IceCube's Search for Relativistic Magnetic Monopoles

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Create Change

Introduction

Paul Dirac first formulated in 1931 that a point-like magnetic charge, a magnetic monopole, called the Dirac charge, $g_D = 68.5e$.[5, 6] Other predictions stem from the Grand Unification Theory, which also includes the prediction of a soliton that must carry magnetic charge when GUT breaks into the electromagnetic U(1) symmetry.[3, 4, 5] These magnetic monopoles can have a wide range of masses from 10^5GeV to the order of 10^{17}GeV, these are created in the early universe, diluted through inflation, and accelerated by intergalactic magnetic fields over billions of years. [3, 4, 5]

Detecting Magnetic Monopoles

The IceCube experiment relies on detecting relativistic magnetic monopoles through the induction of Cherenkov radiation. This Cherenkov radiation can be emitted directly from the magnetic monopole, indirect emission from ejected δ-electrons and luminescence. Such that Cherenkov detectors such as IceCube can then search for monopoles through patterns they leave it their wake.[2, 3, 4, 5]

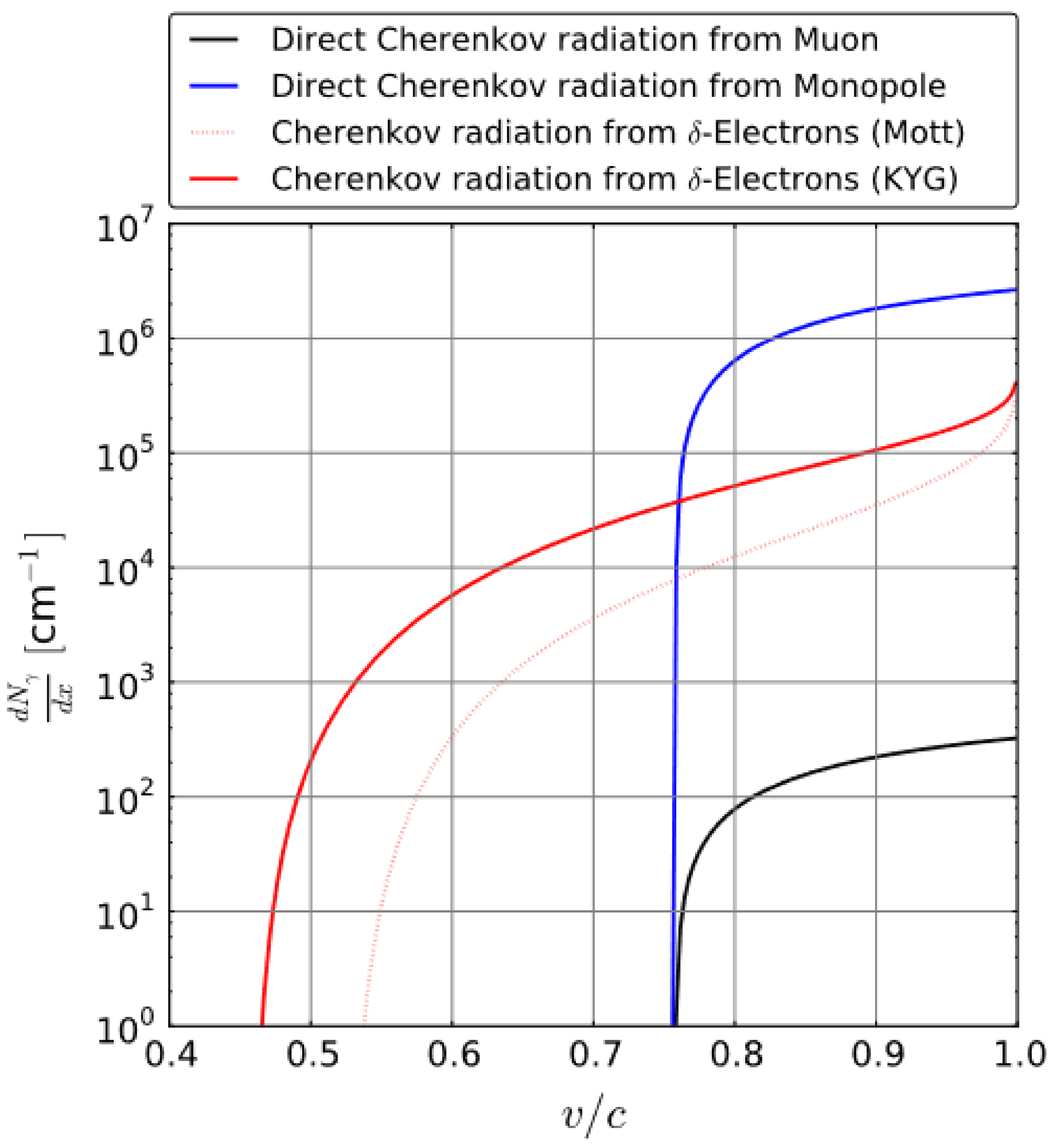

Figure 1. Number of photons per cm produced by a muon (black), a monopole by direct Cherenkov light (blue), and monopoles by δ- electrons. The photon yield per indirect Cherenkov light is shown using two methods, the KYG (red solid) and the Mott (red dotted) cross section. [5]

Cherenkov Radiation

Cherenkov radiation is a result of a charged particle passing through a dielectric medium faster than the phase velocity of light in that medium.[3, 4, 5]

Conclusion

While no magnetic monopole has yet been discovered, continuous research such as the experiments by IceCube, has pushed the limits further down. Supporting other Cherenkov radiation research, and even other methods such as Schwinger mechanism in colliders.[1]

How IceCube Works

The IceCube neutrino observatory is a cubic-kilometer array located at the geographic south-pole. Consisting of 86 strings of 60 digitial optical modules each, placed at depths between 1.45 and 2.45 km below the surface.[3, 4, 5]

IceCube then measures the Cherenkov radiation taken between 2011 and 2018, and then applying a series of filters taking only the most energetic of events and removing astronomical neutrino events. This attempts to retain only the expected relativistic magnetic monopoles.[5]

Analysis Level	n_{obs}	n_{sg}	n_{bg}
Online Filter	1.63×10^8	178	371
Step I:			
Initial Off-Line Cuts	3.16×10^4	89.9	57.2
Track Quality Cut	8.46×10^3	64.1	20.4
Down-Going Cut	3	35.5	10.1
IceTop Surface Veto	3	35.5	$10.0^{+10.3}_{-5.1}$
Step II:	0	33.2	$0.27^{0.27}_{-0.14}$

Table 1. Number of event detections that pass the filters, where n_{sg} are the astrophysical neutrino expected, and n_{bg} is the number of background monopoles expected.[5]

Results

In the end, over the 8 years of detections, zero magnetic monopoles were detected which aligns with the simulated predictions. This has allowed for a new upper limit on the cosmic flux of magnetic monopoles in this relativistic regime.[5]

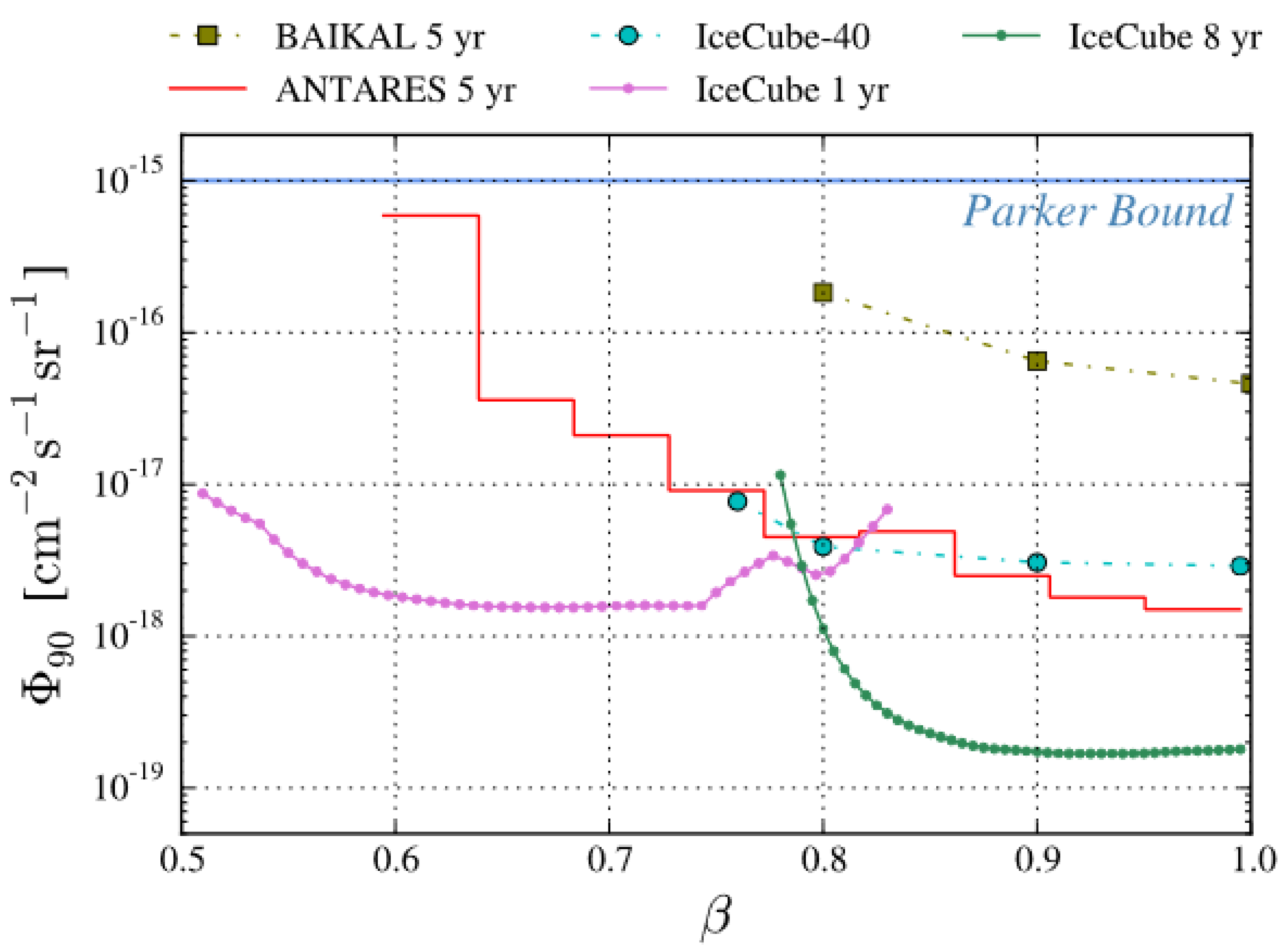

Figure 2. Upper limits for detecting magnetic monopoles from multiple other experiments using the Cherenkov Radiation method.[5]

References

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[3] IceCube Collaboration. Search for non-relativistic magnetic monopoles with icecube. *The European Physical Journal C*, 74(7), July 2014.

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[5] IceCube Collaboration. Search for relativistic magnetic monopoles with eight years of icecube data. *Physical Review Letters*, 128(5), February 2022.

[6] Donald R. Tompkins. Total energy loss and Čerenkov emission from monopoles. *Phys. Rev.*, 138:B248–B250, Apr 1965.