Search for GeV neutrino counterparts to high-energy IceCube neutrinos

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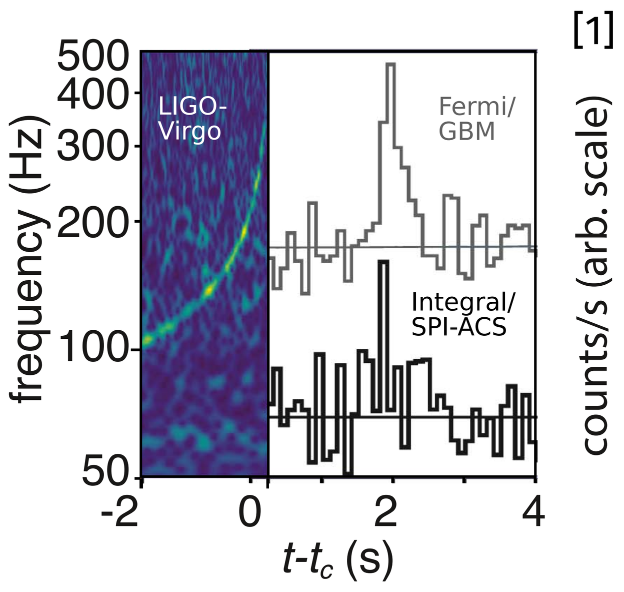
MOTIVATION

Example (A) GW170817 [1]
merger → 1.7 s → GRB170817A (T90 = 2 s)
→ look for GeV + TeV on same time scale



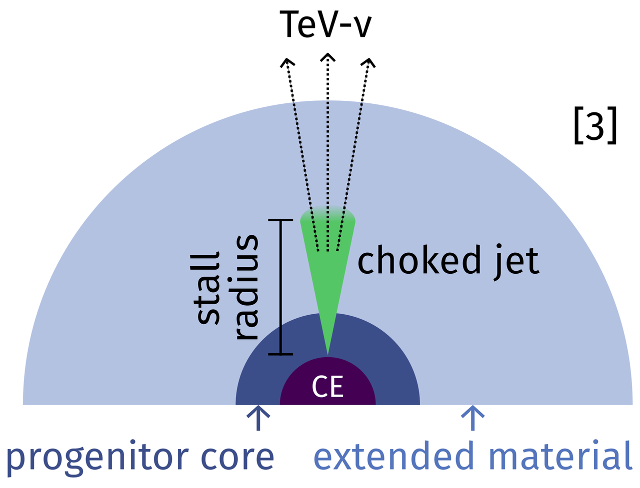
Example (B) Choked-jet GRBs [2,3]
- GRB jet choked in extended material ~$10^{13\text{-}14}$ cm
- TeV neutrinos from p-p and p-γ interactions
- GeV neutrinos from p-n collisions [4]
- many parameters affect the time scale

→ conservative 1000 second time window, but include time series analysis to detect faster variability.

General:
- transients may be unresolved or have obscured electromagnetic emission
- neutrino production traced by TeV component

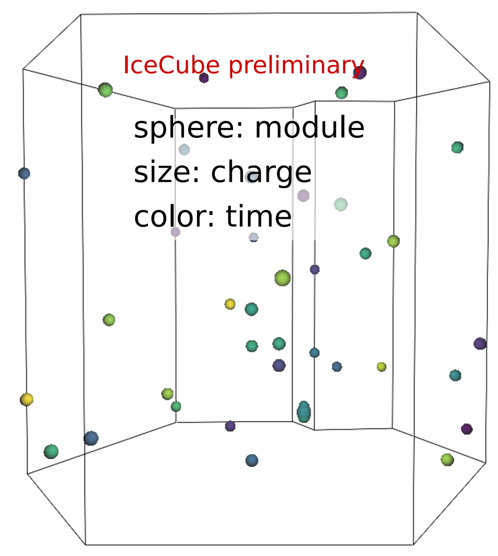
→ IceCube sensitive if flux high enough
- can have a GeV component

→ IceCube/DeepCore sensitive to bursts

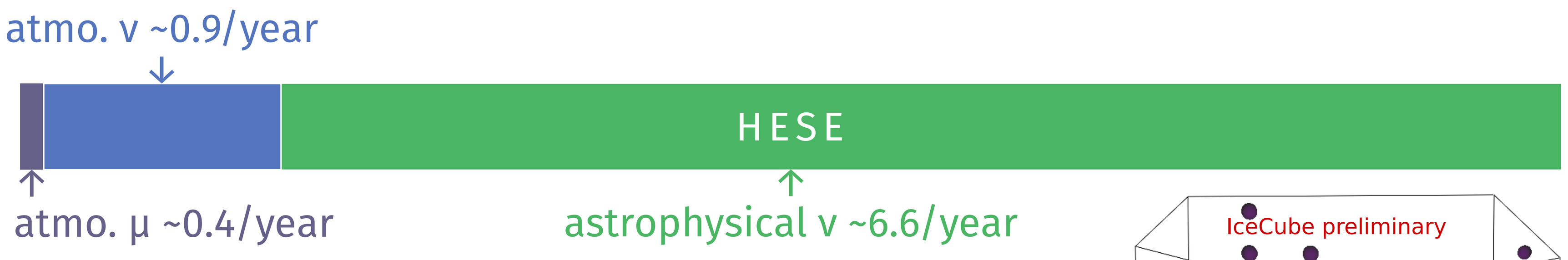


- the faintest events triggering IceCube/DeepCore
- sensitive 1.2 to 29 GeV (90% for $E^{-2.9}$), down to 0.5 GeV
- 20 mHz dominated by background events
- all-flavour, all-sky coverage

→ search for GeV transients e.g. solar flares [5], GRBs [6]

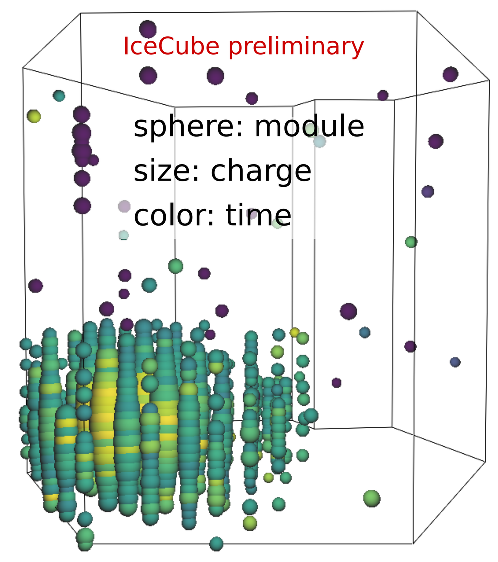


simulated ν_τ, 4.9 GeV, zenith = 116°



- highest-energy events starting inside IceCube
- sensitive 65 to 969 TeV (90% for $E^{-2.9}$), up to O(PeV)
- 97 events in 12 years, mostly astrophysical
- all-flavour, all-sky coverage

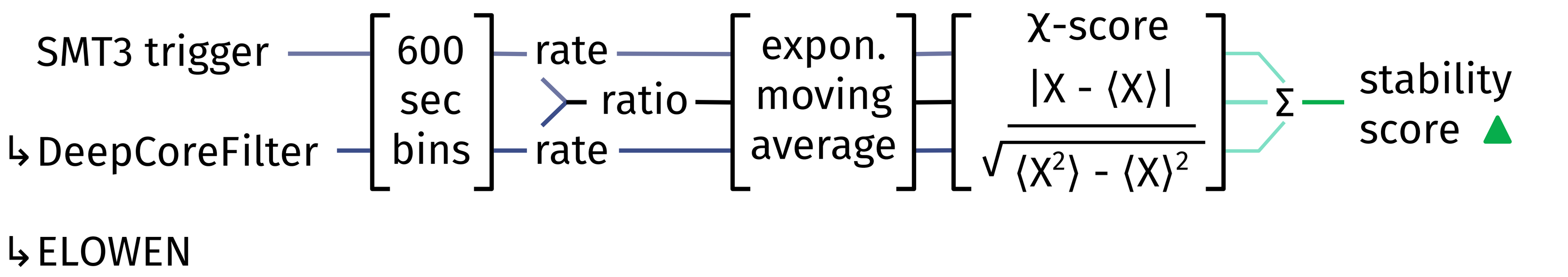
→ fit the astrophysical spectrum [7], trigger multi-messenger followups [8]

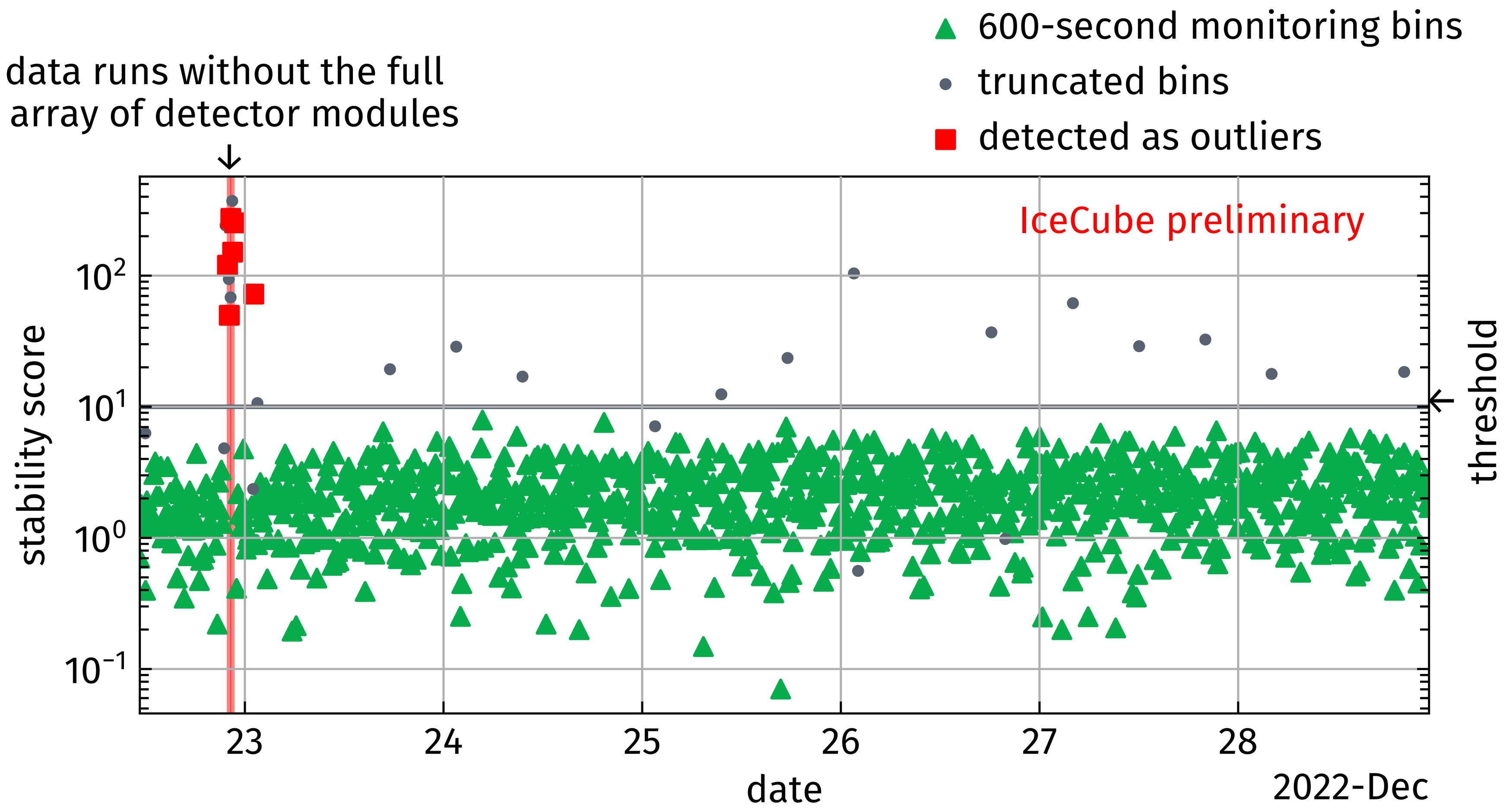


simulated $\bar{\nu}_e$, 154 TeV, zenith = 75°

DATA QUALITY CHECKS

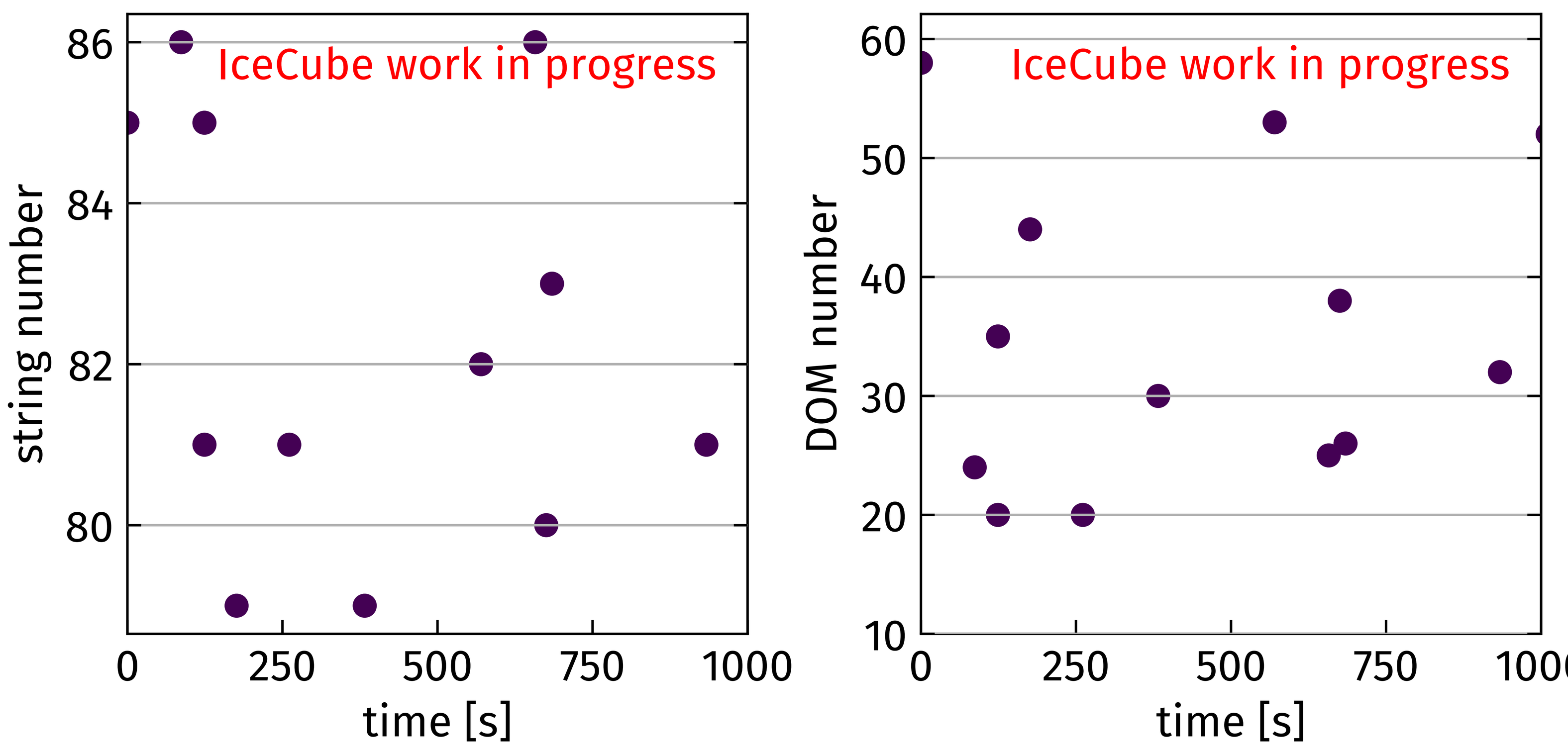
- with ELOWEN dominated by detector backgrounds and time the only observable to separate them from signal, transient detector effects must be well controlled
- in addition to IceCube's run monitoring, we propose analysis-specfic checks
- stability pre-check with an ELOWEN-specific selection stability score
- similar method as ref. [9] using intermediate stages of the ELOWEN selection chain





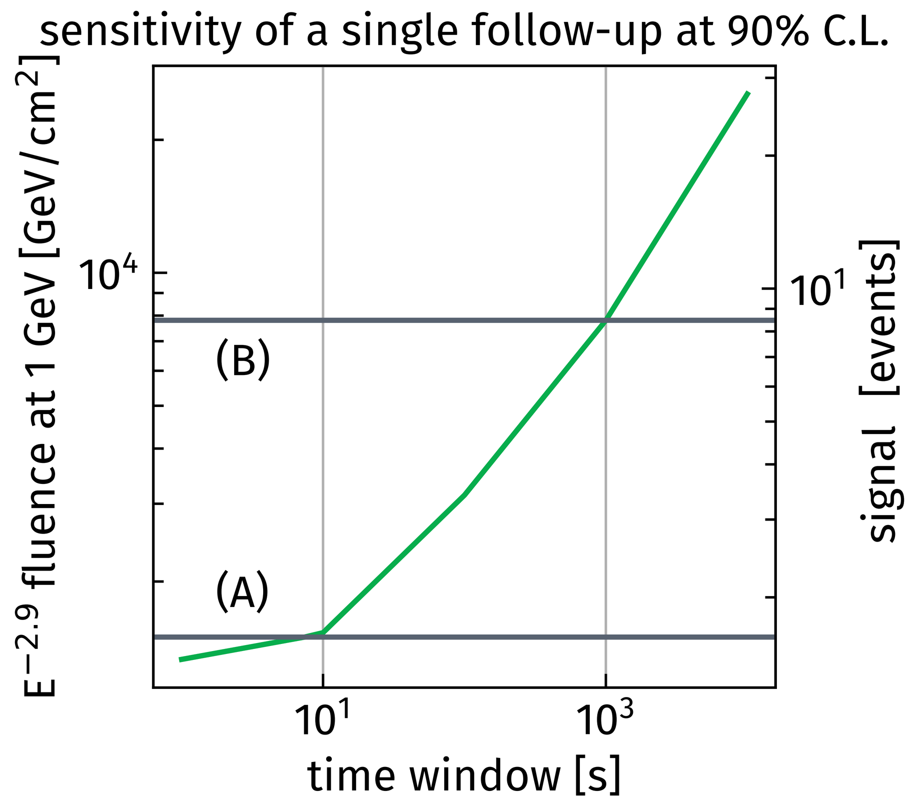
- dark current excess may stem from particular detector modules

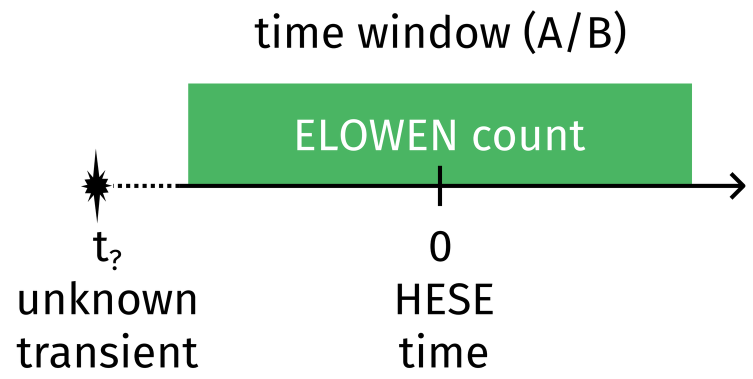
→ post-unblinding check on spurious events stemming from same vertex
- example 1000-second window without correlation, first hit in DeepCore:



ANALYSIS

- **counting analysis** [10] per HESE event in time window according to example (A)/(B)





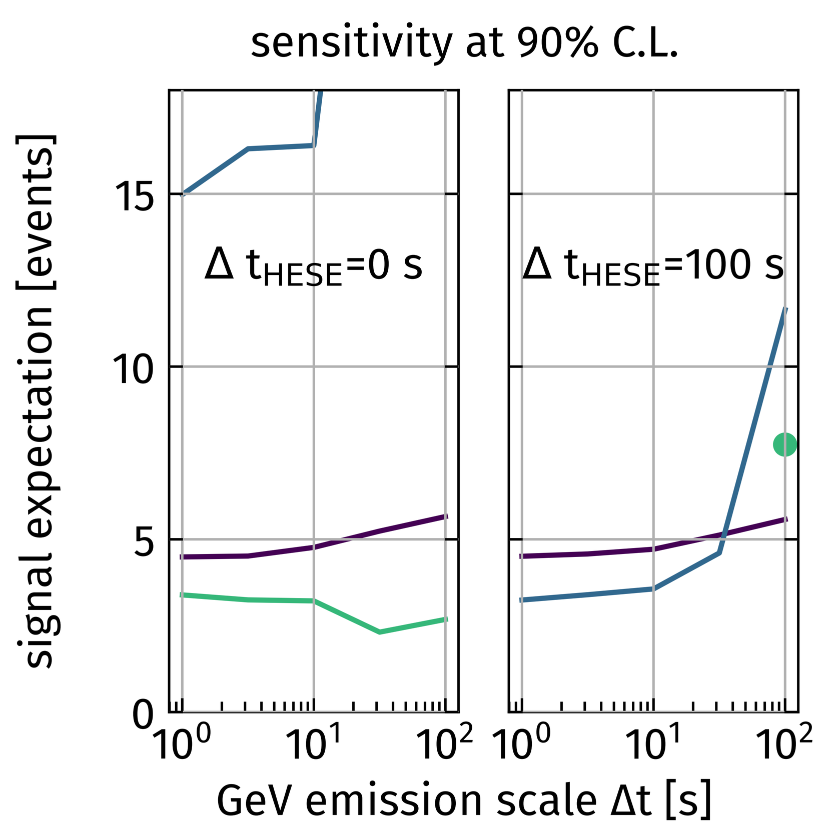
Can be augmented by binomial test (not shown) for ELOWEN signal below significance threshold present for a subset of HESE

- **time series analysis** [11, 12] on events within ± 500 s to exploit faster variability
- hypothesis: GeV emission lasting Δt after unknown transient

1 HESE event on its own time scale Δt_{HESE} → analysis window

→ random relative signal times $(t - t_{HESE})$

\+ 20 mHz background [1]



— extended unbinned maximum LLH
- $P(t) = n_{BG}$ BG + n_S gaussian(t, t_0, σ)
- in unbinned LLH x Poisson term
- fit n_S, t_0, σ>0.1 s
- similar sensitivity across hypotheses

— PCA classifier, trained on long emission
- 10-second bin time histograms

→ vector space for 1-comp. PCA
- trained on 10k BG + 10k "signal" trials
- signal here: Δt = 100 s, Δt_{HESE}= 10 s
- sensitivity depends on hypothesis

— PCA classifier, trained on 10-s bursts
- 10-component PCA reduced to Z-score
- Δt = 10 s, Δt_{HESE}= 300 s

[REFERENCES]

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[3] Senno et al. (2016) doi:10.1103/PhysRevD.93.083003
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[5] IceCube Collaboration (2021) doi:10.1103/PhysRevD.103.102001
[6] IceCube (2023) doi:10.3847/2041-8213/acc077
[7] IceCube Collaboration (2021) doi:10.1103/PhysRevD.104.022002
[8] Abbasi et al. (2023) doi:10.3847/2041-8213/acc077
[9] Method: IceCube/MAGIC/Veritas (2016) doi:10.1088/1748-0221/11/11/P11009
[10] Method: Kruiswijk et al. (2023) doi:10.48550/arXiv.2307.15902
[11] Method: de Wasseige (2021) doi:10.1088/1748-0221/16/12/C12012
[12] Method/code: Lamoureux & De Wasseige (2023) doi:10.22323/1.444.1507

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