

RAPID RESPONSE TO EXTRAORDINARY EVENTS:
THE **GAMMA-RAY FOLLOW UP (GFU)**
PLATFORM FOR ICECUBE

XIX INTERNATIONAL WORKSHOP ON NEUTRINO TELESCOPES



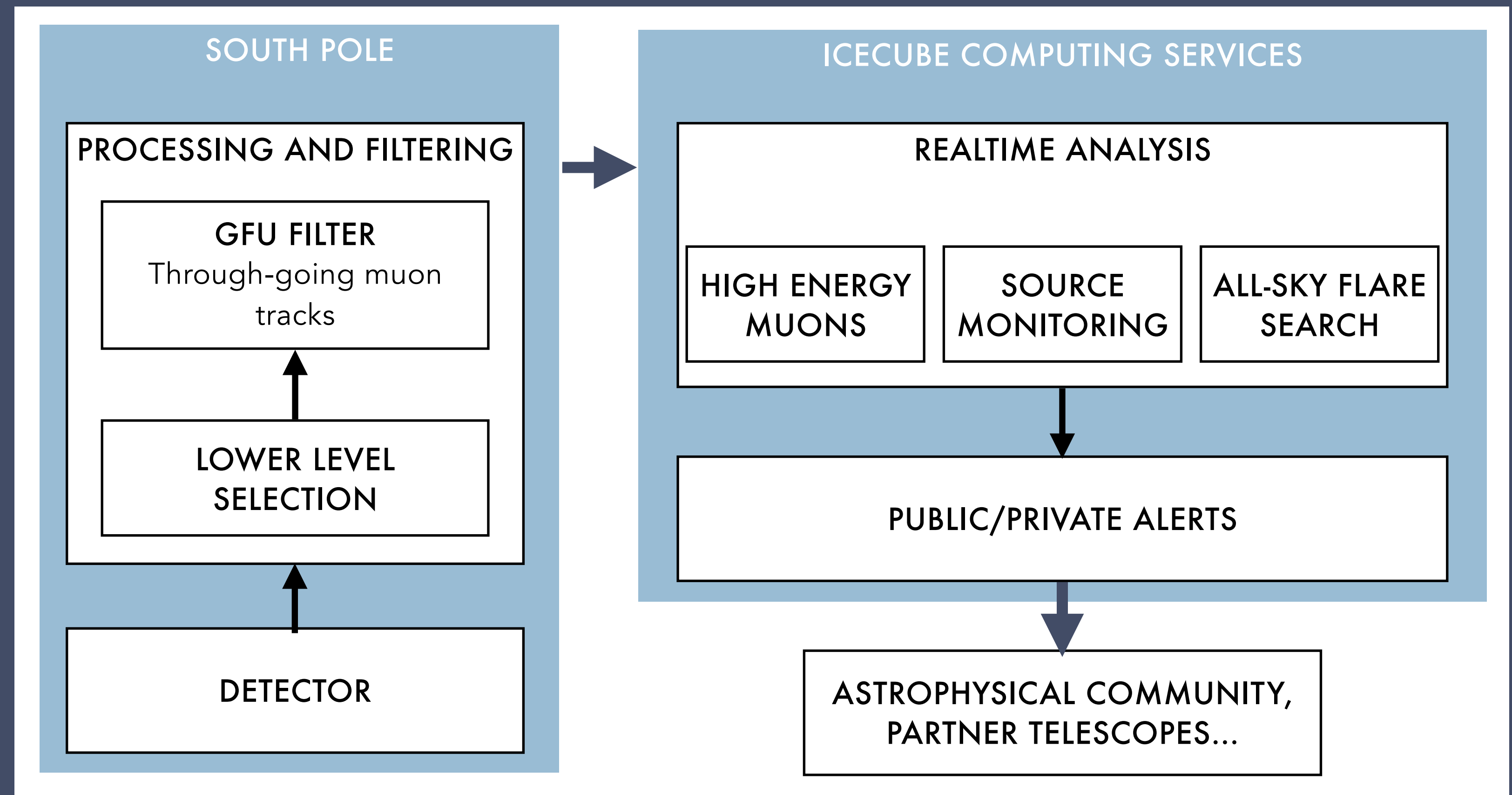
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for the IceCube Collaboration

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THE GFU PLATFORM

AN OVERVIEW

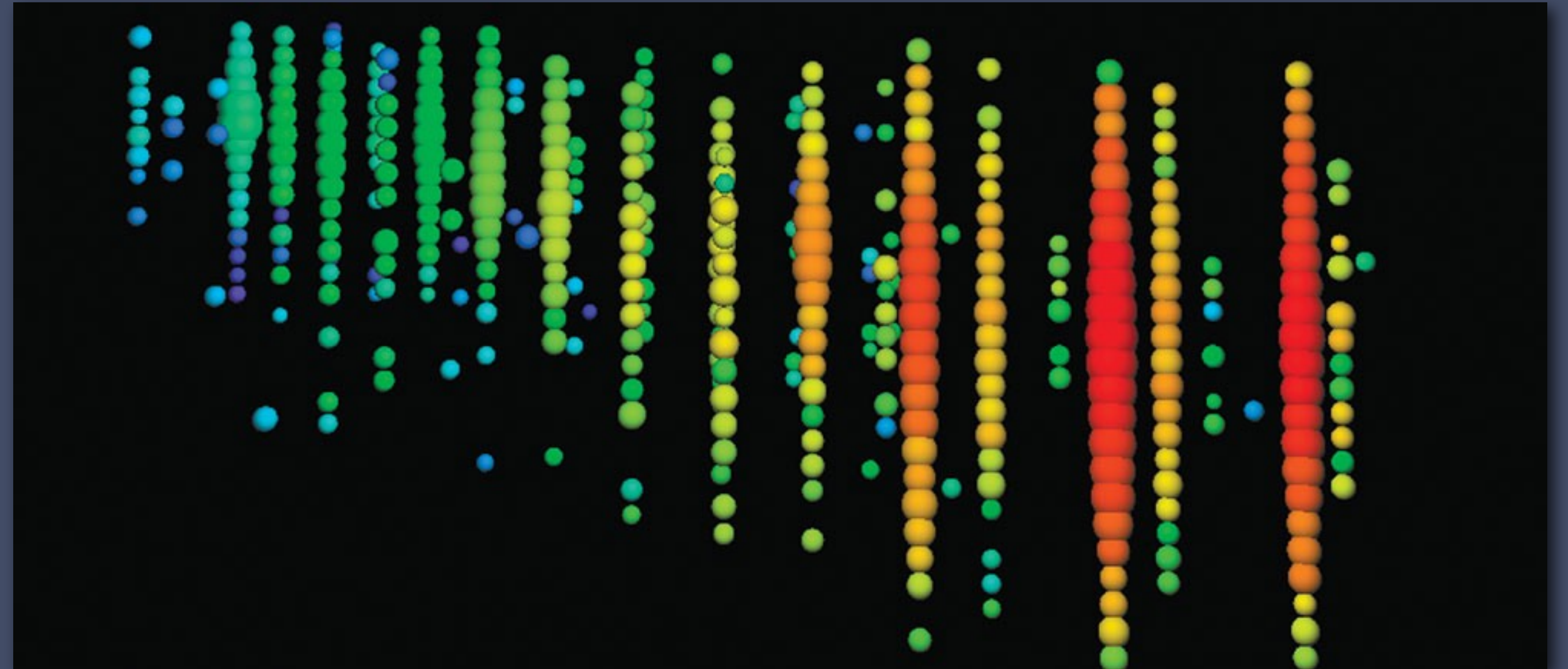
- Time-integrated searches of point sources: unsuccessful so far.
- Realtime analysis of transient sources:
 - GFU filter: 6 mHz
 - Realtime processing
 - Alert generation
- Powerful tool for multimessenger astronomy



REALTIME ANALYSIS

HIGH ENERGY MUONS

- Highest energy = high probability of being astrophysical p_{astro}
- Public Alerts:
 - Bronze: $p_{\text{astro}} > 30\%$ (30/year)
 - Gold: $p_{\text{astro}} > 50\%$ (10/year)
- Aggressive energy cuts to reduce the background
- Mostly sensitive to the region around the horizon

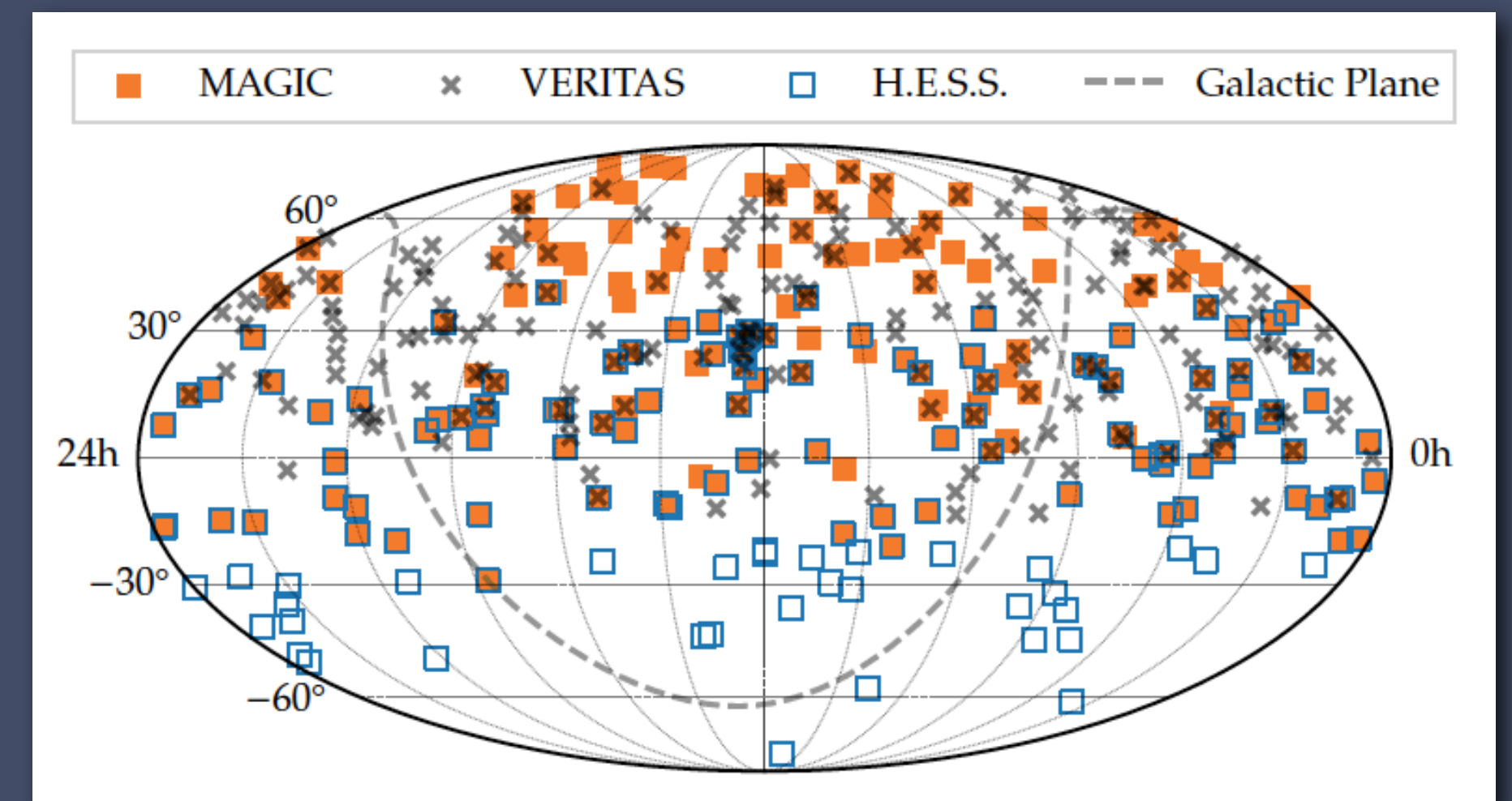


Event view of IC-170922A from Blazar TXS 0506+056.
Credits: IceCube Collaboration

REALTIME ANALYSIS

NEUTRINO CLUSTER SEARCH

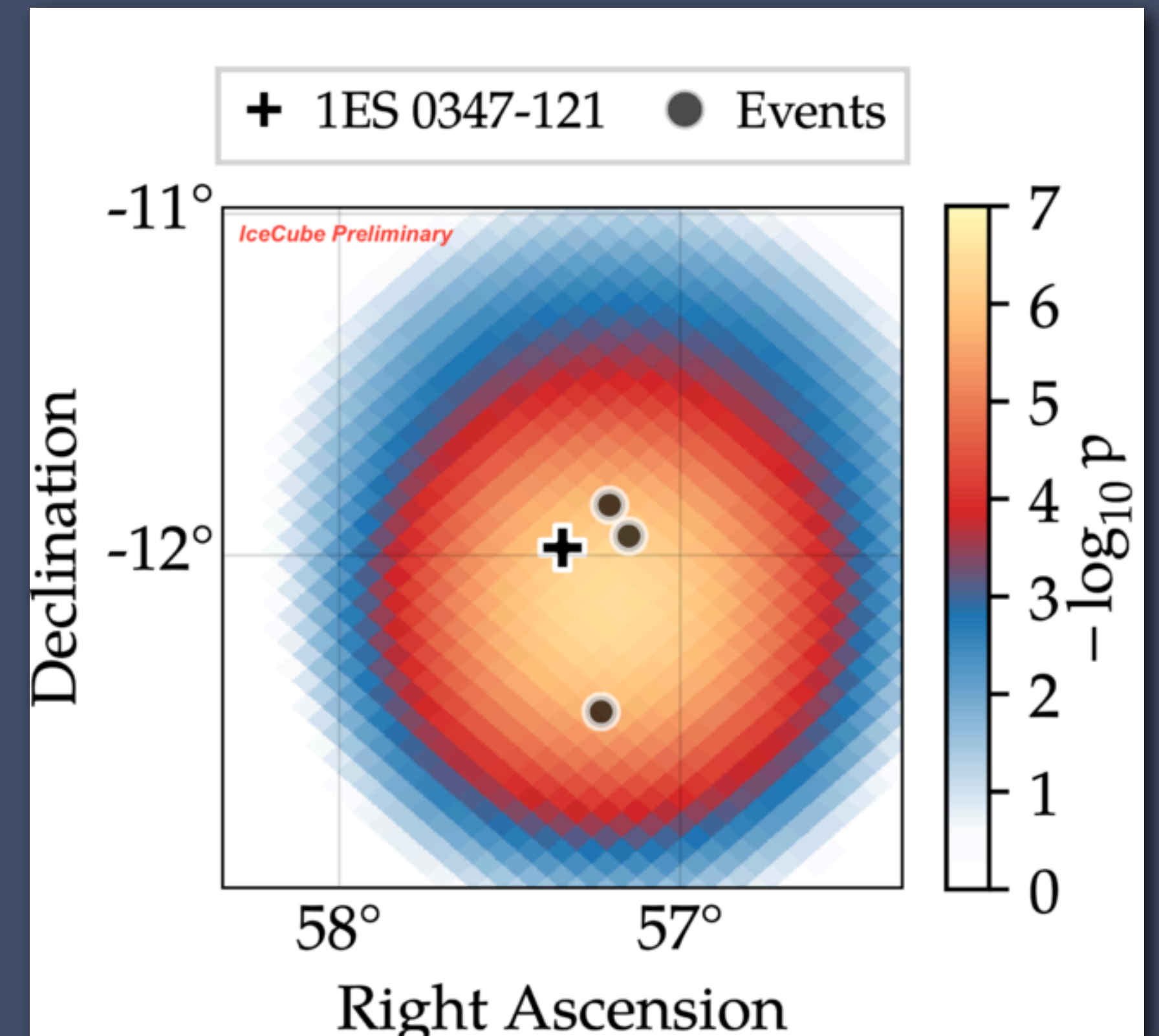
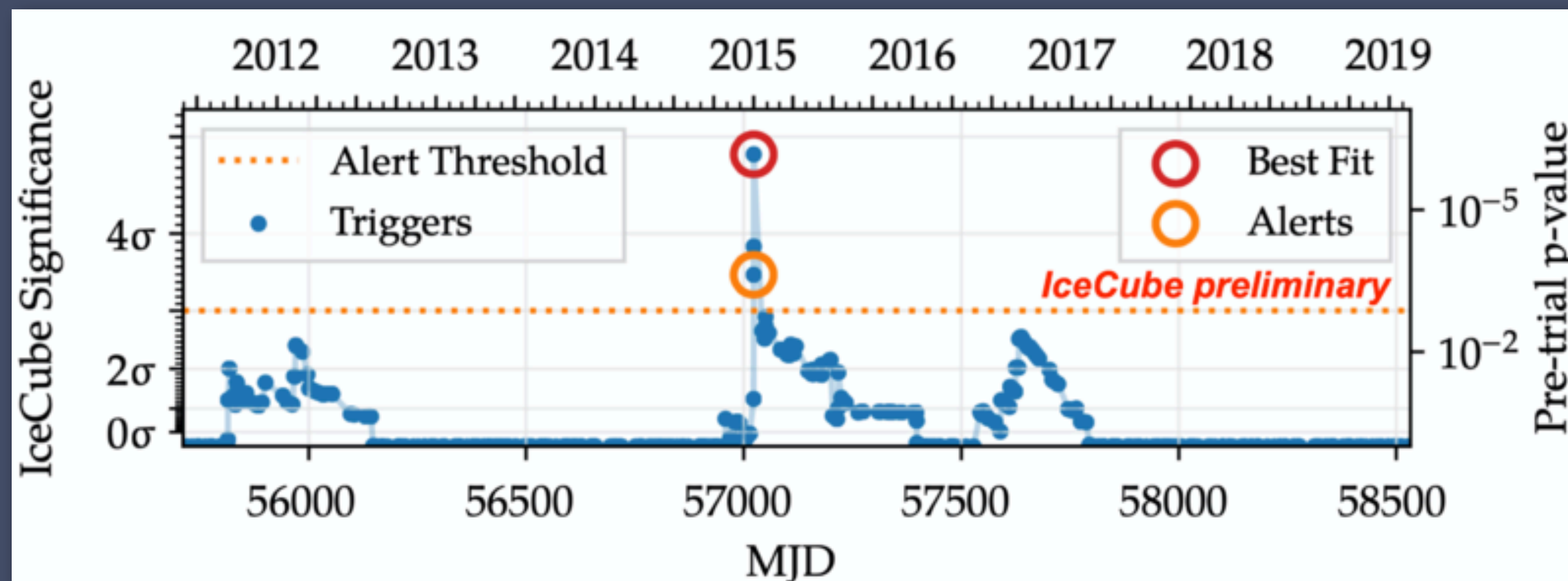
- Maximum-likelihood method:
spatial/energy properties for point source analysis + time clustering algorithm
- Looser cuts, background rejected by scanning limited solid angle and time interval,
sensitive to lower energy, and uniformly to the whole sky
- Private alerts since 2012
- Two analysis:
 - UNBIASED ALL-SKY FLARE SEARCH (~ 1 alert/year)
 - MONITORING OF KNOWN GAMMA-RAY SOURCES
(< 10 alerts/year)
339 sources, MAGIC, VERITAS, H.E.S.S.
 - Partner telescopes have follow-up programs
(see Ilaria Viale's talk on MAGIC follow-up)



MONITORING OF KNOWN GAMMA-RAY SOURCES

EXAMPLE RESULTS FROM ARCHIVAL DATA

- Most significant flare, May 2011 – March 2019:
1ES 0347-121 ($\alpha = 57.35^\circ$, $\delta = -11.98^\circ$)
- Neutrino cluster in ~ 7 h
- Post-trial significance: 2σ
- No activity reported by Fermi All-sky Variability Analysis (FAVA)



THANK YOU

Further info:

- T. Kintscher for the IceCube Collaboration, at KM3Net Town Hall Meeting 2019, Marseille, FR
https://indico.cern.ch/event/848390/contributions/3614228/attachments/1964044/3265348/2019_12_18_Marseille_IC2.pdf

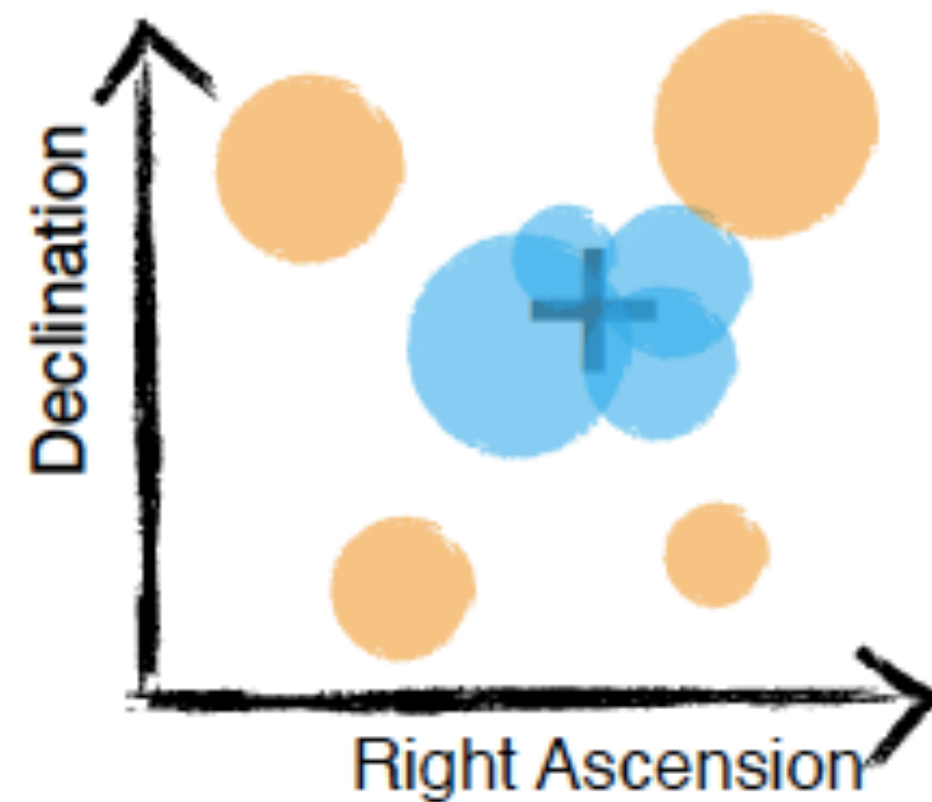
BACKUP SLIDES

TIME-DEPENDENT ANALYSIS

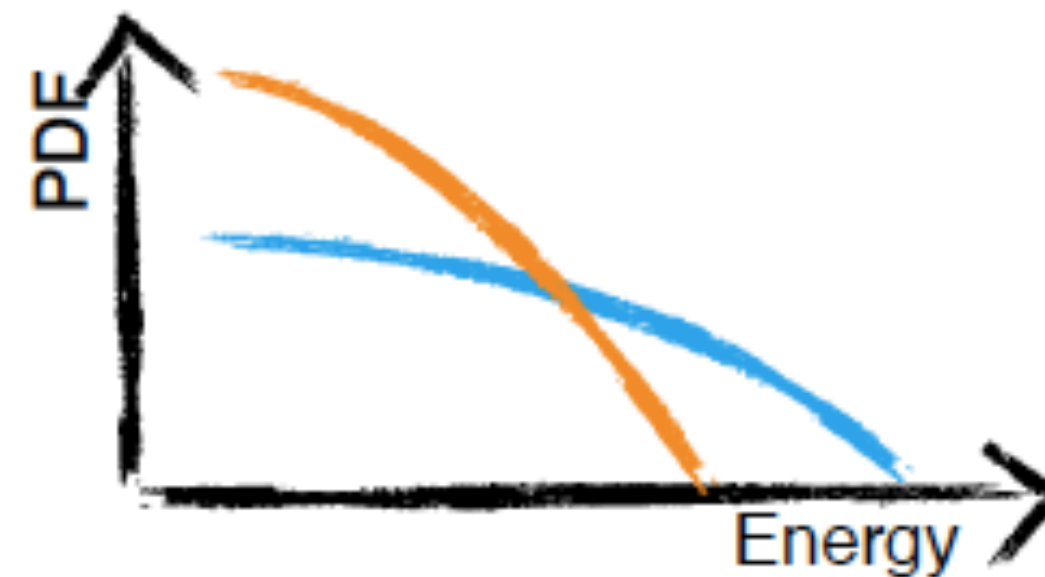
▶ Unbinned maximum-likelihood method:

$$\mathcal{L} = \prod_i^{\text{events}} \left[\frac{n}{N} S_i + \left(1 - \frac{n}{N} \right) B_i \right]$$

$$\text{TS} = -2 \log \left(\frac{\mathcal{L}(\hat{n}, \hat{\gamma})}{\mathcal{L}(n=0)} \right)$$



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Spatial PDF

- ▶ Test compatibility with source location
- ▶ Use per-event angular uncertainty

Energy PDF

- ▶ Exploit different spectra of **signal** and **background**
- ▶ Use per-event energy estimate

Time PDF

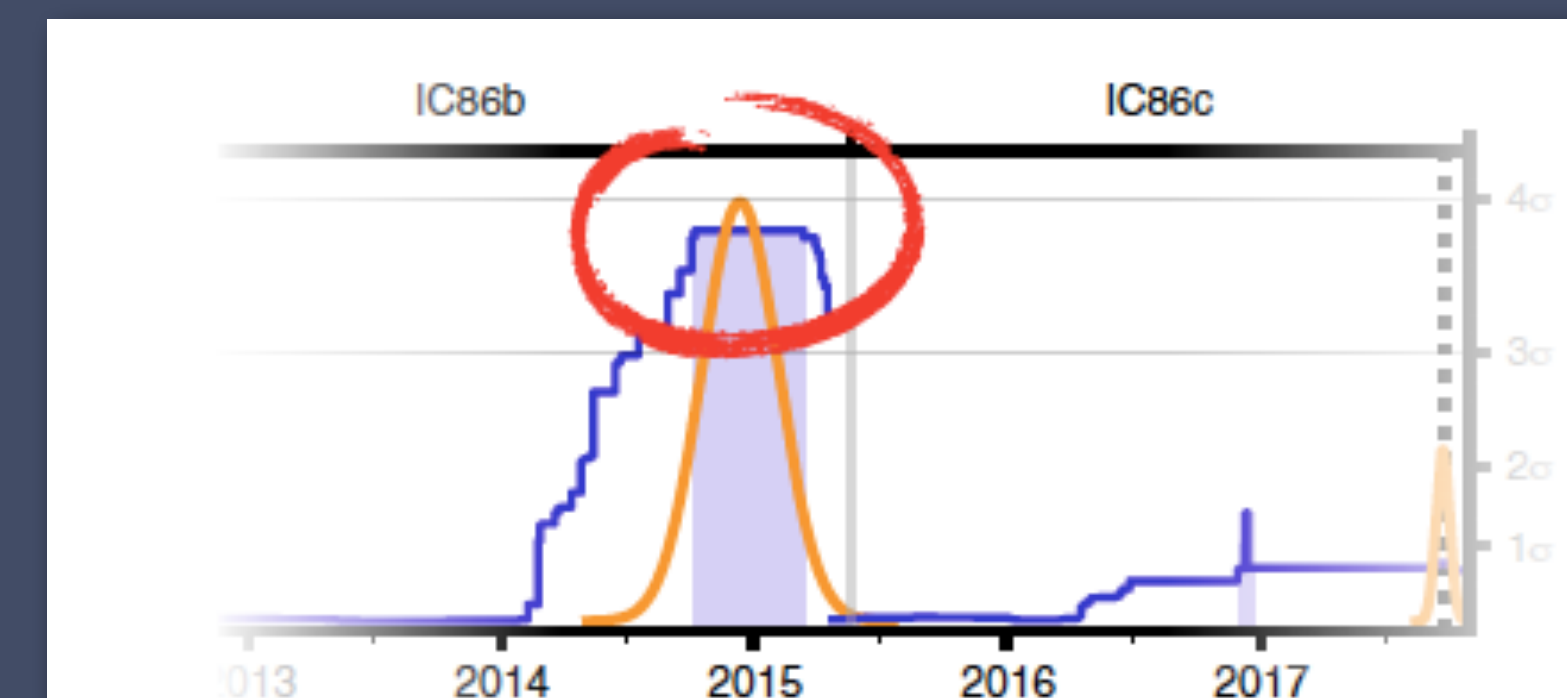
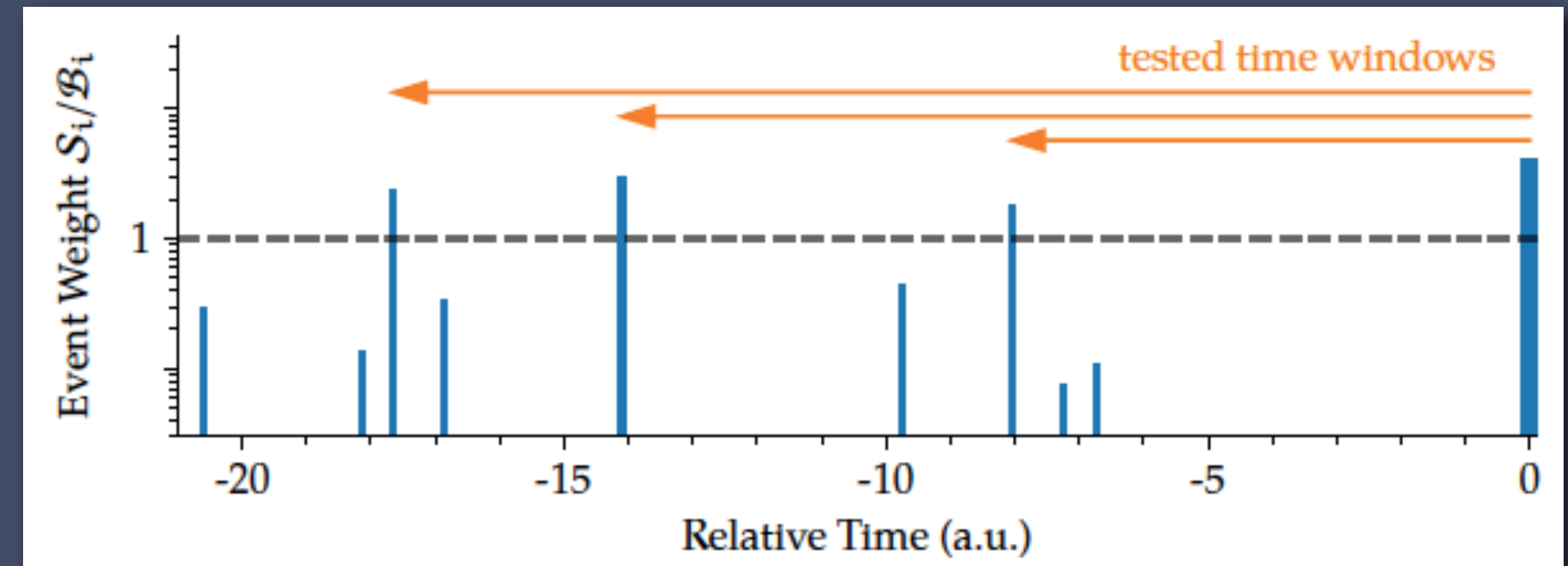
- ▶ Clustering of **signal** over flat **background**
- ▶ Generic box shape

▶ Fit parameters: number of events, spectral index and time window

From: T. Kintscher, at KM3Net Town Hall Meeting 2019, Marseille, FR

MONITORING OF KNOWN GAMMA-RAY SOURCES

- “Rolling analysis” on a pre-defined list of sources:
 - 339 sources from 3LAC/3FHL catalogs
 - Selected according to potential visibility in VHE gamma-rays with IACTs and other criteria (extragalactic, known $z \leq 1$, known history of variability)
 - Generates 5–10 alerts per year at 3σ level
 - TXS 0506+056 now monitored, would have triggered 2 alerts in 2014!



ALL-SKY SEARCH FOR NEUTRINO CLUSTERS

- Operate rolling analysis on the entire sky, unbiased:
 - Treat every incoming event as a trigger
 - Test contribution to possible cluster in the vicinity
 - Generate 1 alert per year at 4.3σ level
- Median angular resolution:
 - ~ 0.5 deg for \sim TeV events
 - Clusters of multiple events: 0.2-0.3 deg!
 - Comparable to single, very energetic tracks!

