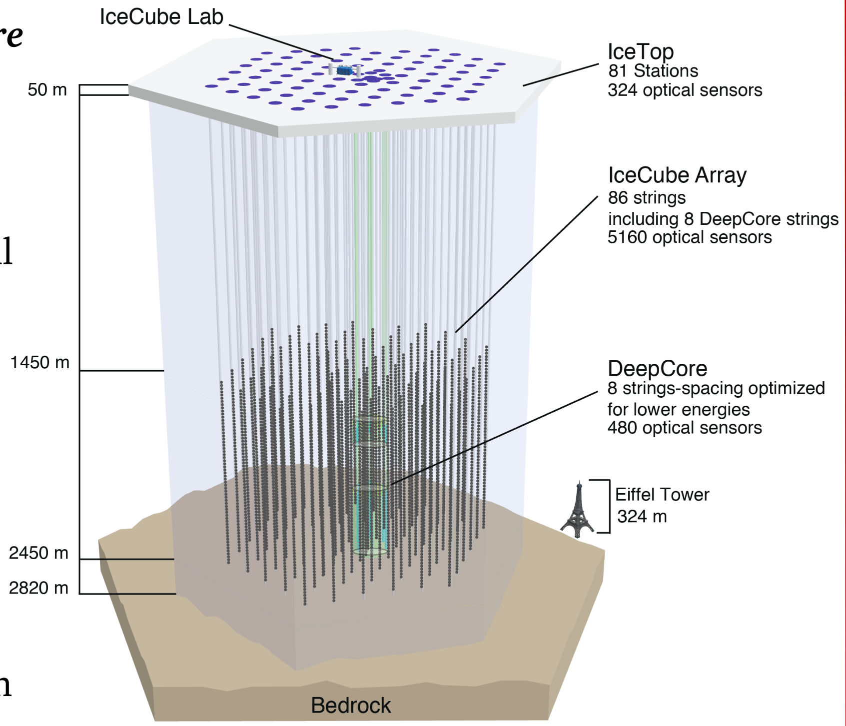
Gravitational Wave Follow-Up Using Low Energy Neutrinos in IceCube DeepCore

A. Balagopal V.[1], R. Hussain[1], A. Pizzuto[1] for the IceCube Collaboration, PoS(ICRC2021)939

[1]University of Wisconsin-Madison

1 The IceCube DeepCore

- The IceCube Neutrino Observatory at the South Pole observes astrophysical neutrinos with energies greater than 100s of Gev
- Horizontal string spacing: 125 m; vertical spacing of optical sensors (DOM): 17 m
- IceCube DeepCore: the infill array of IceCube with DOMs of higher quantum efficiency and deployed in the clearest ice

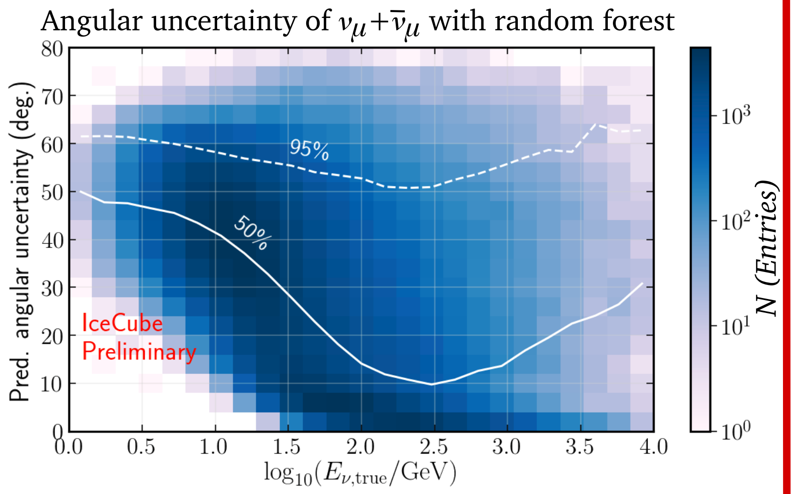


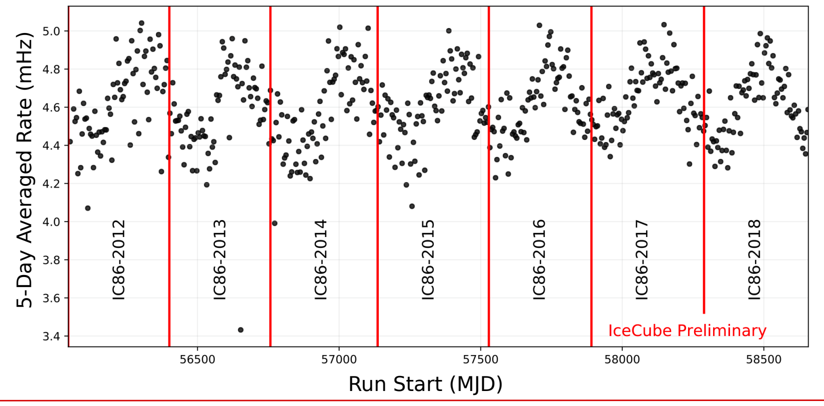
- DeepCore string spacing: 72m; DOM spacing: 7m
- This lowers the threshold down to ∼ 10 GeV

2 The GRECO Dataset

(GeV Reconstructed Events with Containment for Oscillations)

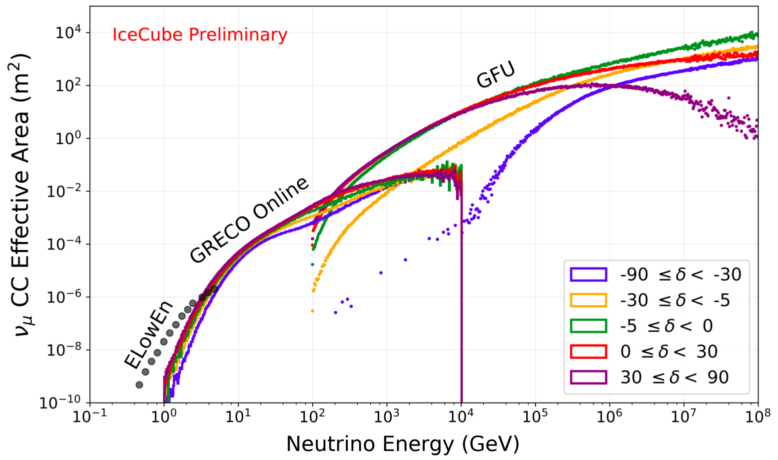
- Event selection originally developed for tau neutrino appearance studies[1]
- Neutrinos of all flavors
- Includes data from both Southern and Northern hemispheres
- Angular resolution worse than that of high-energy events
- Event selection has an average rate of 4.5 mHz[2]

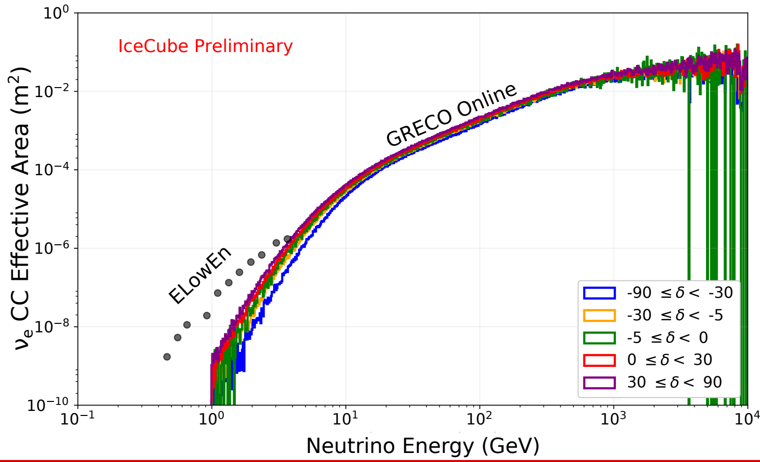




3 Effective Area

- Nearly uniform effective area which varies by less than an order of magnitude across the whole sky[2]





- Complements high-energy[3] and extremely low-energy[4] datasets
- Has already been used to search for astrophysical transients[4]

4 Gravitational Wave Follow-up with the GRECO Dataset

- Use the dataset to search for counterparts to gravitational waves in the 10s -100s of GeV energy range
- Time window of ± 500 s around the time of each GW event observed by LIGO-Virgo
- Use probabilities from the gravitational wave skymap as spatial prior
- Unbinned maximum likelihood method used to look for transients (method similar to the high-energy analysis[6])

$$\mathcal{L} = \frac{(n_s+n_b)^N}{N!} e^{-(n_s+n_b)} \prod_{i=1}^{N} \left(\frac{n_s \mathcal{S}_i}{n_s+n_b} + \frac{n_b \mathcal{B}_i}{n_s+n_b} \right)$$

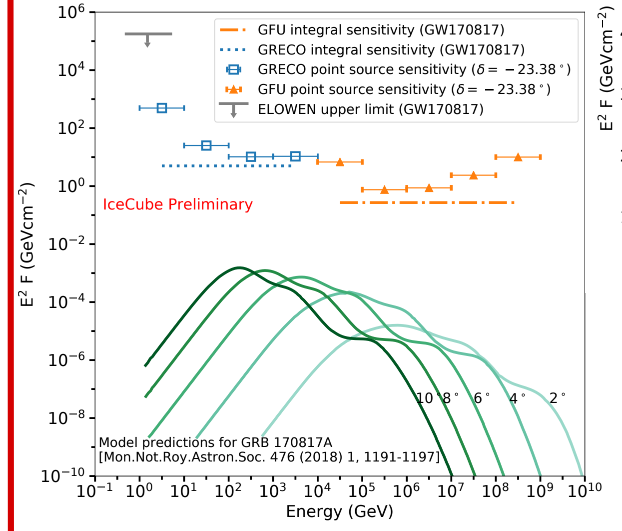
Signal PDF; Background PDF; signal events; background events

- Look for spatially and temporally coincident neutrinos by likelihood maximization

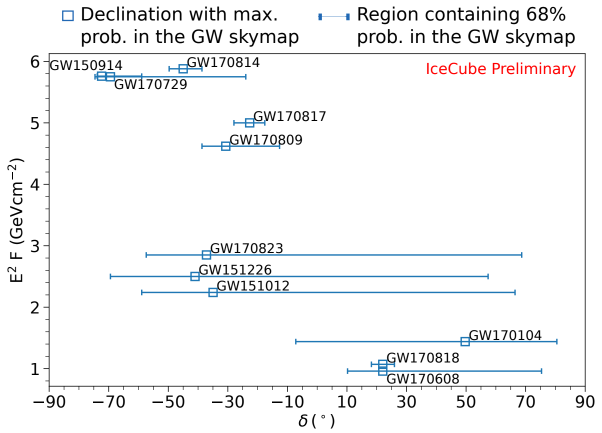
$$\text{Test Statistic (TS)} = \max. \left\{ 2\ln\left(\frac{\mathcal{L}_k(n_s,\gamma)\,.\,w_k}{\mathcal{L}_k(n_s=0)} \right) \right\}$$

Runs over all pixels; Spatial prior from GW skymap (direction dependent)

5 Sensitivities



Differential point source sensitivities and integral sensitivities (with spatial prior) of IceCube low-energy and high-energy analyses, upper limit of IceCube very-low energy analysis, and model predictions of low-energy neutrino emissions[8]



Sensitivities of GRECO to GW events in O1 & O2 runs

- 90% flux sensitivity of muon neutrinos (flux normalization that 90% of the time will lead to a TS > median background TS) for all 11 GW events in O1 & O2 runs of LIGO-Virgo[7]

6 Summary

- Data selection focused on IceCube DeepCore to probe neutrinos with energies above 10 GeV
- Enables the detection of astrophysical transients at these low energies
- Used to follow-up gravitational-wave events as a complementary study to similar high-energy analyses with IceCube
- Flux sensitivity of muon neutrinos shown; which will be updated with neutrinos of all flavours in the future

References

[1] M. G. Aartsen et al. Phys. rev. D. 99, 032007, 2019
[2] M. Larson et al. PoS(ICRC2021)1131
[3] M. G. Aartsen et al. JINST 11 P11009, 2016
[4] G. de Wasseige et al. PoS(ICRC2019)865
[5] R. Abbasi et al. arXiv:2011.05096
[6] M. G. Aartsen et al. ApJL 898 L10, 2020
[7] B. P. Abbott et al. Phys. Rev. X 9, 031040, 2019
[8] D. Biehl, et al. Mon. Not. Roy. Astron. Soc. 476 no. 1, (2018) 1191–1197

Contact: abalagopalv@icecube.wisc.edu