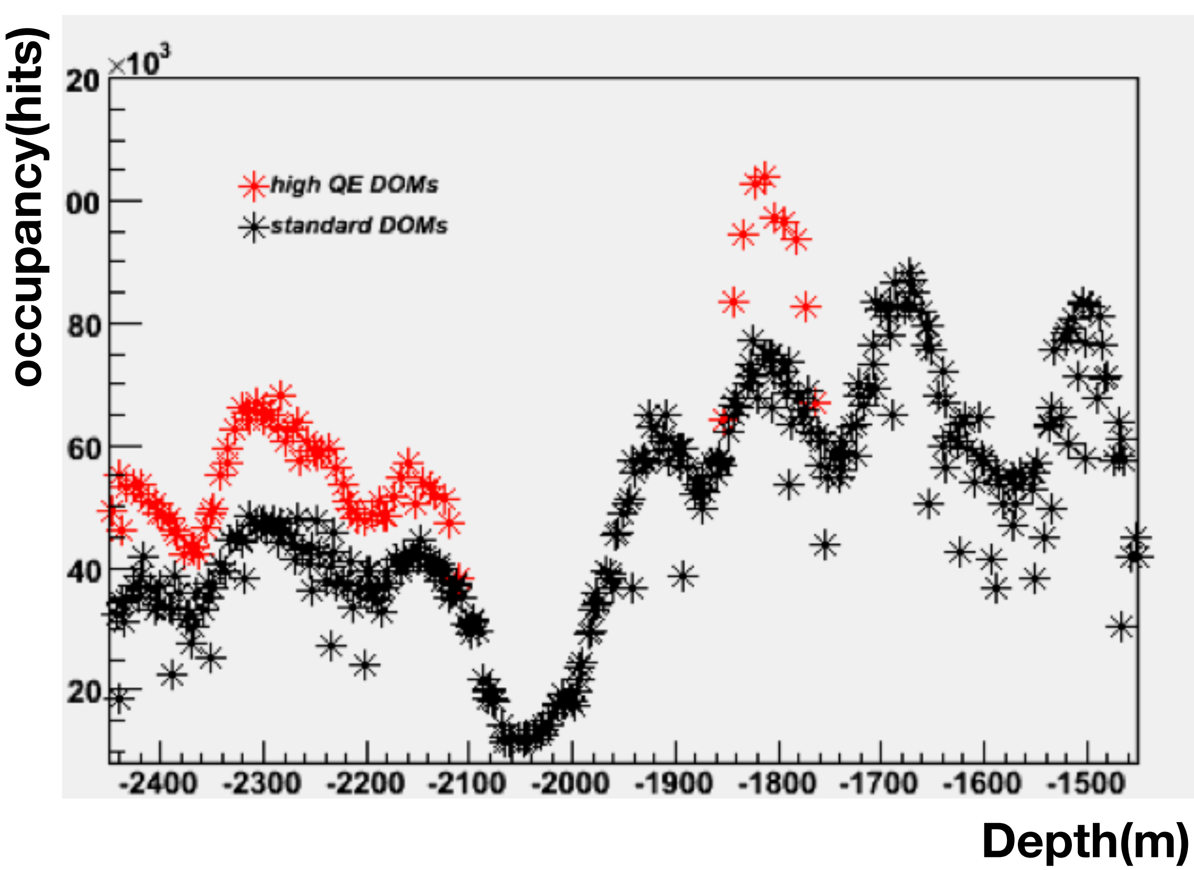
Non-accelerator based
Gamma Ray Bursts
Neutrino Oscillations
Southern Sky 'Soft' Sources
Dark Matter

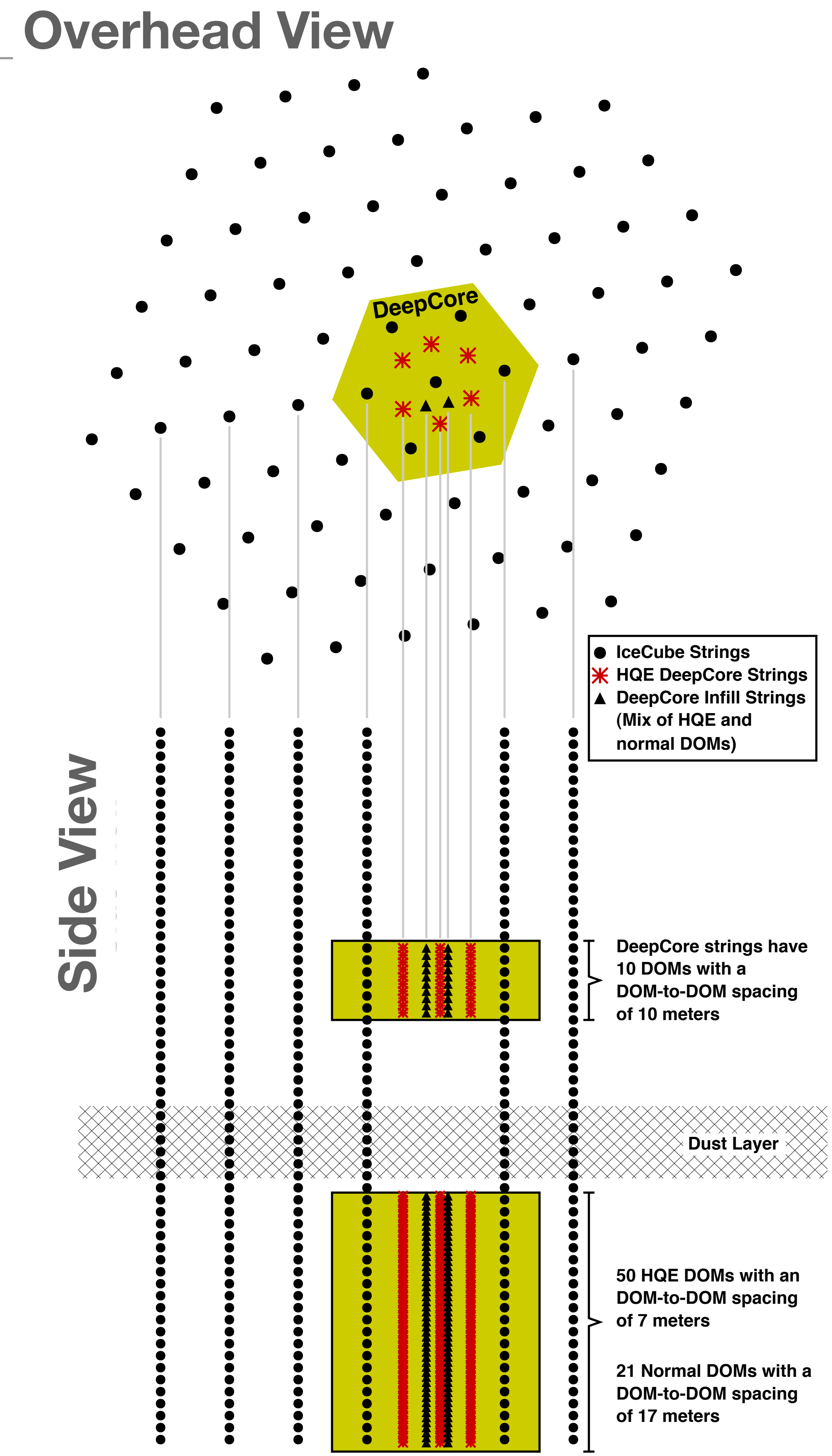
Experimental Neutrino Landscape



Moving to Low Energy Neutrino Detection - DeepCore

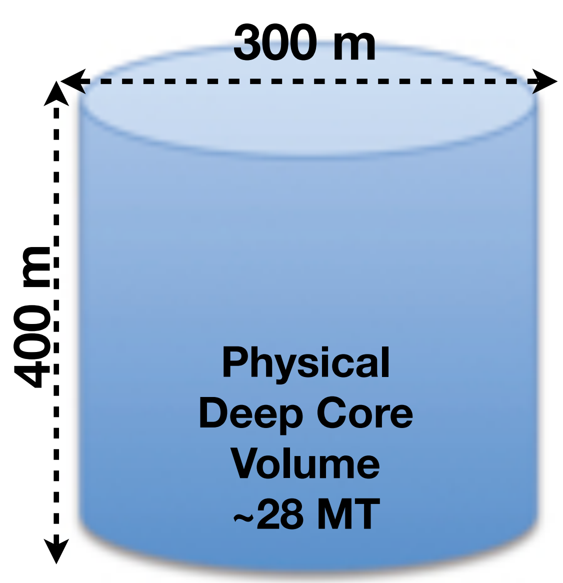
- DeepCore extends the energy reach of IceCube via
  - More Sensitive PMTs (High Quantum Efficiency)
  - Denser module spacing
  - Deployed in clearest ice



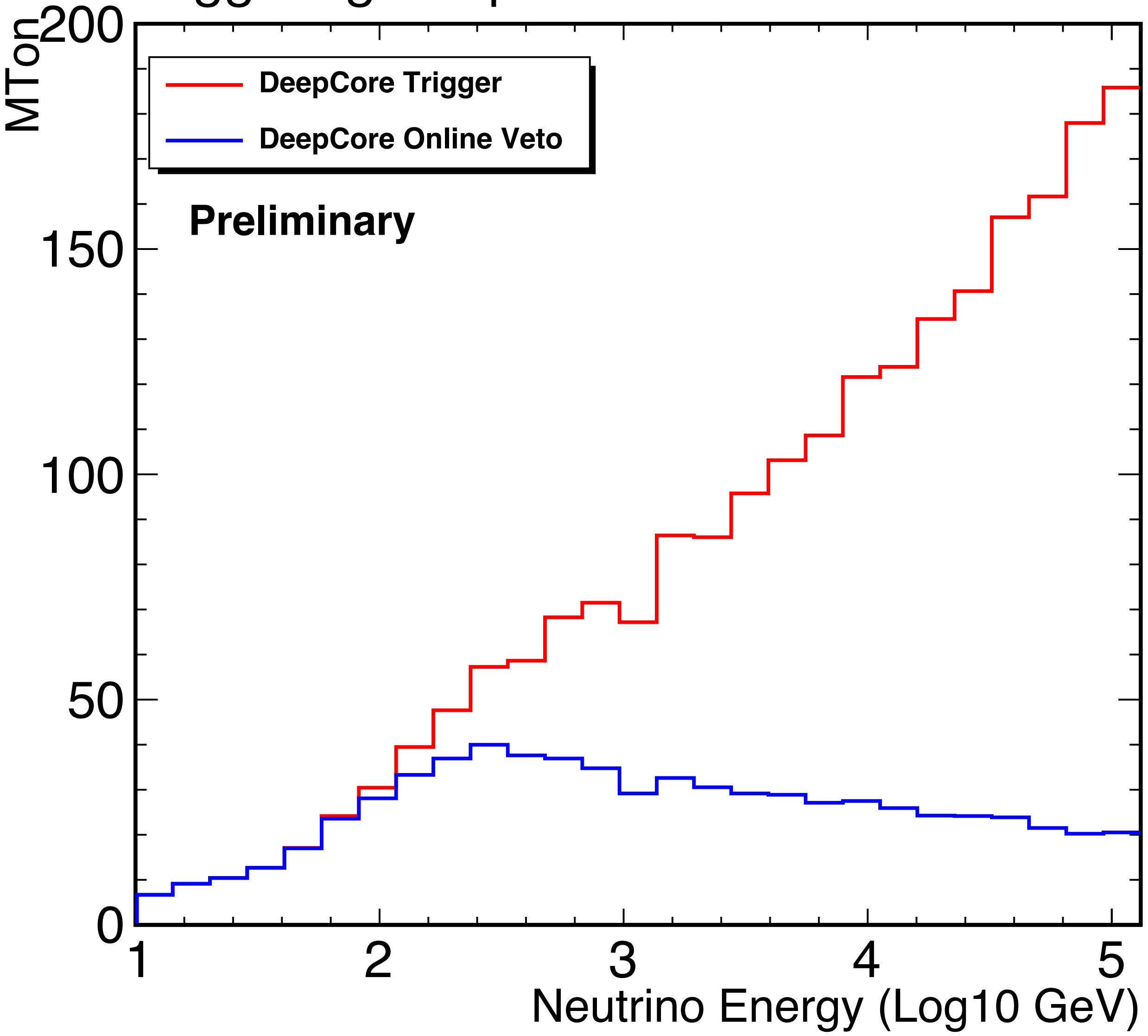


Size Matters

- DeepCore, being a multi-MTon detector, will collect hundreds of thousands of neutrinos at trigger level
- Online Veto constrains vertex to be within DeepCore volume
- Physical size is ~28 MegaTons



Effective volume for muons from ν_μ triggering DeepCore



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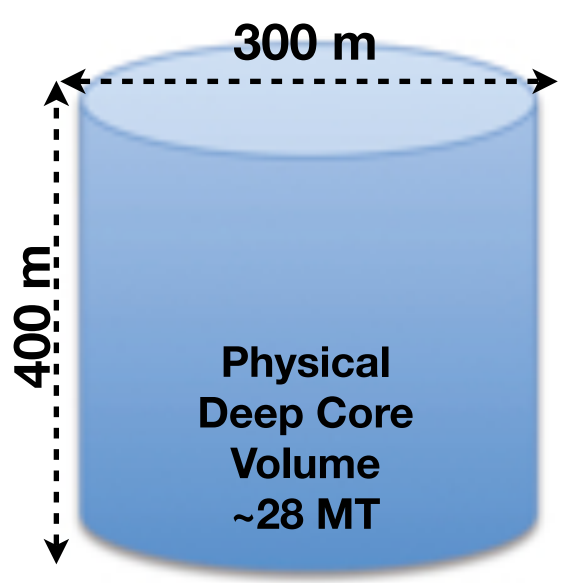

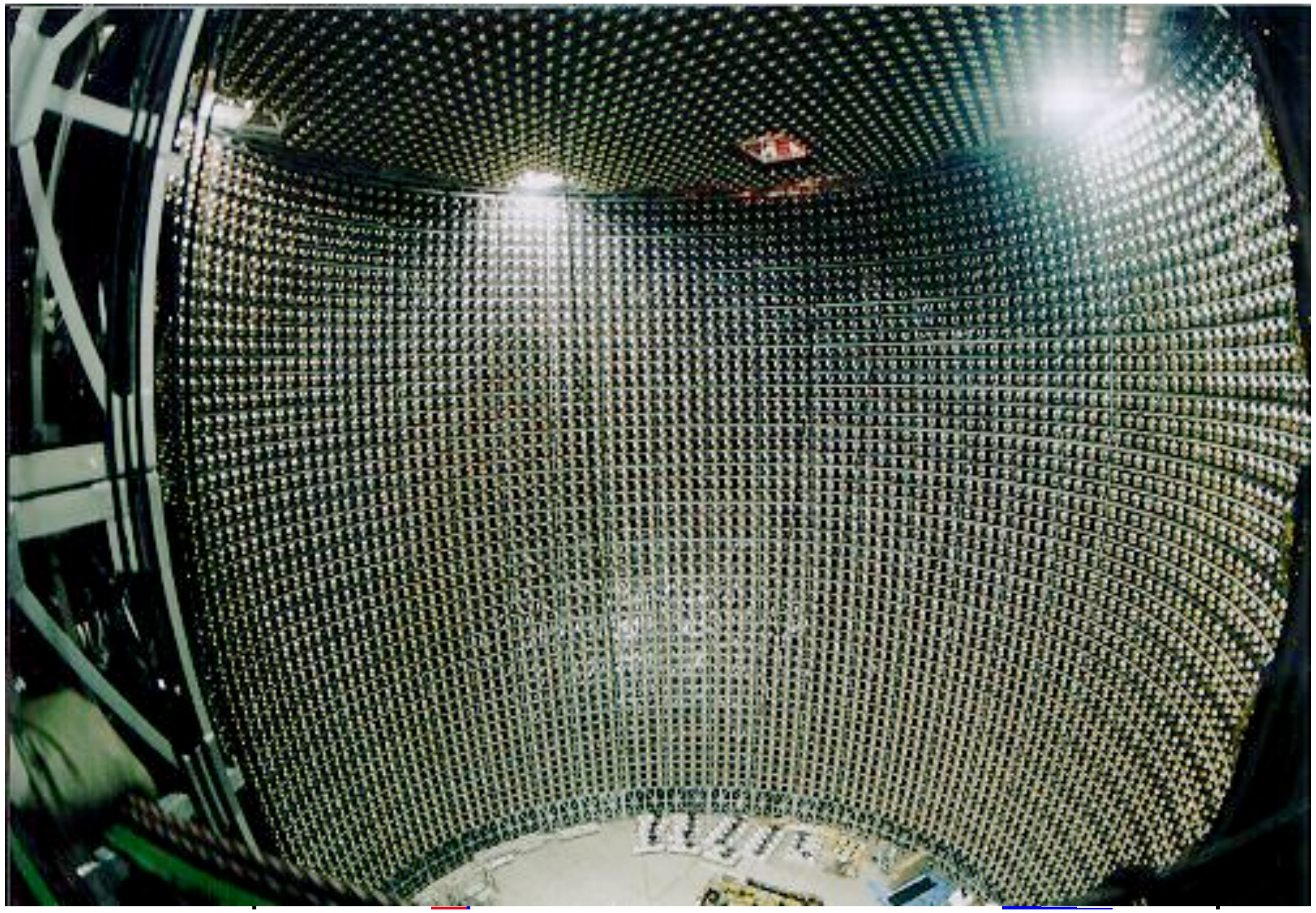

Super-K

Size Matters

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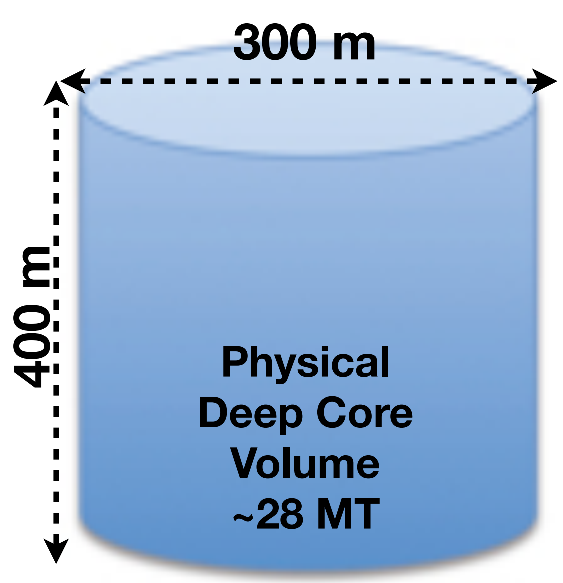

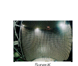

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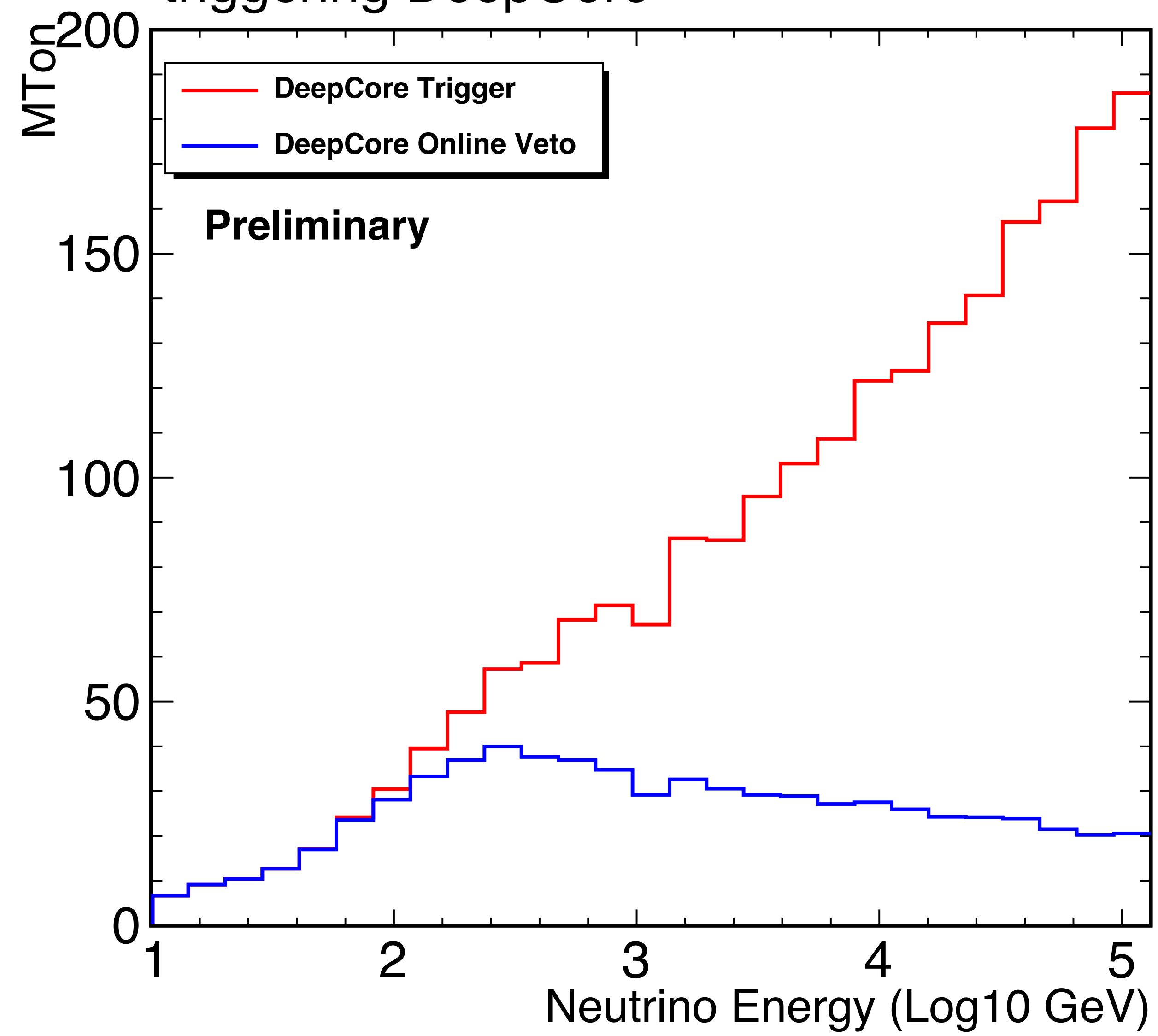
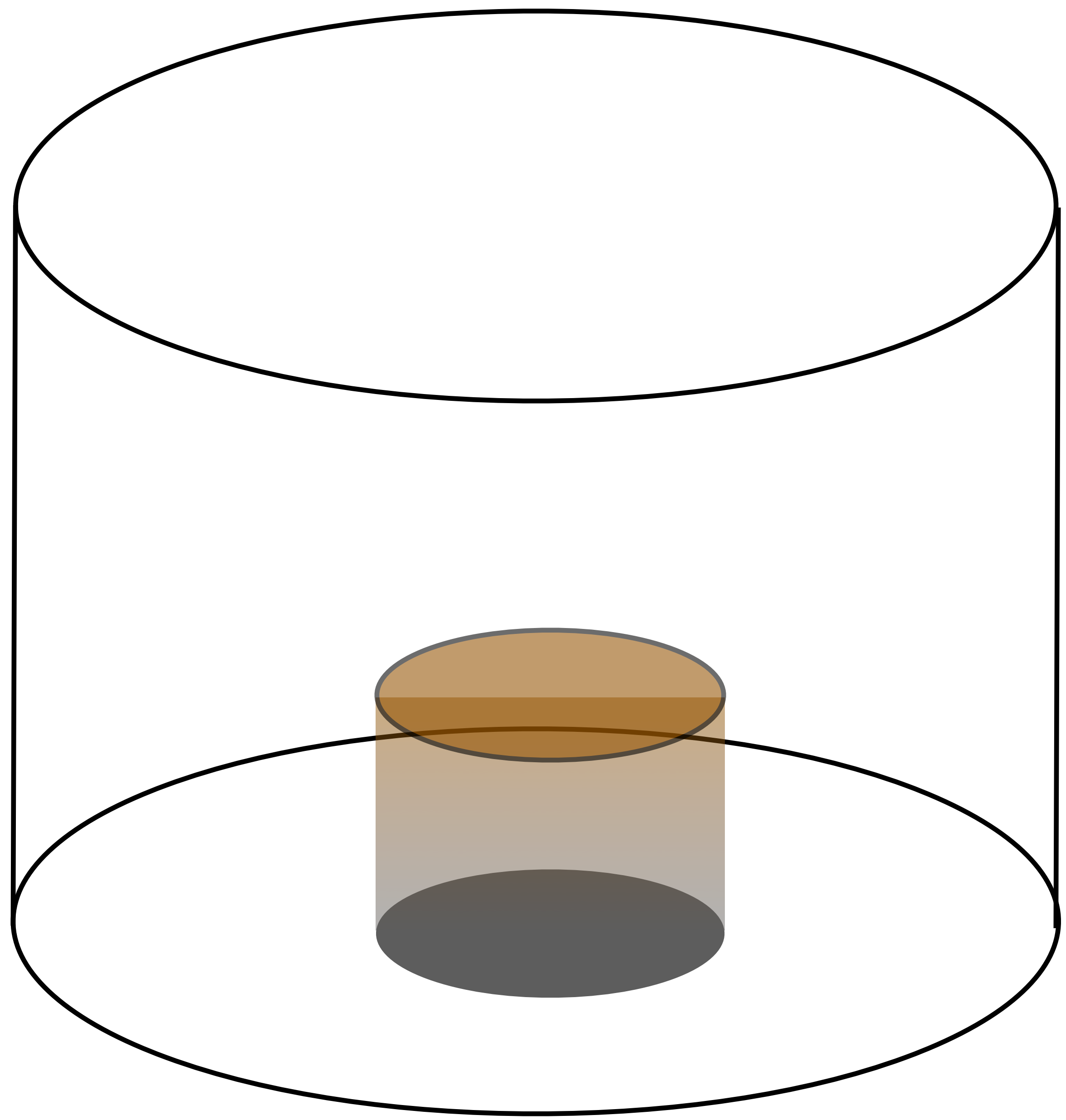


More Signal = More Bkg



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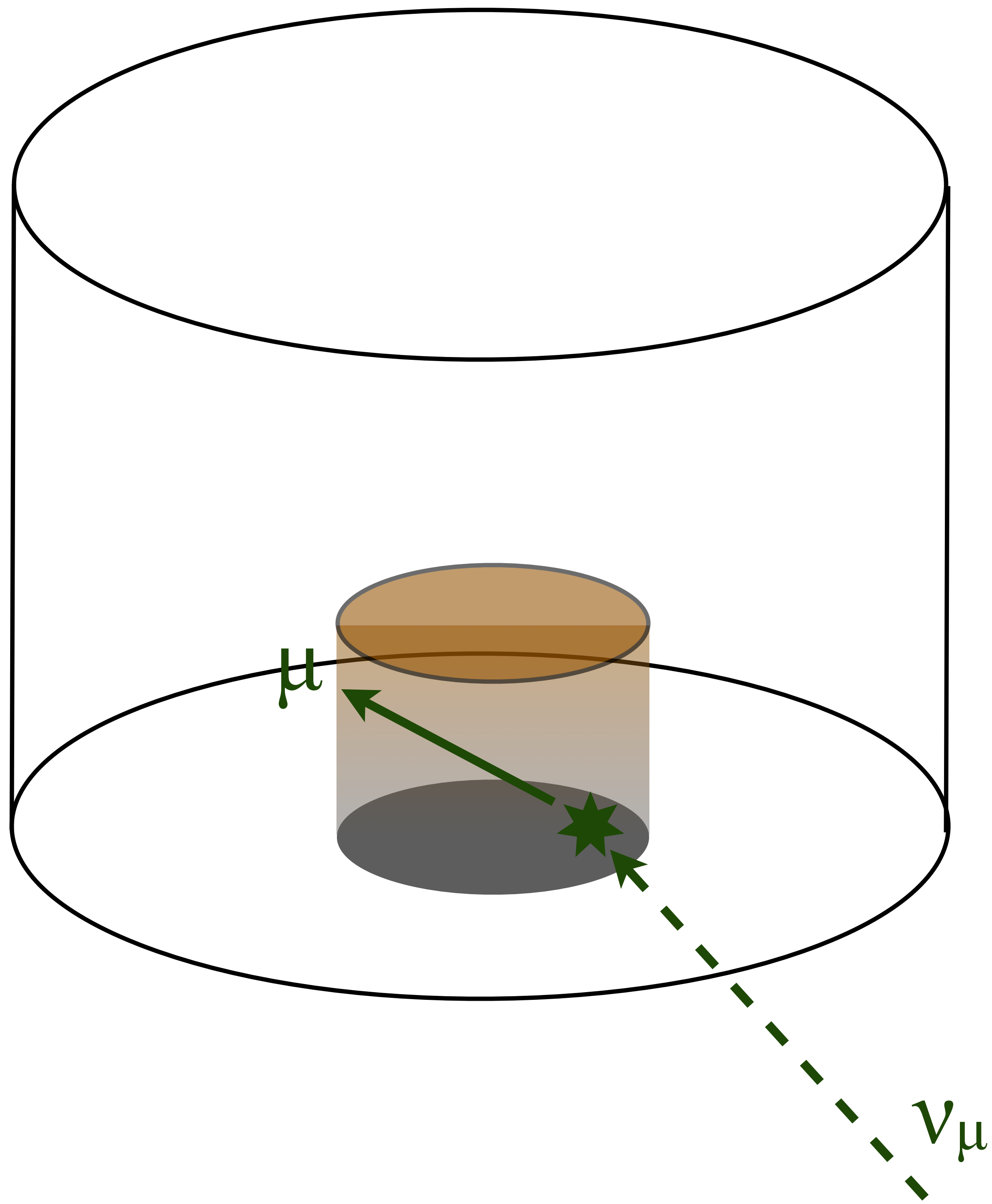

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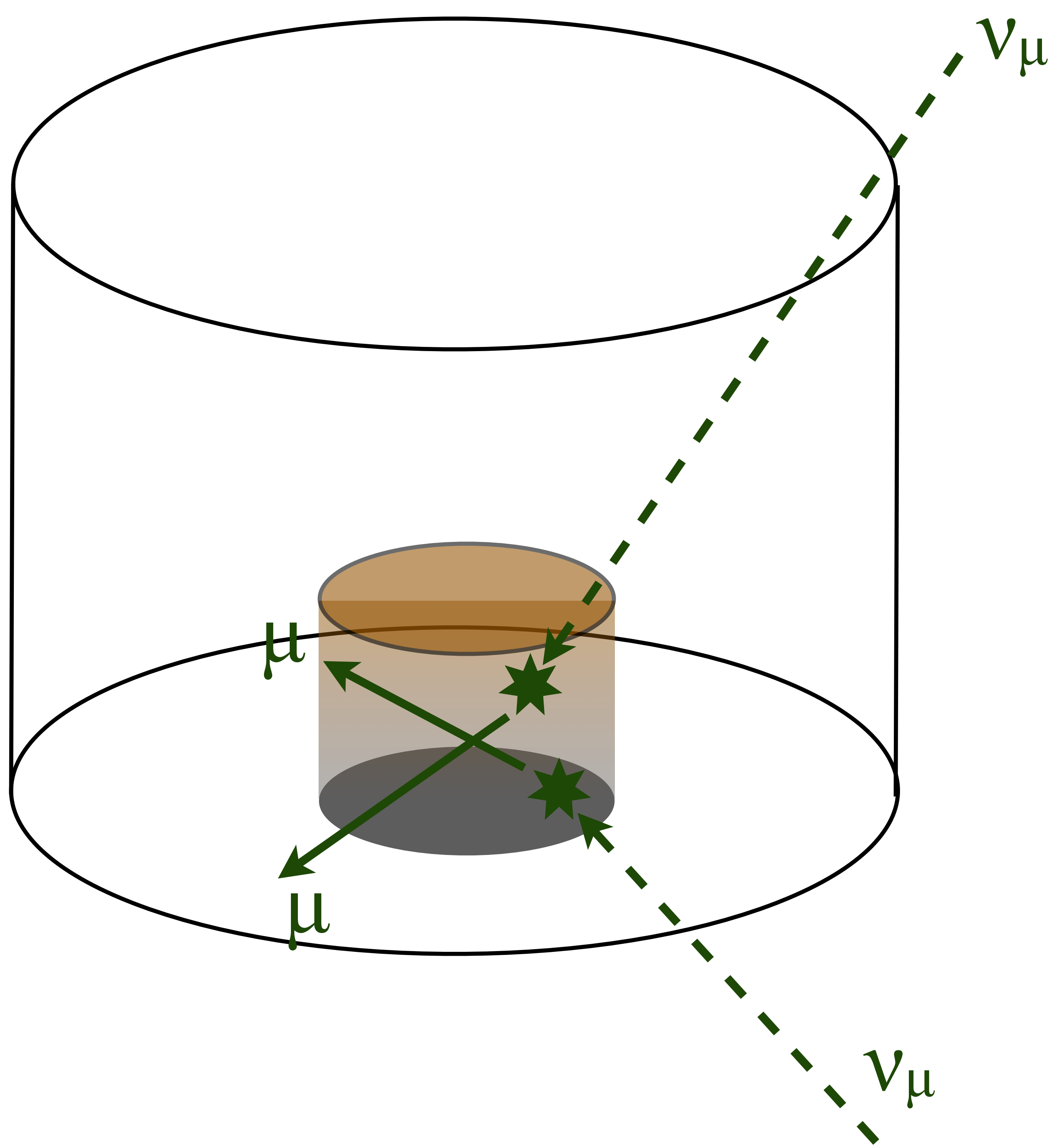

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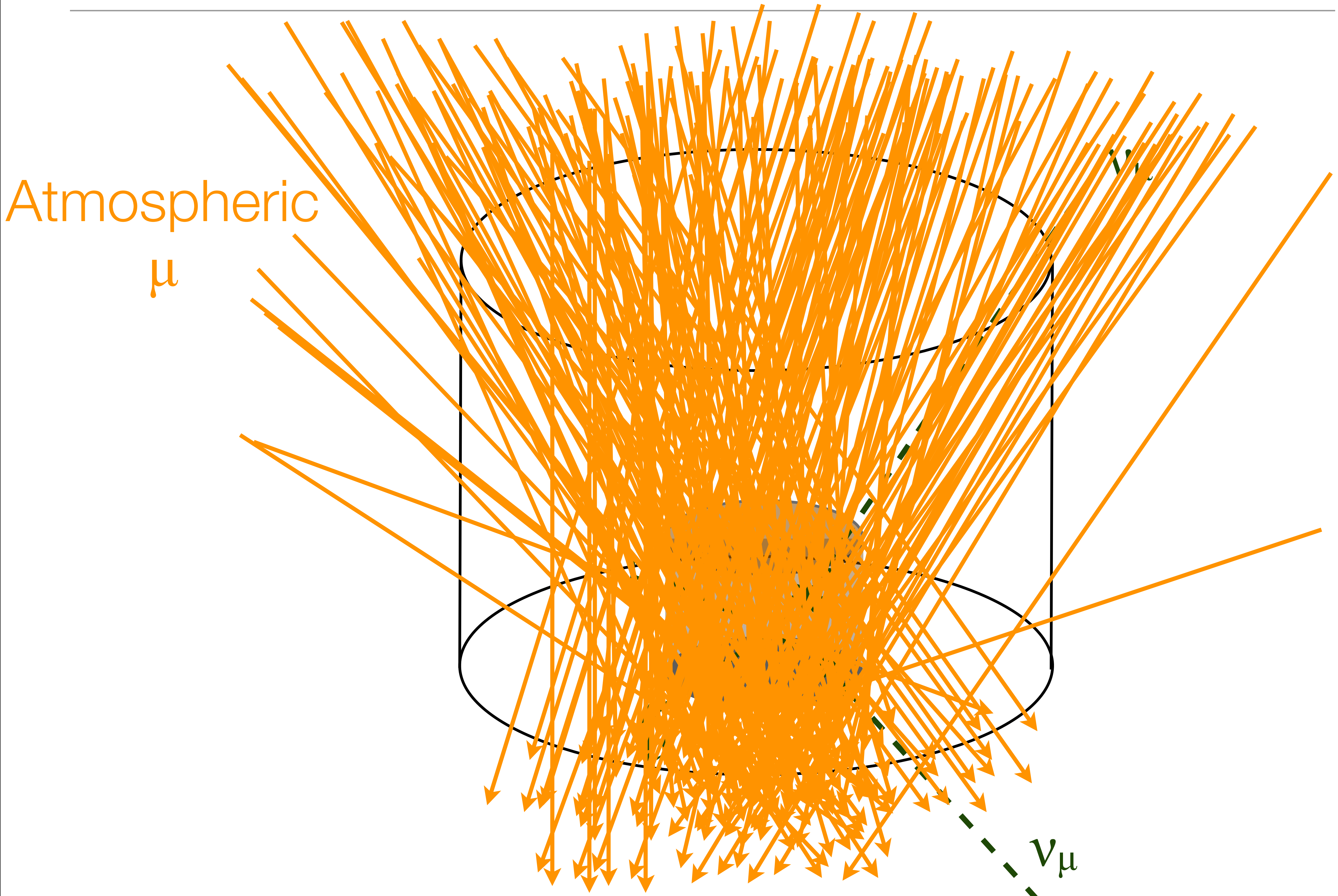
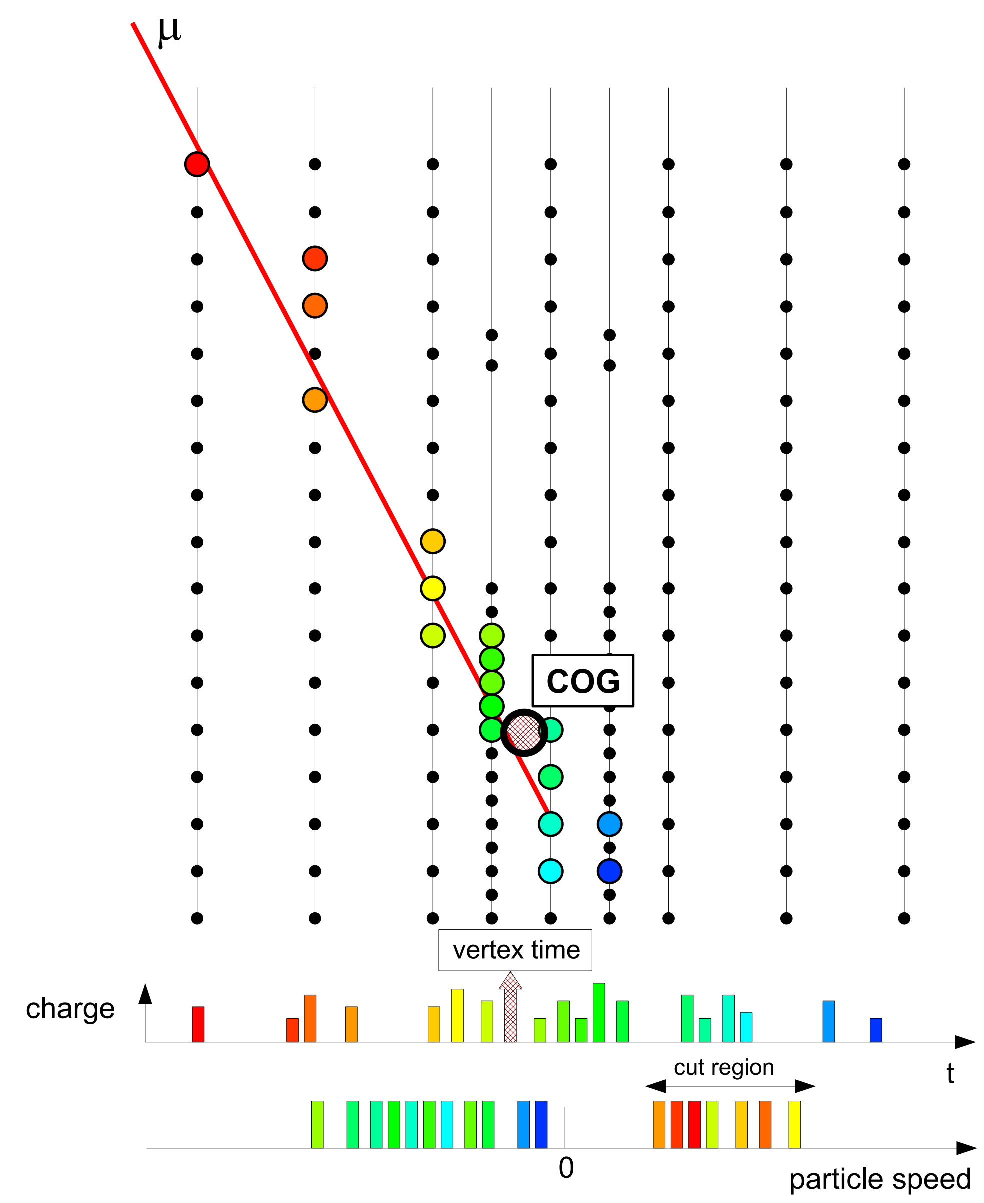


Background Rejection

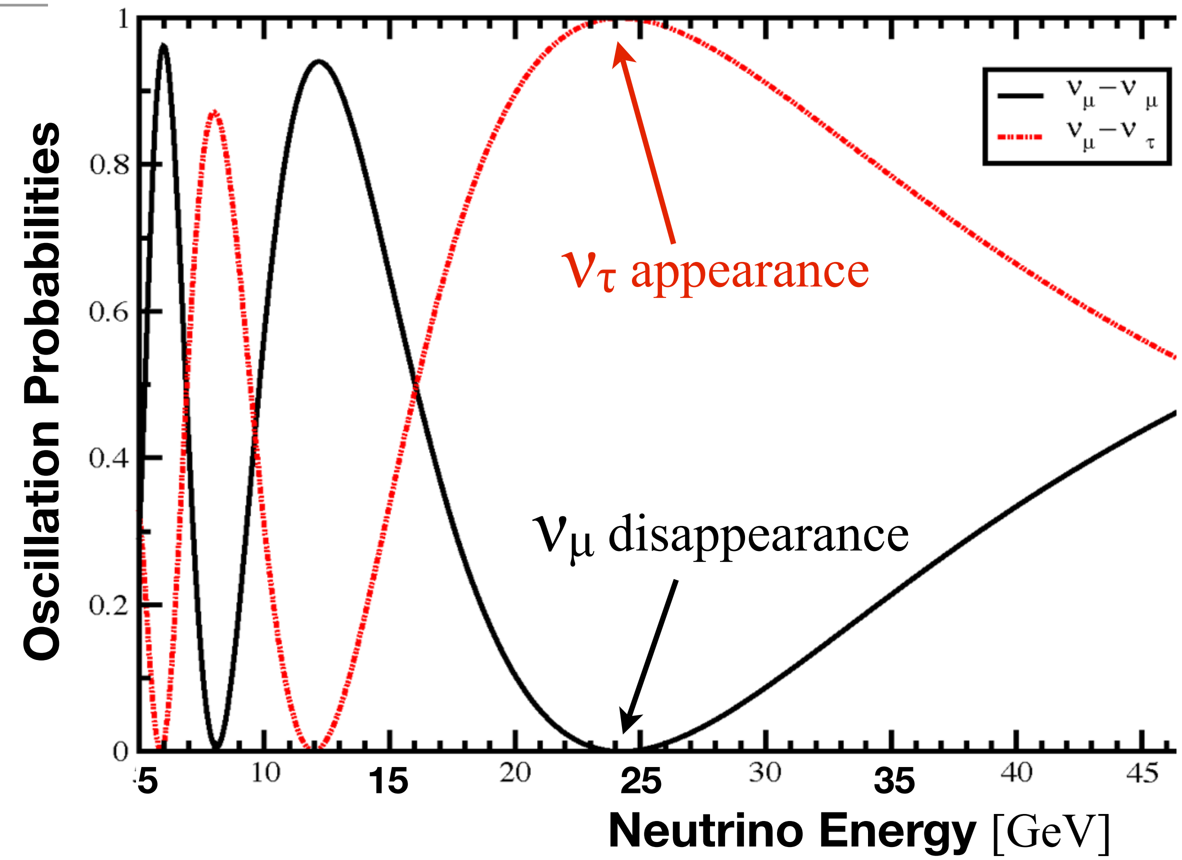
- Trigger level bkg to signal ratio is 10^6:1
- DeepCore uses IceCube as an active veto to reject down-going atmospheric muons and neutrinos
- Online veto uses center-of-gravity (CoG) of hits within DeepCore and looks for >1 hit in veto region that is consistent with an atmospheric muon
- Atmospheric muon reduction of ~8×10^3 with neutrino retention of ~99%
- Offline methods are used for further background reduction

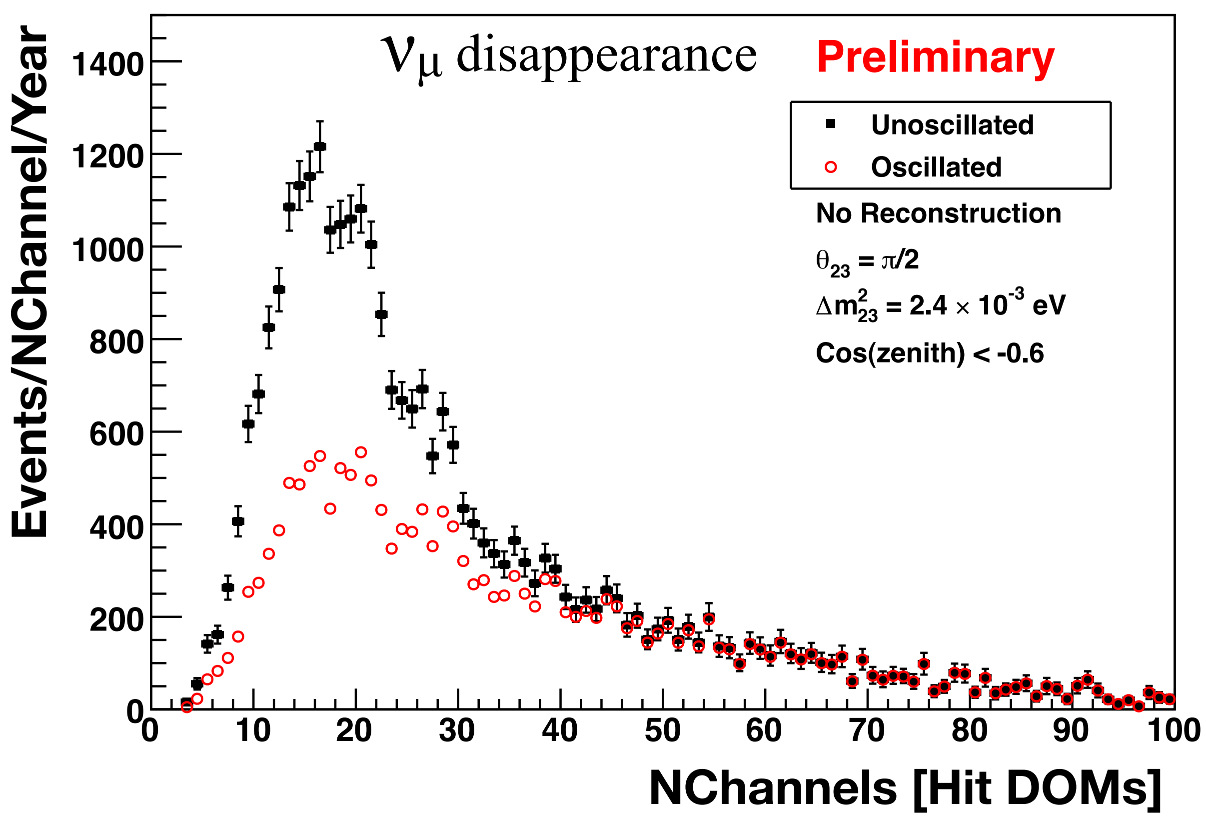


Neutrino Oscillations

- Northern Hemisphere neutrinos oscillating over one earth radii produce ν_μ (ν_τ) oscillation minimum(maximum) at ~25 GeV
- Higher energy region than accelerator based experiments
- ν_τ appearance - measure excess in up-going cascade events
- Plot of ν_μ disappearance shows only signal Monte Carlo and uses hit DOMs as a simple energy estimator

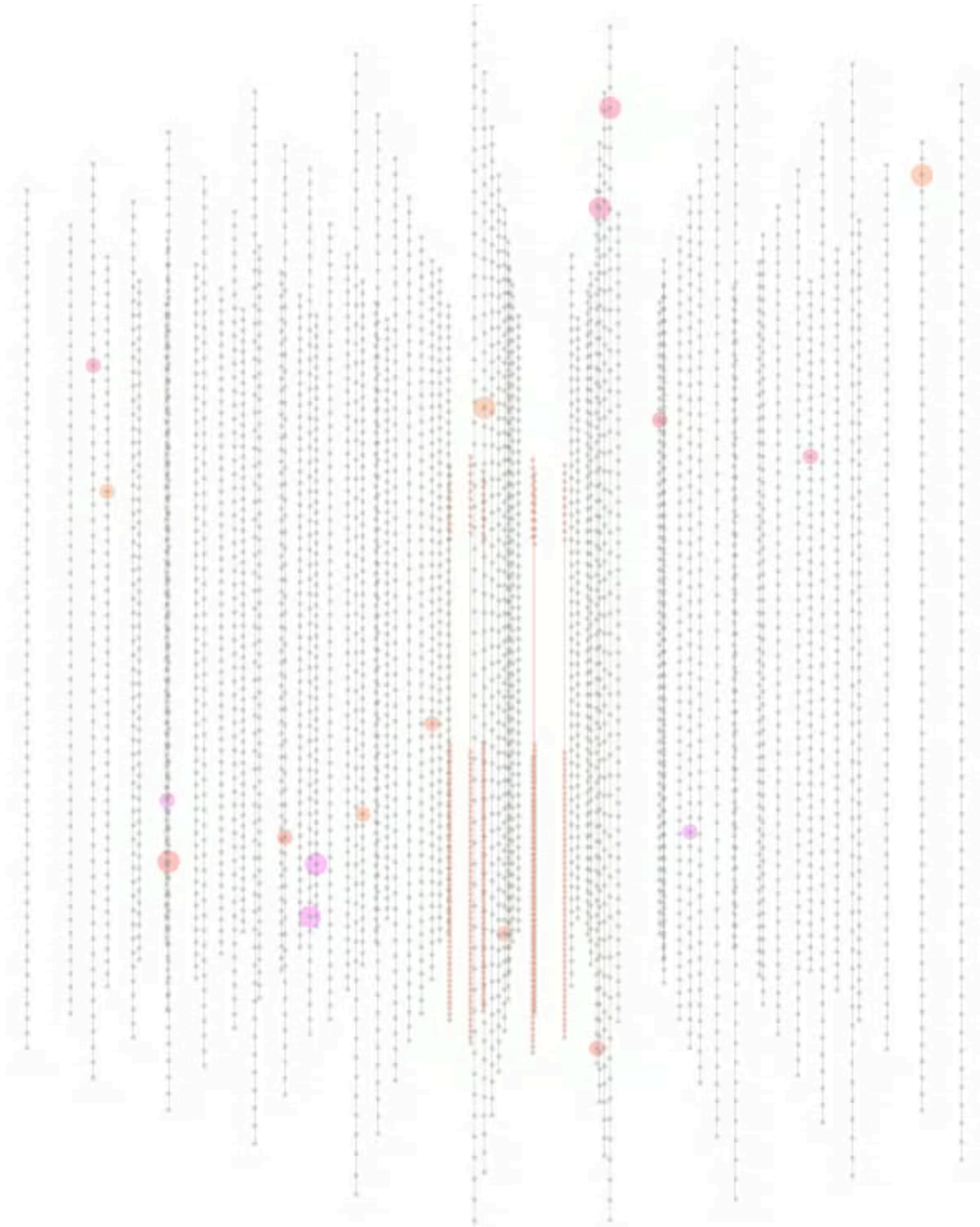
Mena, Mocioiu & Razzaque, *Phys. Rev.* D**78**, 093003 (2008)





Real Data

- 8 hours of test data
- Specific DeepCore vetoes and a Boosted Decision Tree
- Up-Going muon neutrino candidate



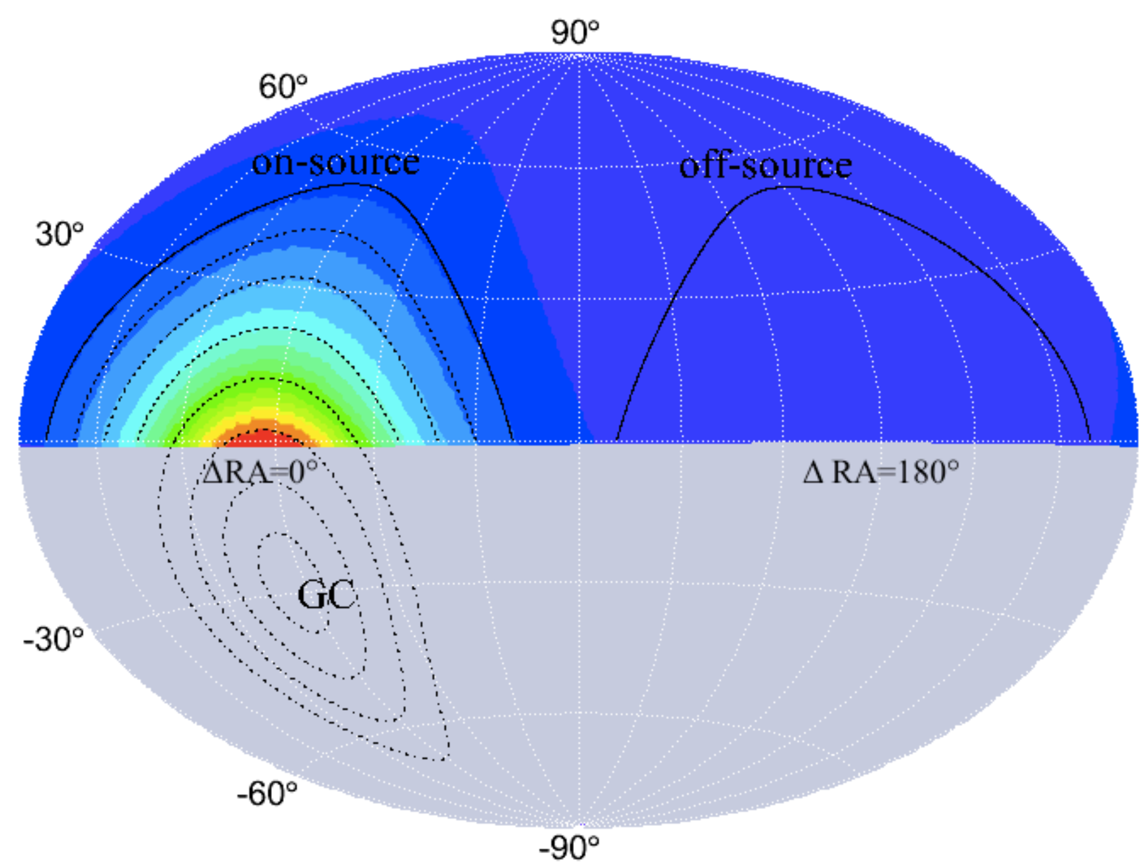
Indirect Dark Matter Search

- Galaxy clustering, Gravitational lensing, Bullet Cluster galaxies, etc... strongly suggest existence of Dark Matter
- Popular candidate for Dark Matter particle is **W**eakly **I**nteracting **M**assive **P**article (WIMP)
- IceCube-DeepCore searches for Dark Matter self-annihilation creating neutrinos
  - Point towards galactic objects where Dark Matter clumps (Sun, Galactic Halo)

$$\chi\chi \rightarrow \begin{matrix} q\bar{q} \\ l\bar{l} \\ W^{\pm}, Z, H \end{matrix} \rightarrow \cdots \rightarrow \nu_{\mu}$$

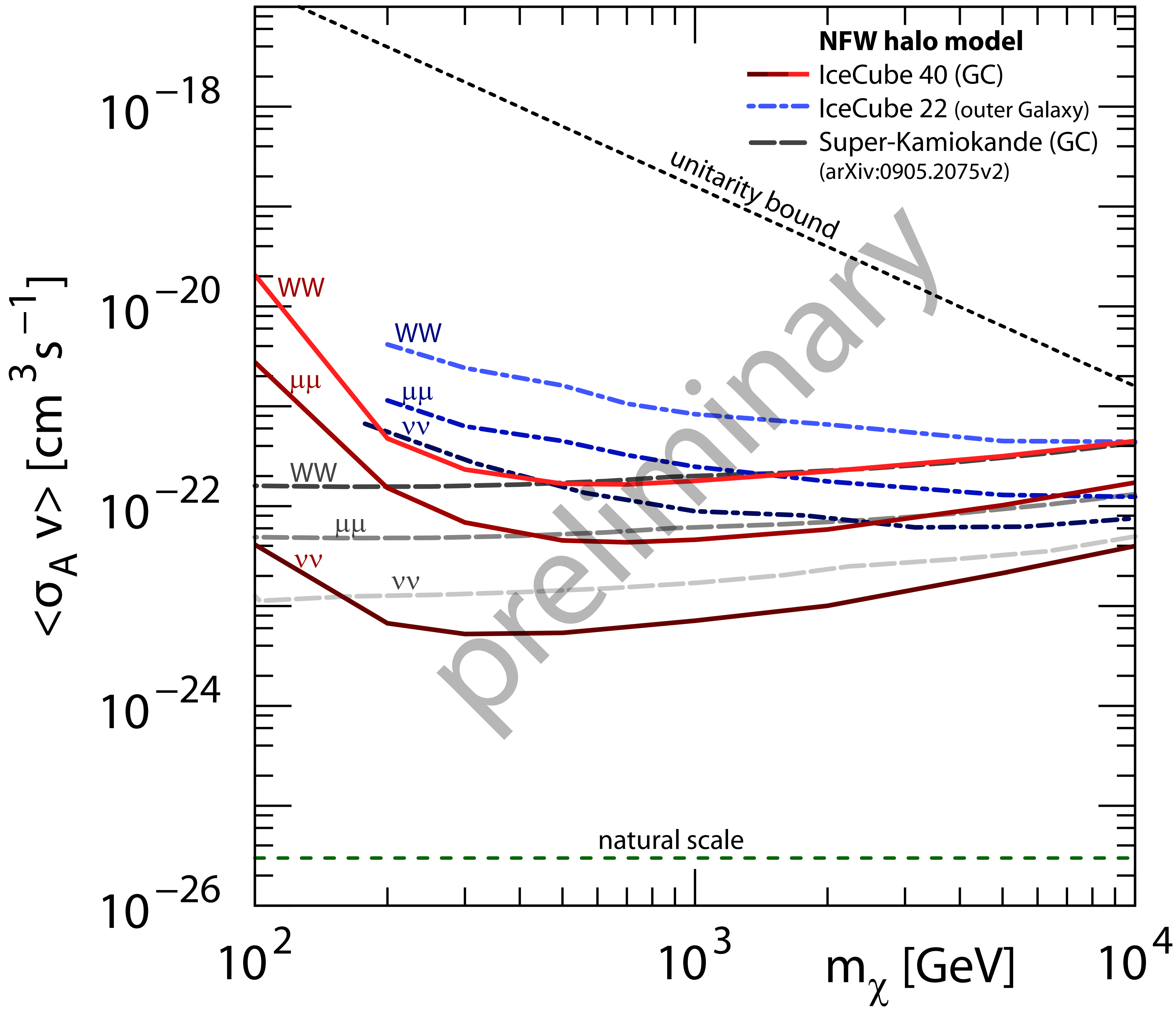
W. H. Press and D. N. Spergel. Astrophys. J. **296**, 679, (1985)
T. Gaisser, G. Steigman and S. Tilav. Phys. Rev. D**34**, 2206, (1986)
A. Gould. Ap. J. 328, 919, (1988).

- Signal depends on Halo distribution(DM density) model and SUSY model(DM annihilation channels)
- on-source versus off-source anisotropy
- IC22 analysis did not observe a large scale anisotropy and has a 90% C.L. on WIMP self-annihilation cross-section of $<\sigma_A v>$ 10^{-22} cm^3s^{-1} in the WIMP mass range of 200 GeV-10 TeV



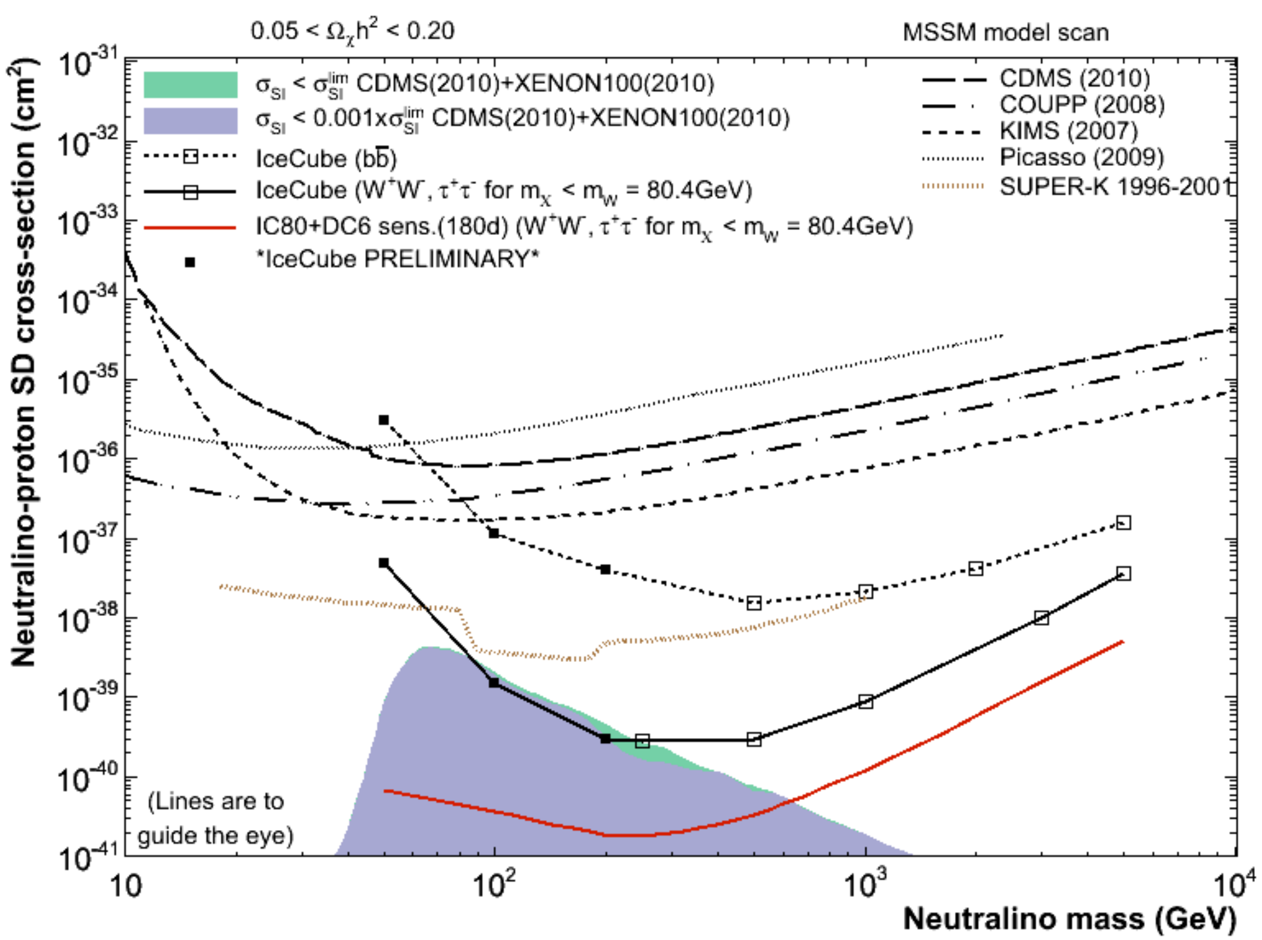
arXiv:1101.3349

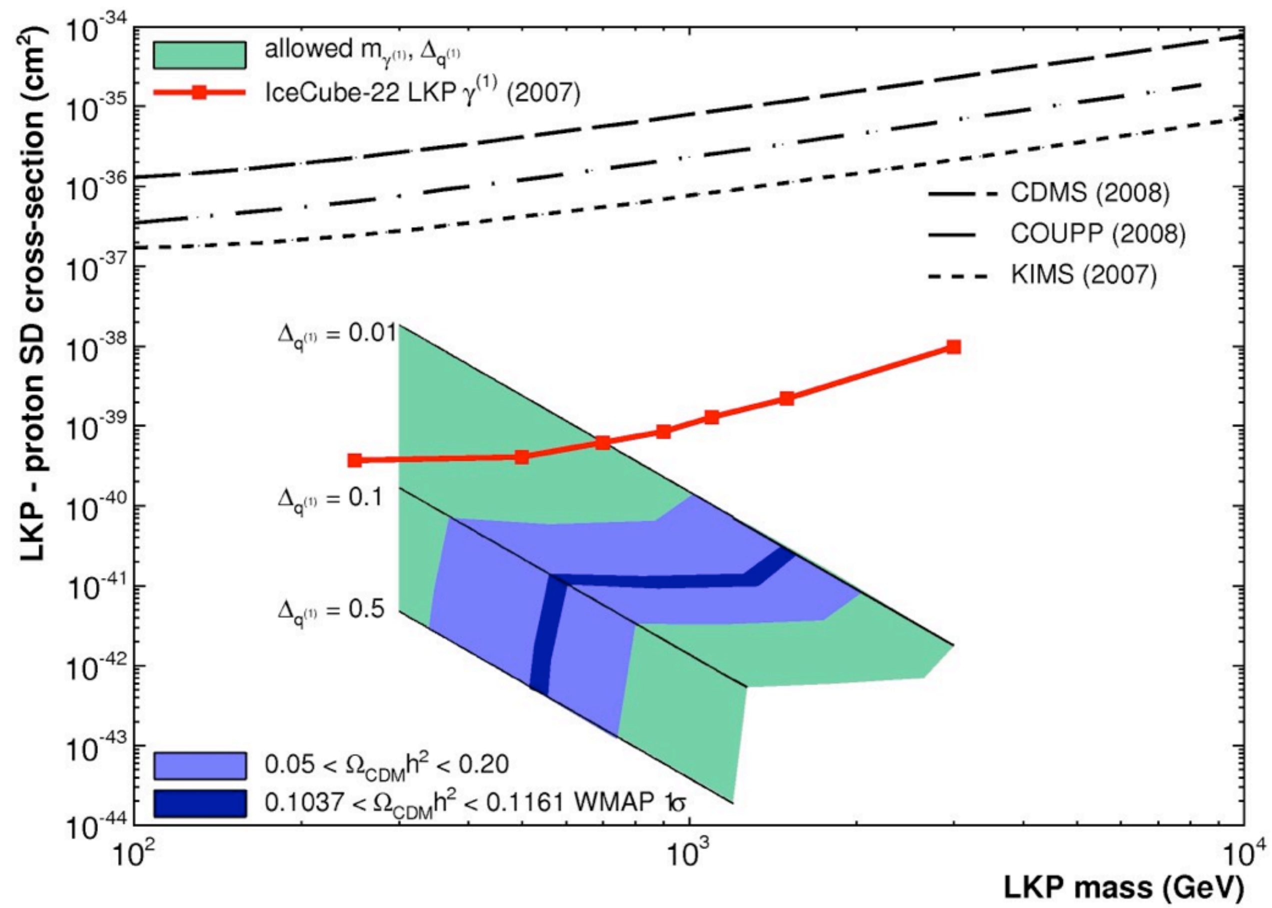
Limits (90% C.L.) on the self annihilation cross section (χχ -> WW, μμ, νν)



Solar Dark Matter Limits

- Look for neutrino excess when the Sun is below the horizon
- Neutrino flux translates to cross-section
- DeepCore will provide order of magnitude improvement in spin dependent searches for Dark Matter
- Limits on MSSM model Dark Matter and Kaluza-Klein model





Conclusion

- Full 86 string IceCube deployment finished Dec. 18, 2010, and first test run occurred Jan. 18, 2011
- IC22 & IC40 analyses are setting neutrino flux limits ranging from GRBs and diffuse astrophysical neutrinos to Dark Matter candidate cross-sections
- Full deployment of the DeepCore low energy extension enhances Dark Matter searches and opens up energy ranges sensitive to neutrino oscillations

Backup

Real Data 2