Neutrinos From TXS 0506+056

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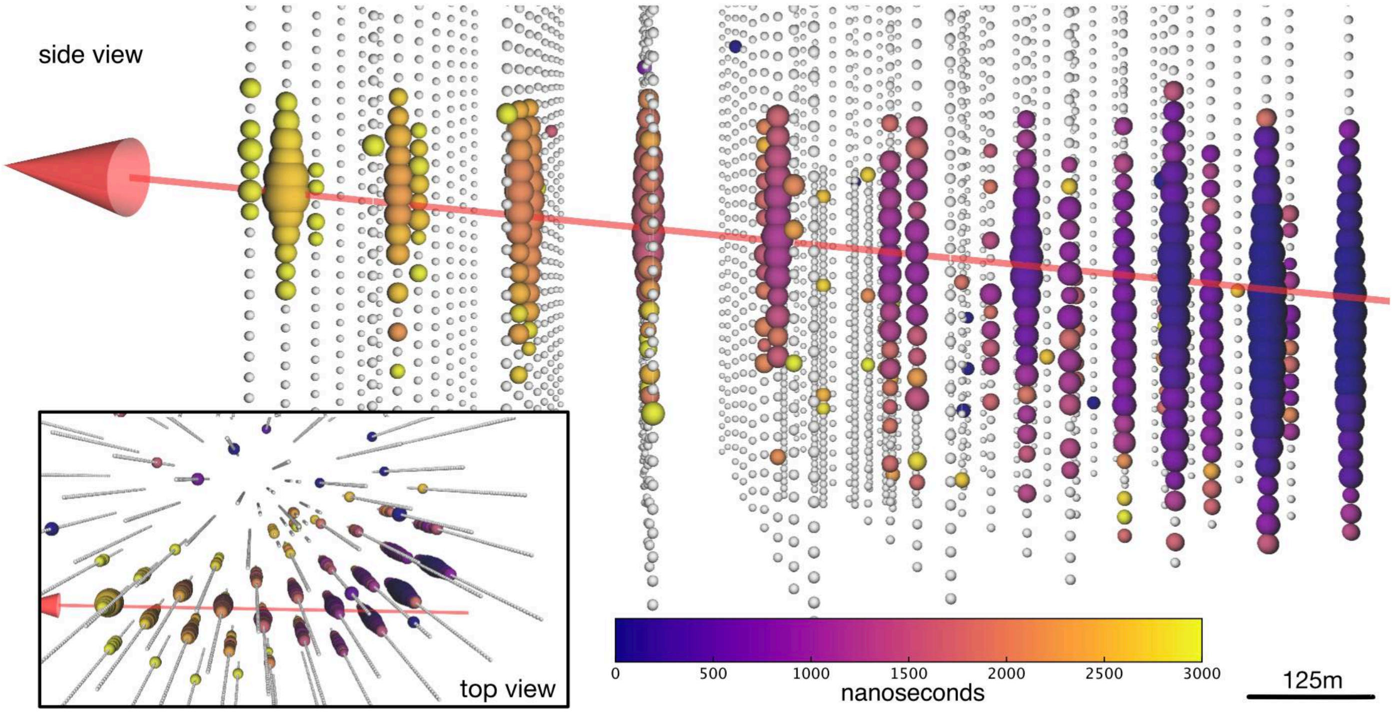
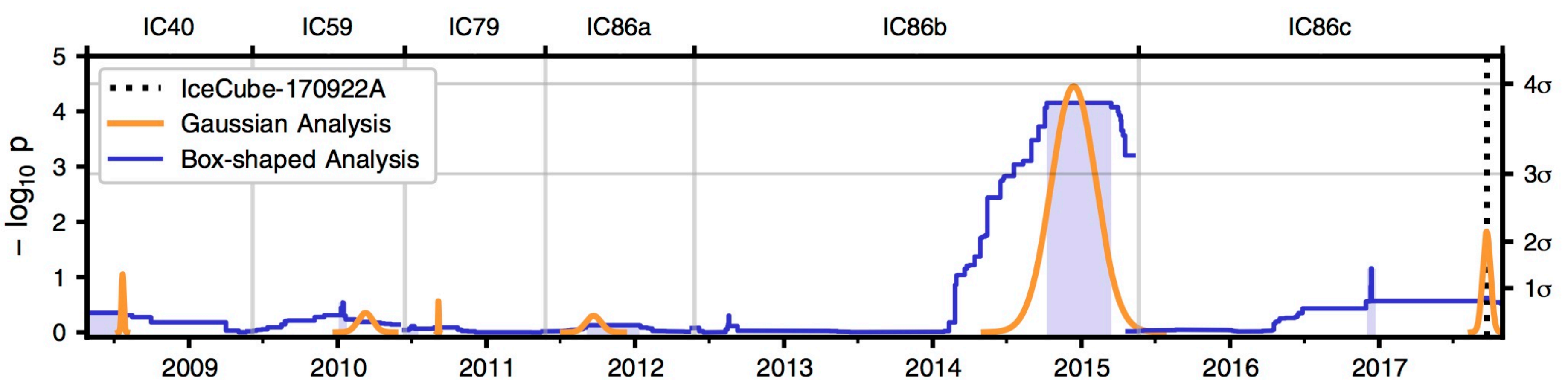
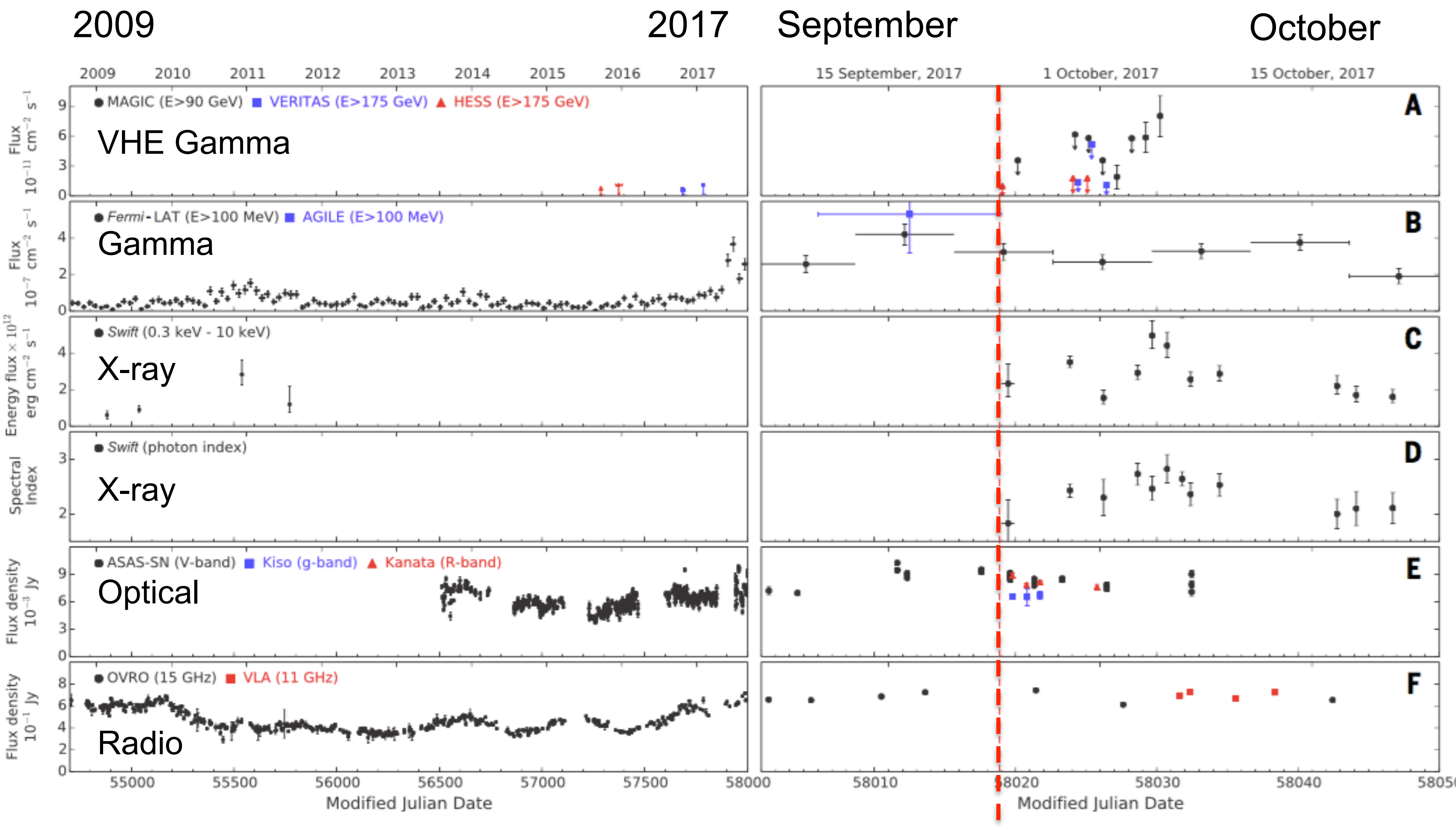


Science 361, 6398, (2018) eaat1378



Science 361, 6398, (2018) 147

Time-dependent multi-wavelength observations of TXS 0506+056 before and after IceCube-170922A



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Alert

"Untriggered" Time-Dependent Likelihood

Braun et al. Astropart.
33, 175 (2010)

Generic Time Window can be
Gaussian (here) or Box ("Top Hat")

$$\mathcal{S}_i = \frac{1}{2\pi\sigma_i^2} e^{-|\vec{x}_i - \vec{x}_s|^2/2\sigma_i^2} \cdot P(E_i|\gamma) \cdot \boxed{\frac{1}{\sqrt{2\pi}\sigma_T} e^{-(t_i - T_0)^2/2\sigma_T^2}}$$

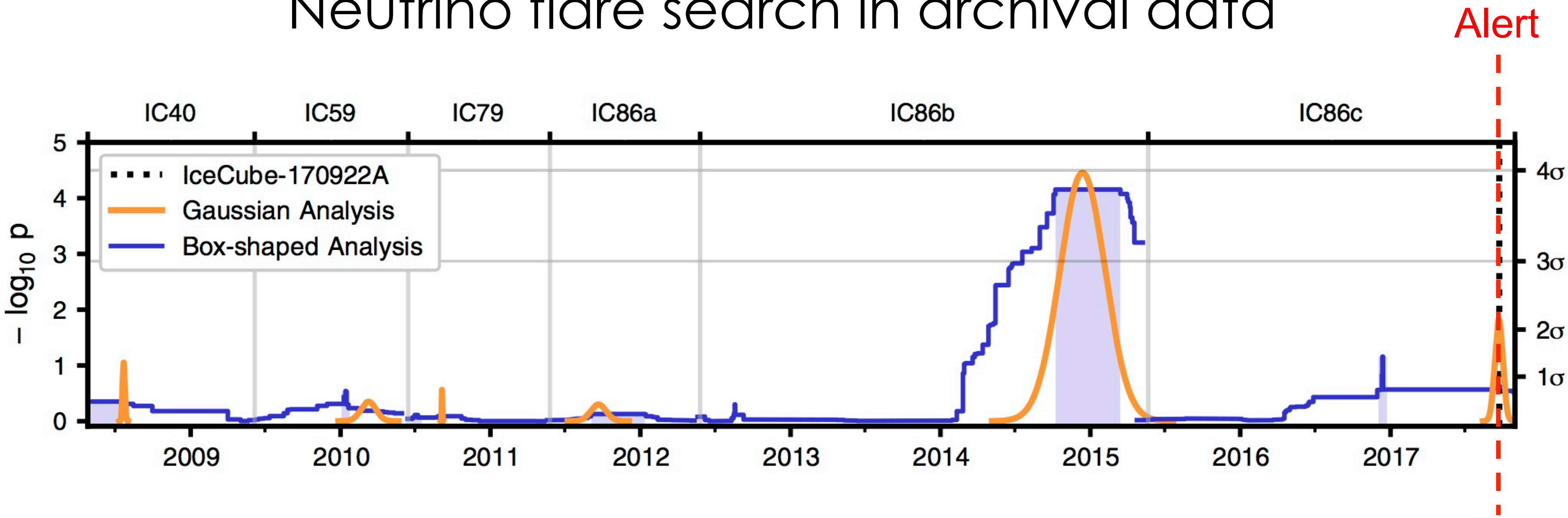
$$\mathcal{L}(n_s, \gamma, \underline{\sigma_T, T_0}) = \prod_{i=1}^{N} \left(\frac{n_s}{N} \mathcal{S}_i(\gamma, \underline{\sigma_T, T_0}) + (1 - \frac{n_s}{N}) \mathcal{B}_i \right)$$

For "untriggered" search, consider **all** possible time windows and durations:

$$TS = 2 \log \left(\boxed{\frac{\hat{\sigma}_T}{T_{tot}}} \times \frac{\mathcal{L}(\hat{n}_s, \hat{\gamma}, \hat{\sigma}_T, \hat{T}_0)}{\mathcal{L}(n_s = 0)} \right)$$

Penalty for choosing a short-time window duration σ_T
(corresponds to the fact that there are many more short than long windows)

Neutrino flare search in archival data



Analysis is performed at coordinates of TXS 0506+056

Six data periods analyzed separately

Report most significant **Gaussian-shaped** and **Box-shaped** time window for each period

(For the Box-shape analysis, the **outer blue curve** also shows less significant time windows)

Same excess is found by both analyses centered in December 2014.

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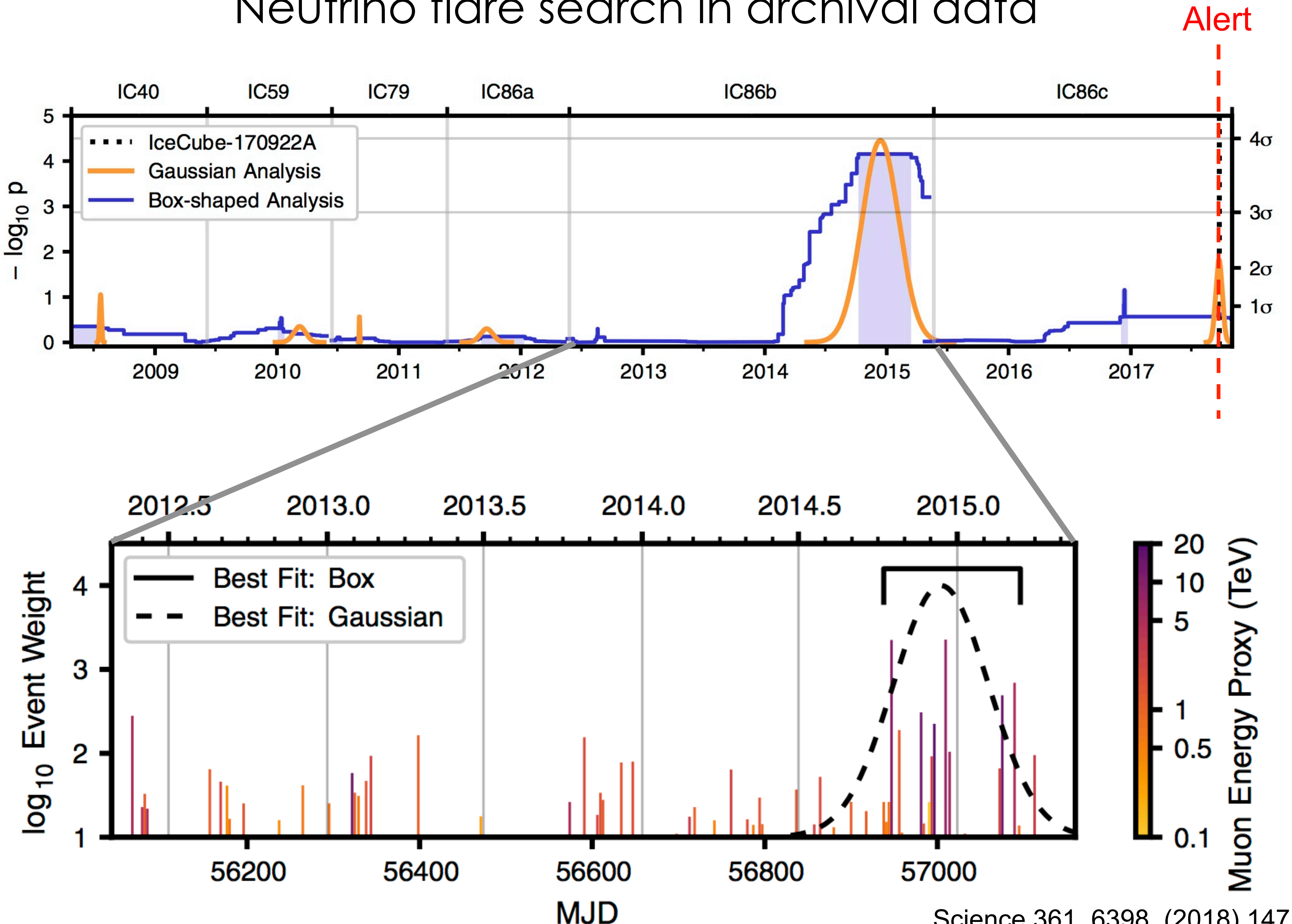

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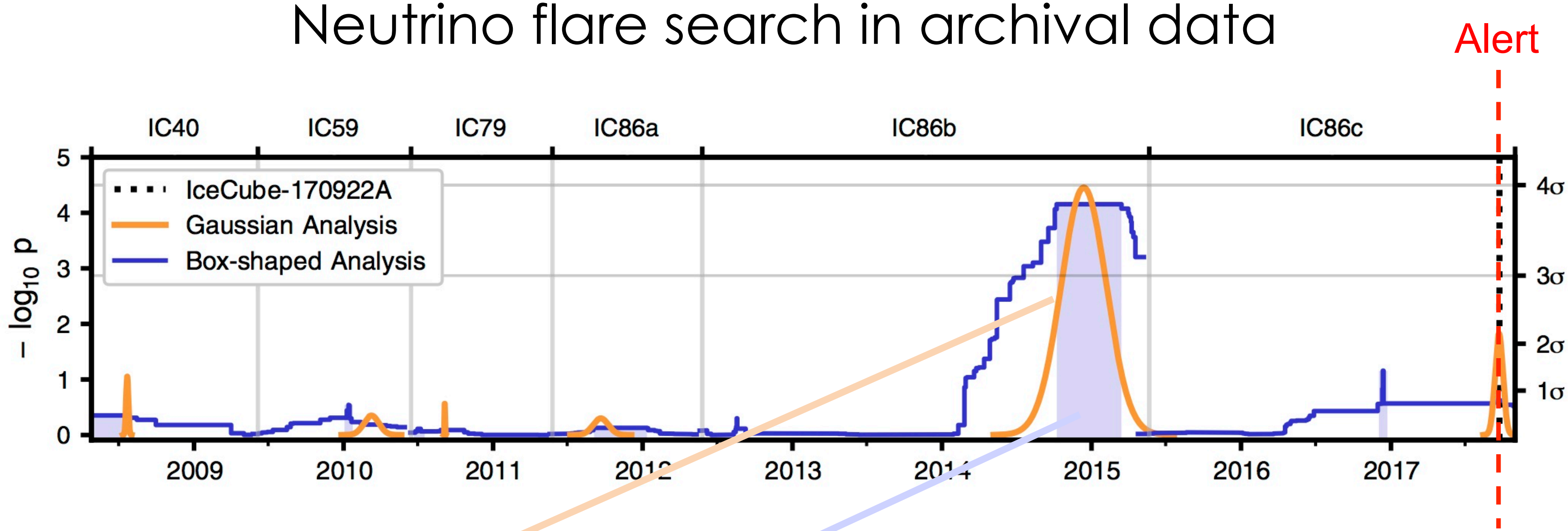
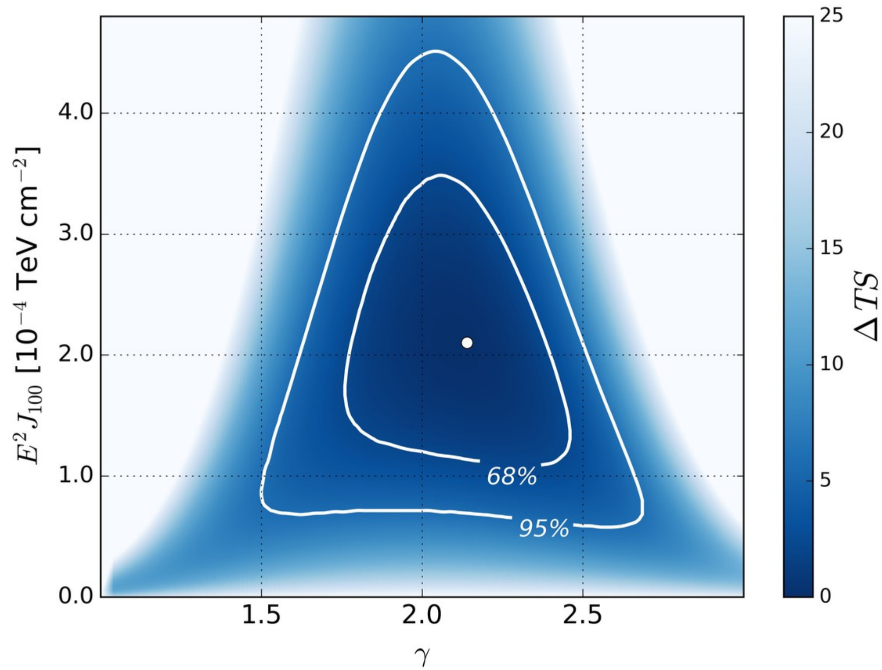
Neutrino flare search in archival data

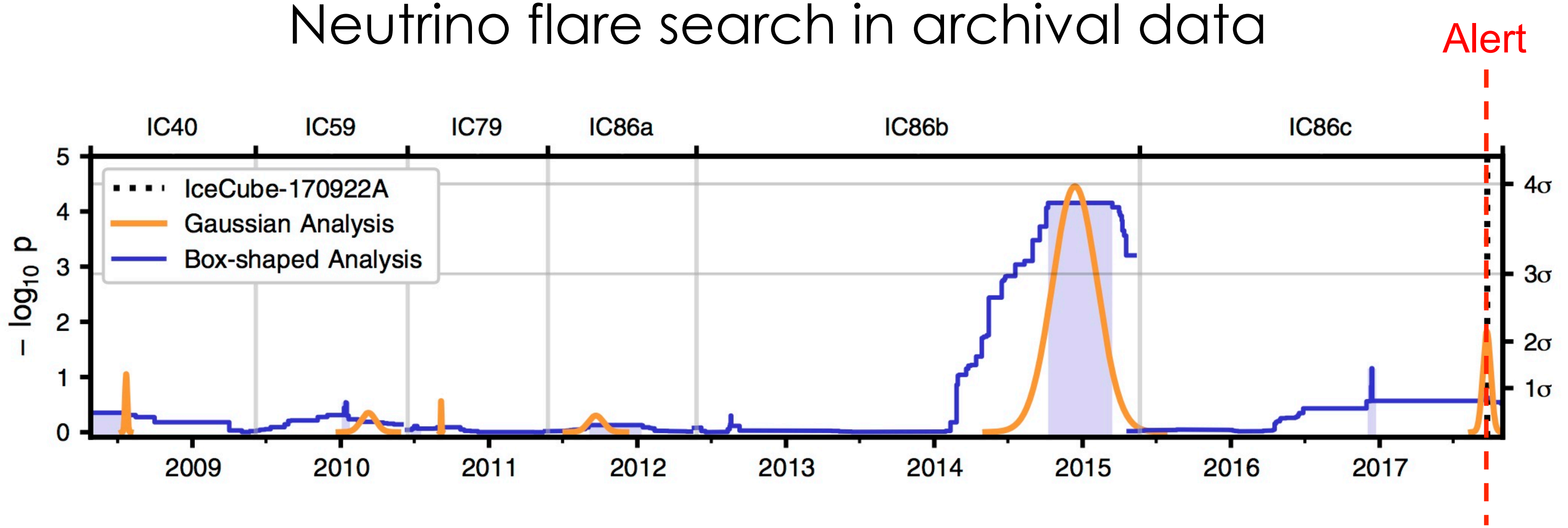


Best-fit values	Gaussian	Box
Central Date	2014 Dec. 13	2014 Dec. 26
Width	110 days (-1σ to +1σ)	158 days
$\nu_\mu+\bar{\nu}_\mu$ fluence	2.1×10^{-4} TeV cm^{-2}	2.2×10^{-4} TeV cm^{-2}
spectral index	2.1	2.2



Joint uncertainty on fluence and index for Gaussian time window

Neutrino flare search in archival data

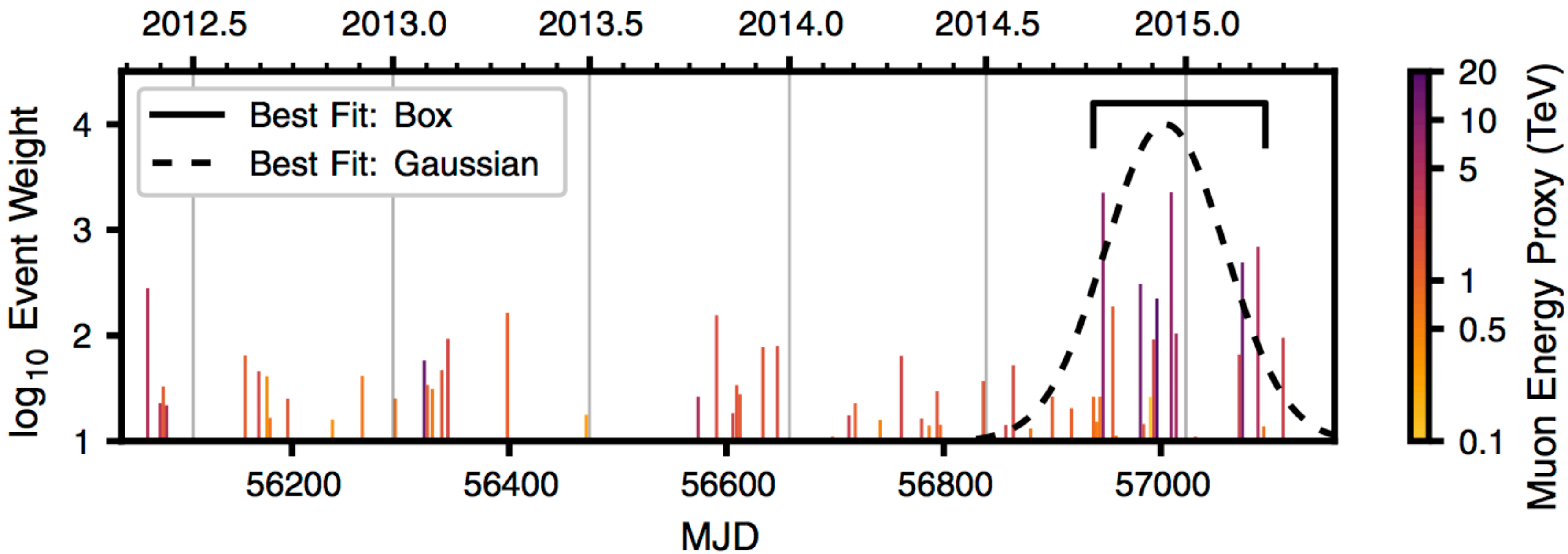


Significance Estimation:

Scramble 2012-2015 data in right ascension
Repeat analysis (search for any time window) at TXS location
Such a high TS value as found by Gaussian (for **any** time window) occurs at a rate of 3 times per 100 000 scrambled data sets.

Two final trial corrections were applied after this:
Max was found in 3-year data-set; 9.5 yr / 3 yr other chances to find a Max.
Two analyses (Gaussian and box) (this is overkill, as they are correlated).

Final significance cited: 2 in 10 000, or 3.5 sigma

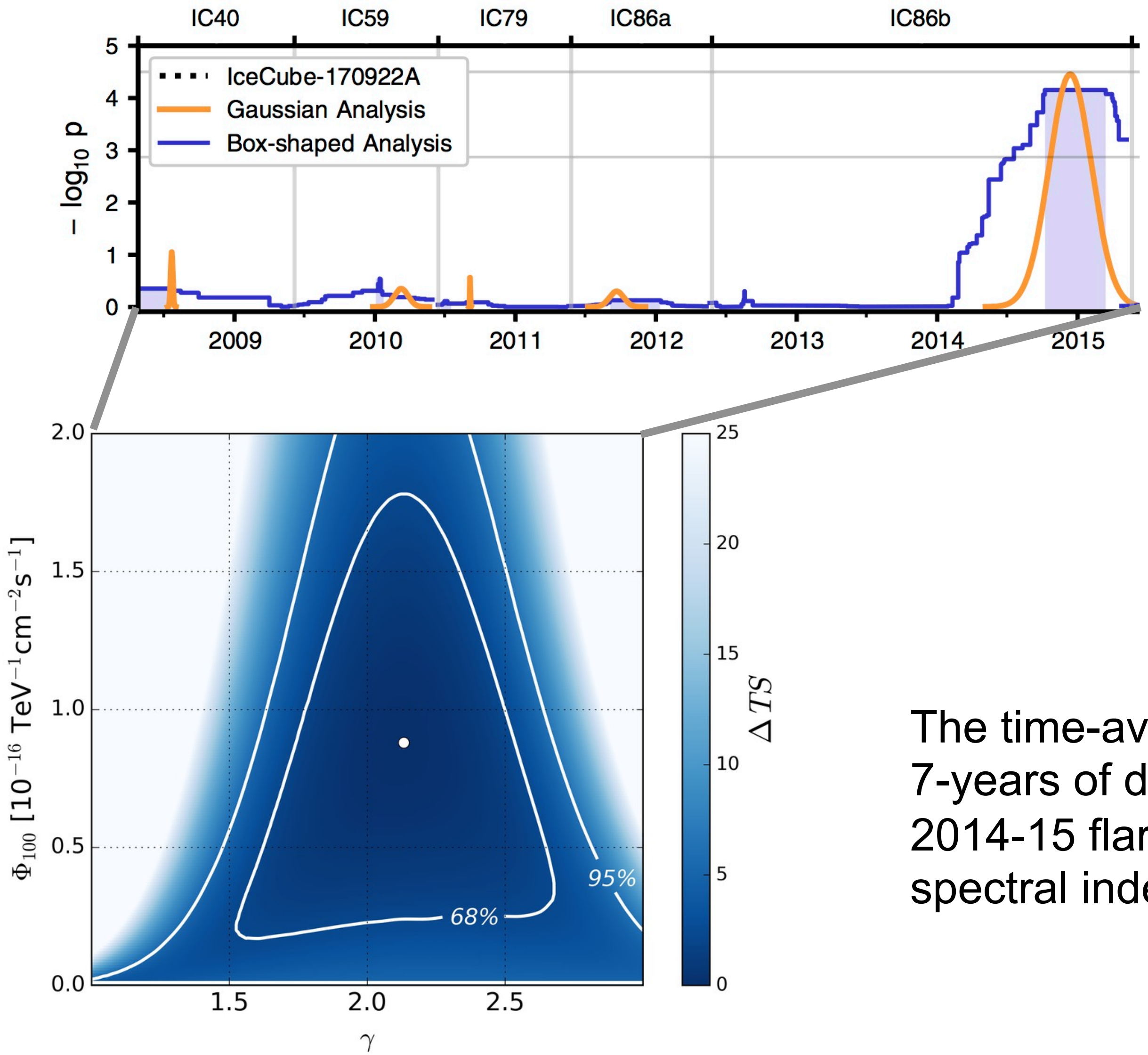


Note: Significance of the Time-Dep. analysis is w.r.t. a null hypothesis of **no signal, rather than of a constant signal**

A strong, <u>constant</u> neutrino signal would also get picked up by the time-dep analysis

But, for constant signal, the time-integrated result is usually more significant

Time-Integrated Analysis

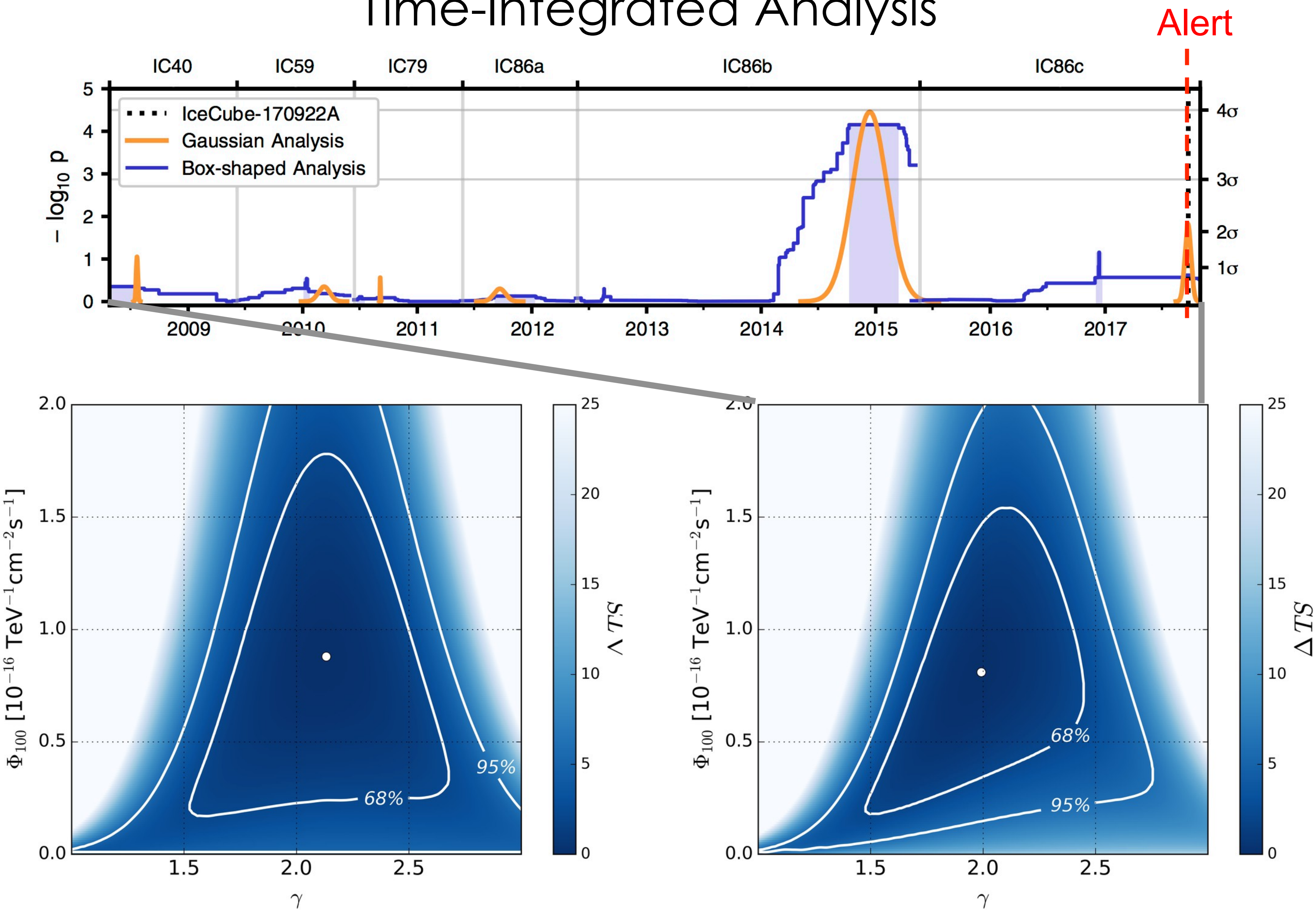


2008-2015 (7yr average)

2.1 σ

The time-averaged result for first 7-years of data is similar to the 2014-15 flare result (i.e. fluence, spectral index).

Time-Integrated Analysis



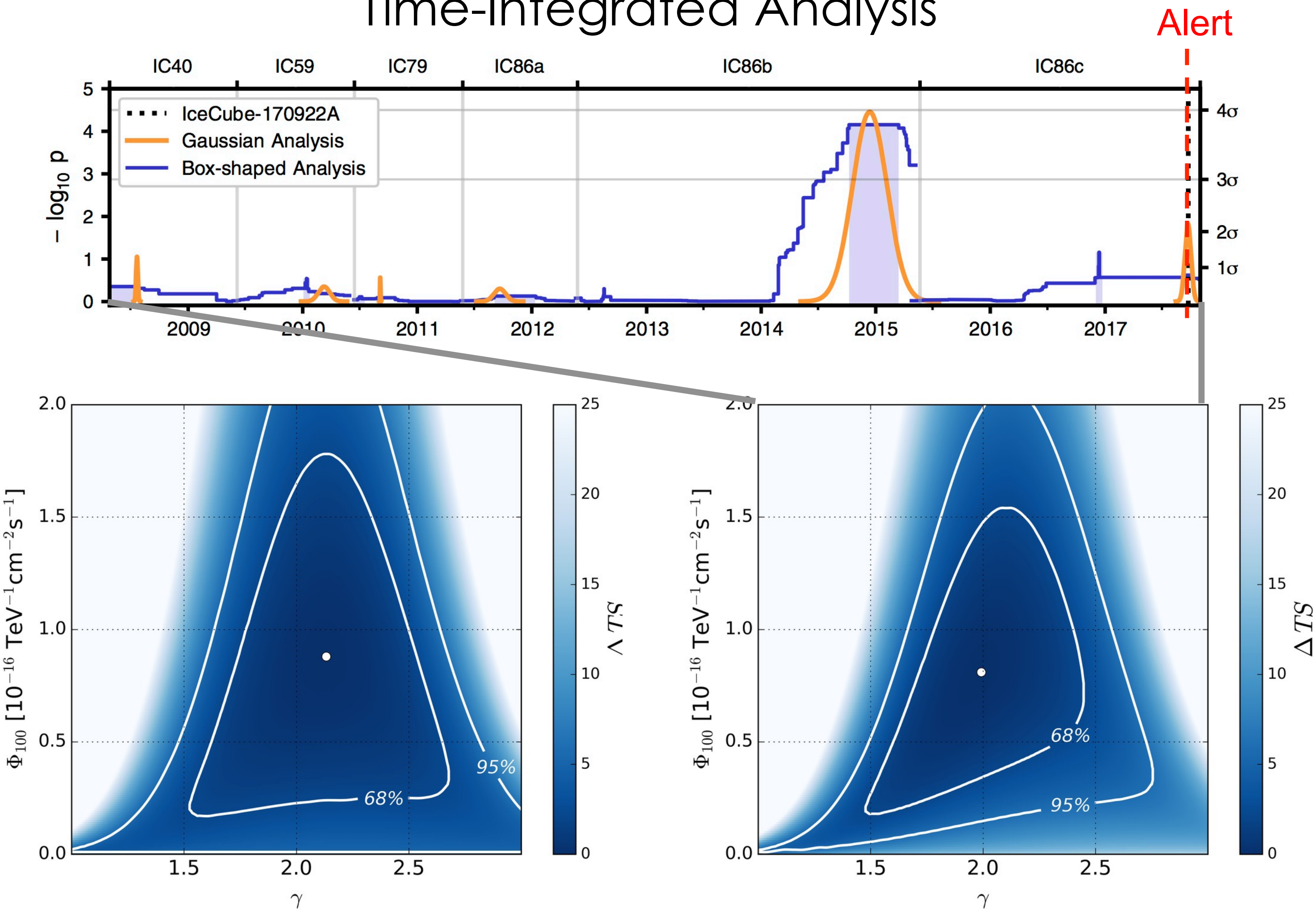
2008-2015 (7yr average)

2.1 σ

2008-2017 (9.5yr average)

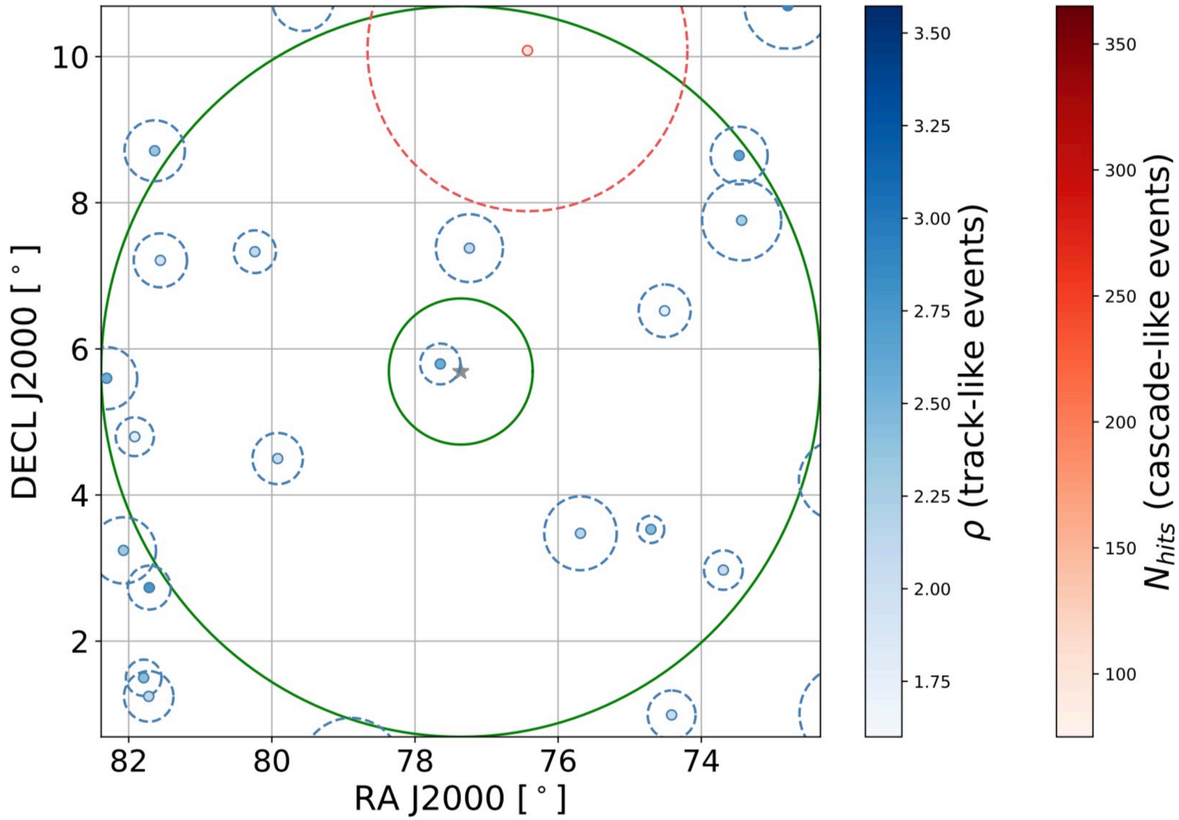
4.1 σ (including alert event)

Time-Integrated Analysis



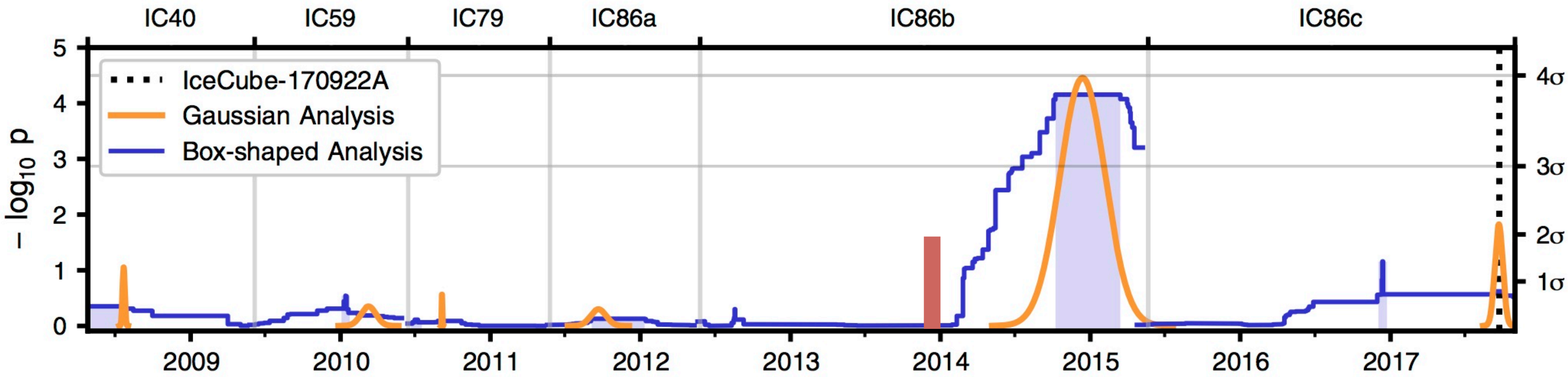
Flux fit parameters (number of events, spectral index) similar for 2014-15 flare, 7 year average, and 9.5 year average

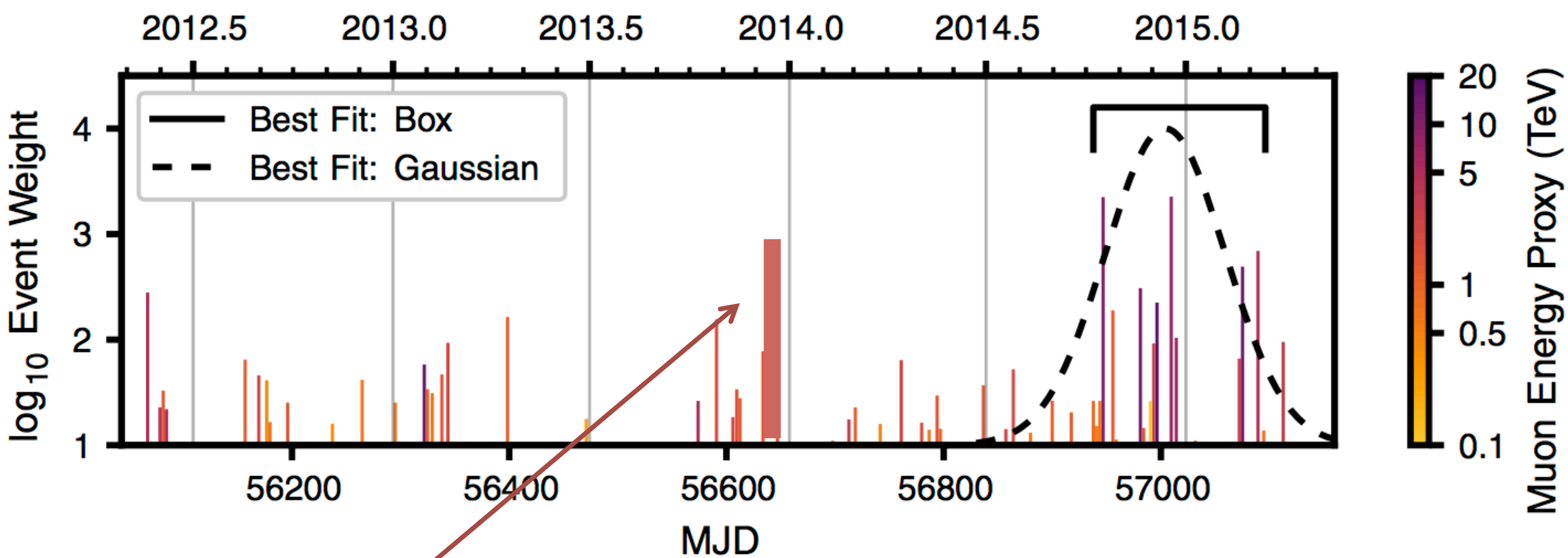
ANTARES Analysis of TXS 0506+056



ANTARES, ApJ 863 (2018) 2, L30

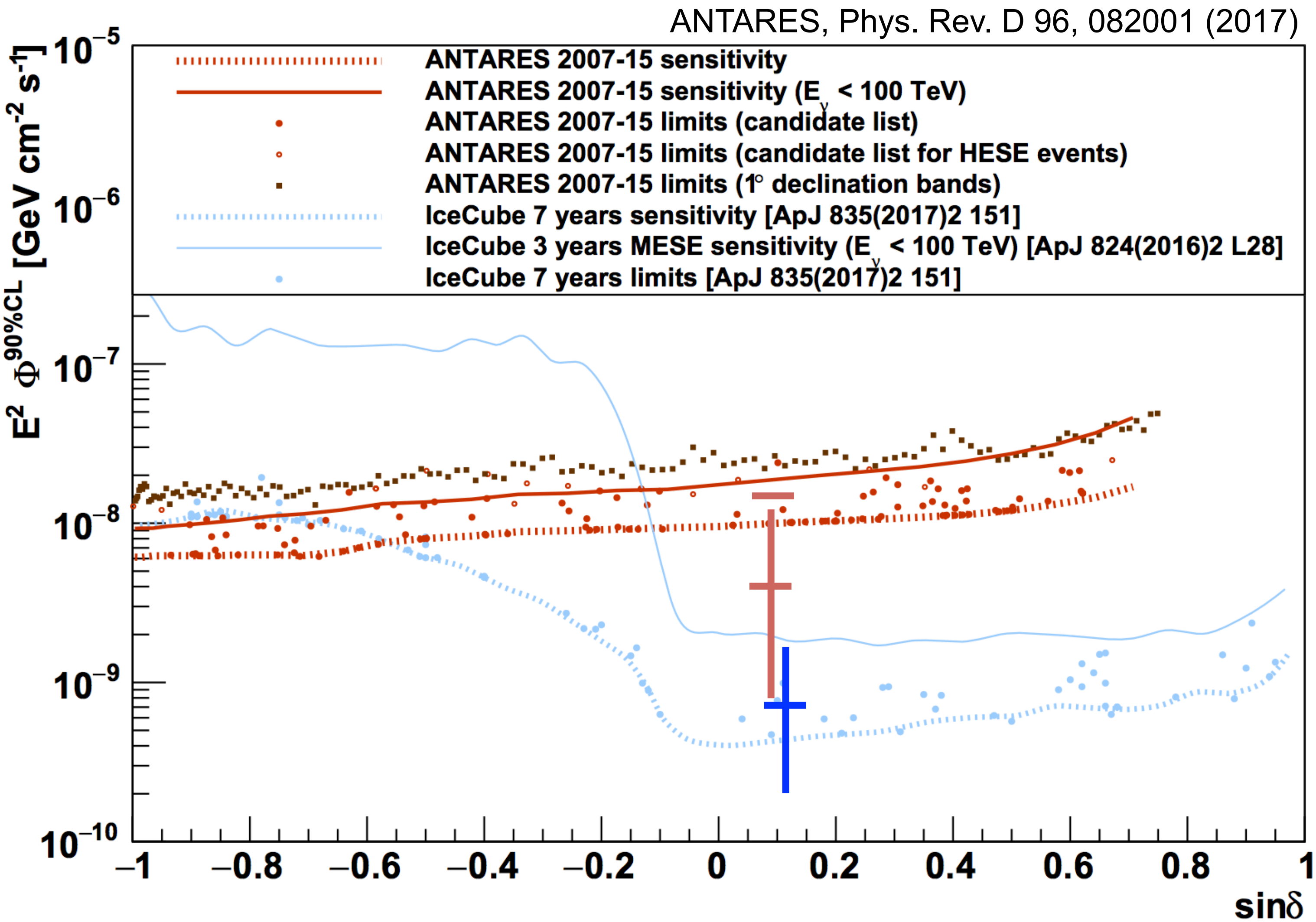
2007-17 Time-integrated analysis: best-fit number of signal events: 1.03
Significance (p-value) 3.4%





ANTARES event 2013.12.12

1 year earlier … so, not related to flare?



For time-integrated (steady source) analysis:

ANTARES best-fit flux (my estimate) is within 1-σ of IceCube best-fit flux

Independent pieces of evidence (3σ alert coincidence, 3.5σ archival)
=> Likely identification of a blazar as a source of high-energy neutrinos

But still in regime of Poisson statistics =>
Precise characterization of the neutrino emission is uncertain

Flux normalization uncertainty > factor of 2

Energy ~ definitely above atm. bkg, but not necessarily power law

Time – different flaring episodes? Or “steady” emission?

Will only get clearer with additional data (from TXS or other blazars).
Meanwhile, keep in mind this freedom if you are trying to model the emission.