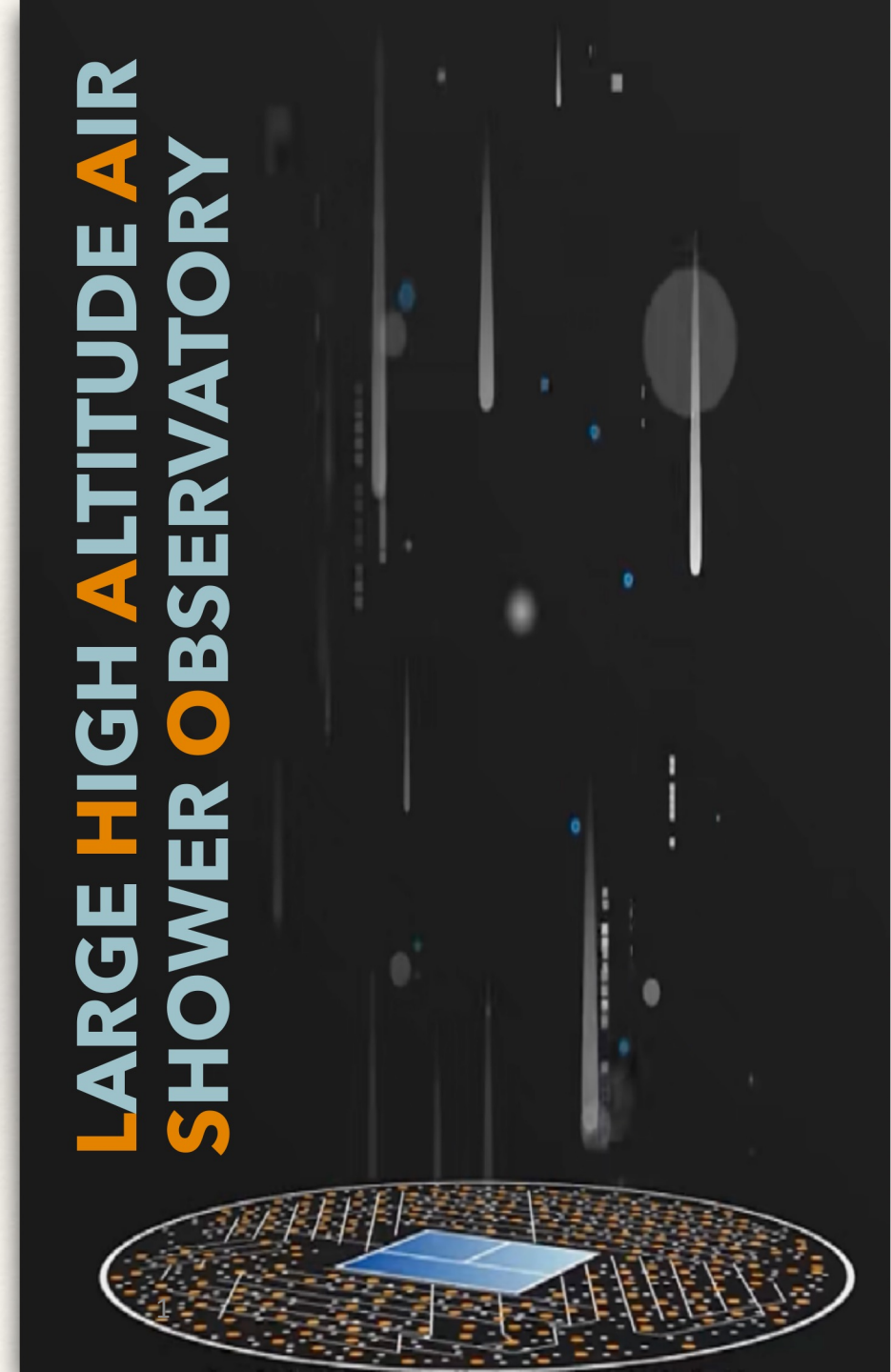
Real-time Transient Monitoring and Automated Follow-up with LHAASO-WCDA

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Oct. 22 – 27, 2026



Outline

- Motivation
- Monitoring: two parallel strategies
- Follow-up
- Summary & outlook

Motivation: Why Continuous Wide-FoV VHE Monitoring?

TeV variability is a window into extreme astrophysics

AGN/Blazar flares
minutes-to-year spectral evolution
probes jet particle acceleration

GRBs
last second-to-hour Gamma-ray emission

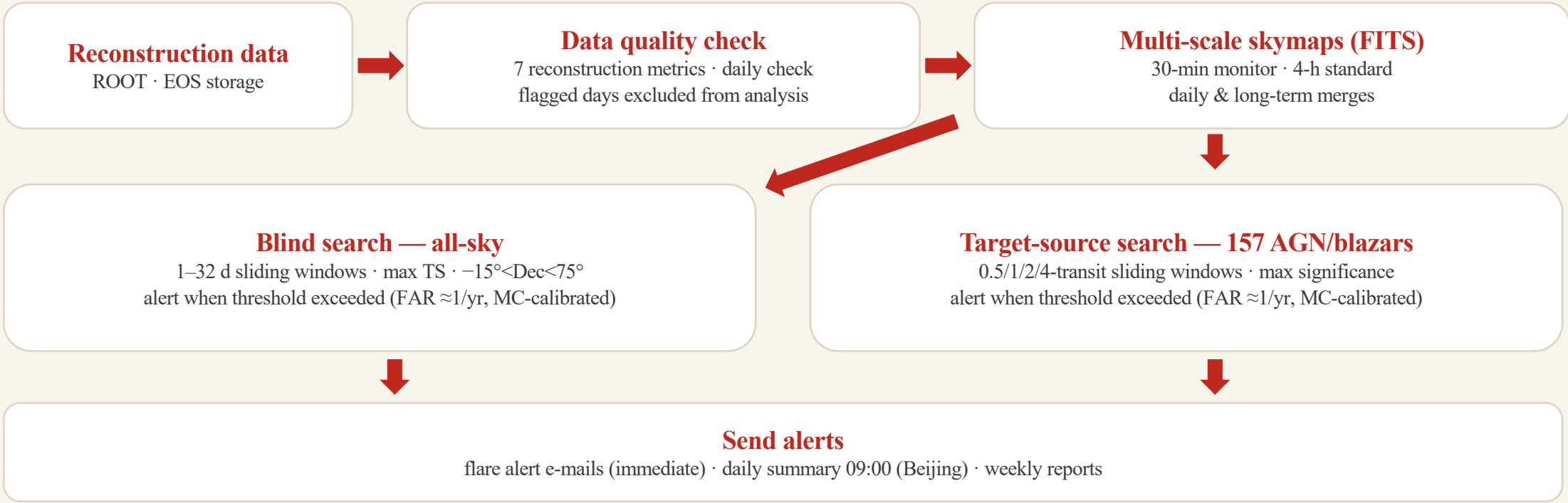
Neutrino counterparts
arcminute-to-degree localizations call for
unbiased, continuous TeV coverage

WCDA collects it anyway: ~2.2 sr field of view · >98% duty cycle · >100 GeV threshold — every source, every transit in FoV

A wide-FoV, full-duty-cycle TeV survey is a node in the multi-messenger network — sending alerts out, acting on alerts in

The Monitoring Pipeline at a Glance

From raw data to alerts and follow-up — fully automated, 7×24, no human in the loop



Data Quality Check & Skymap Production

data filtering + background estimation matched to each map's timescale

① Data quality check — every day

χ^2 | θ | φ | x_core | y_core | pool | N25/T30

7 reconstruction parameters, per file

Filter rule (robust):

$$|\, x - \mathrm{median}_{7d}(x) \,| > 4\,\sigma_{7d} \quad \Rightarrow \quad \text{reject the file}$$

median & σ from the previous 7 days — robust against outliers

- ❖ flagged runs are excluded from all skymaps
- ❖ bad days cannot create fake hotspots
- ❖ 7-params trends browsable on the website

(daily check · weekly summary)

② Skymap production — background

Standard maps
every 4 hours
full sky · deep

➡ **Direct integration**
bkg estimated by the same direction band

long window → enough OFF statistics in the same map itself

Monitor maps
every 30 minutes
fresh · real-time

➡ **Previous-day acceptance**
acceptance template of the same solar time,
× current livetime

too short for OFF integration → borrow the detector response from yesterday

How We Compute the Test Statistic

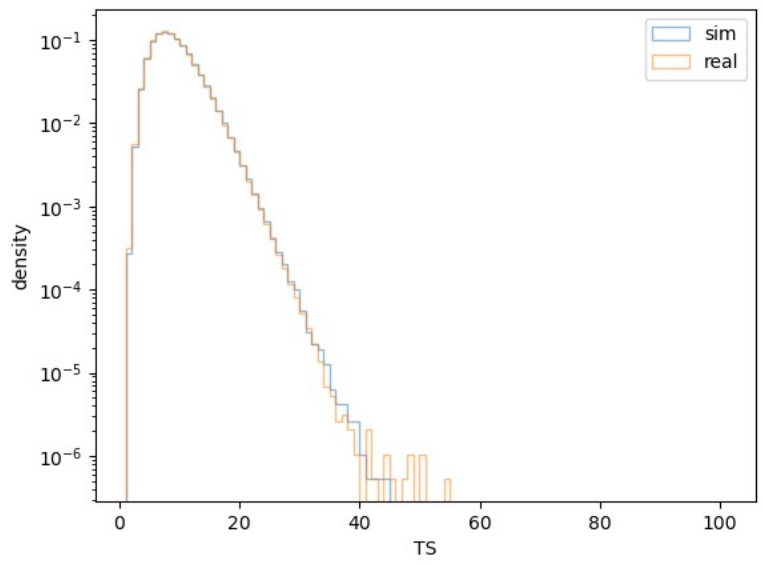
Li & Ma (1983) likelihood ratio — evaluated per pixel and per sliding time window

$$TS_i = 2 \ln \lambda = 2\left[N_{on} \ln\left(\frac{N_{on}(1+\alpha)}{N_{on}+N_{off}}\right) + N_{off} \ln\left(\frac{N_{off}(1+\alpha)}{\alpha(N_{on}+N_{off})}\right)\right]$$

In practice

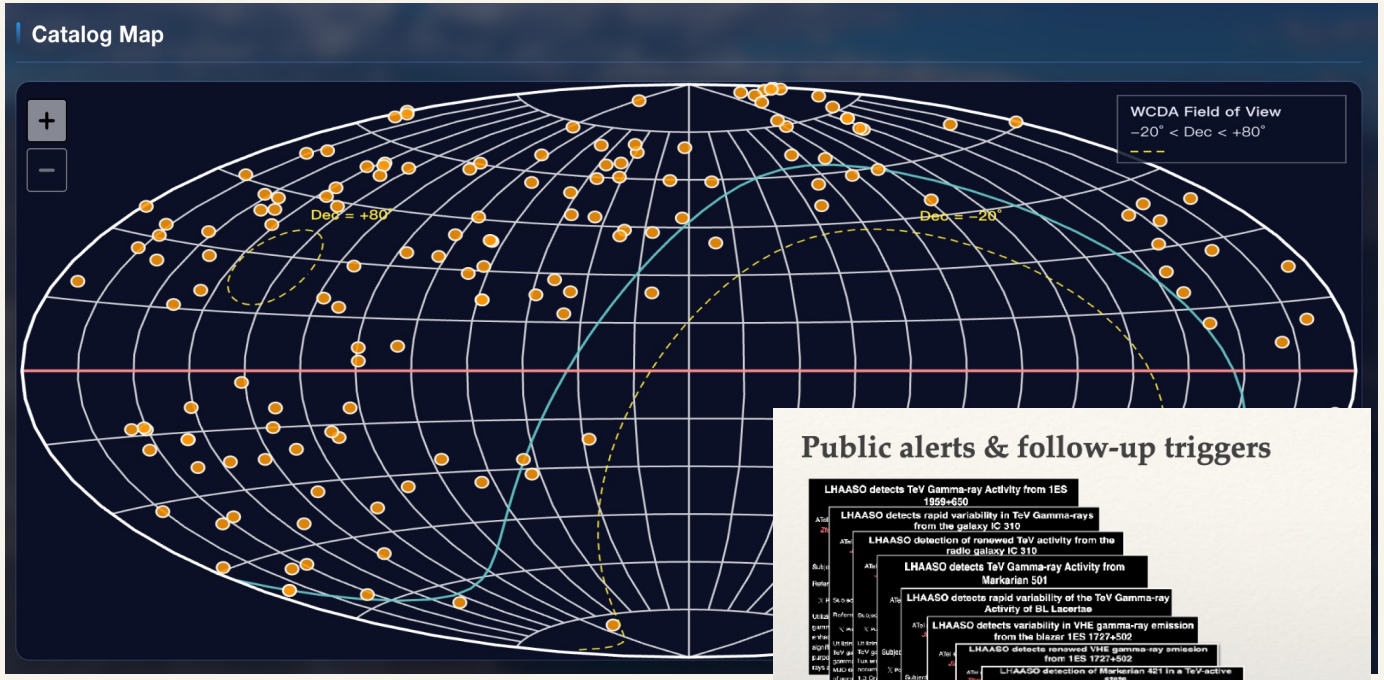
- TS=0 (N_on < N_bkg)
- $TS_{all} = \sum_i TS_i$
- Alert thresholds from 2×10^6 toy-MC:

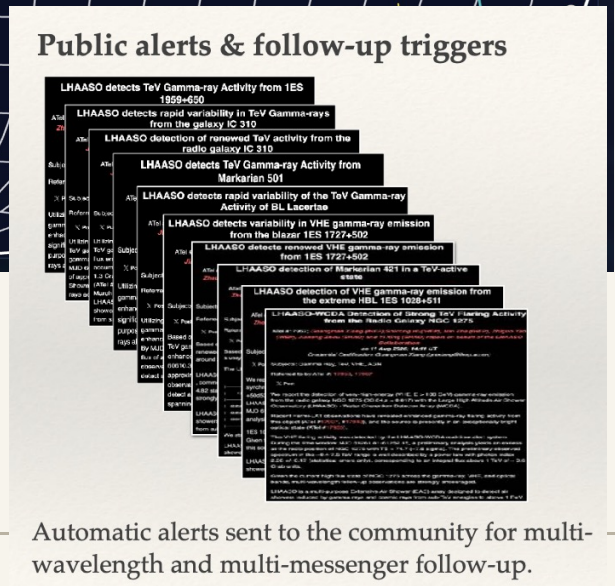
  FAR ≈ 10 / yr and ≈ 1 / yr,
- Background TS distribution matches MC



1 day TS distribution of MC vs Data

Selected-target Monitoring





Automatic alerts sent to the community for multi-wavelength and multi-messenger follow-up.

157 sources

Mkn421 ,Mkn501; TeVCat; 3FHL (z<0.3)

Spatial search

pixels < 0.1 deg

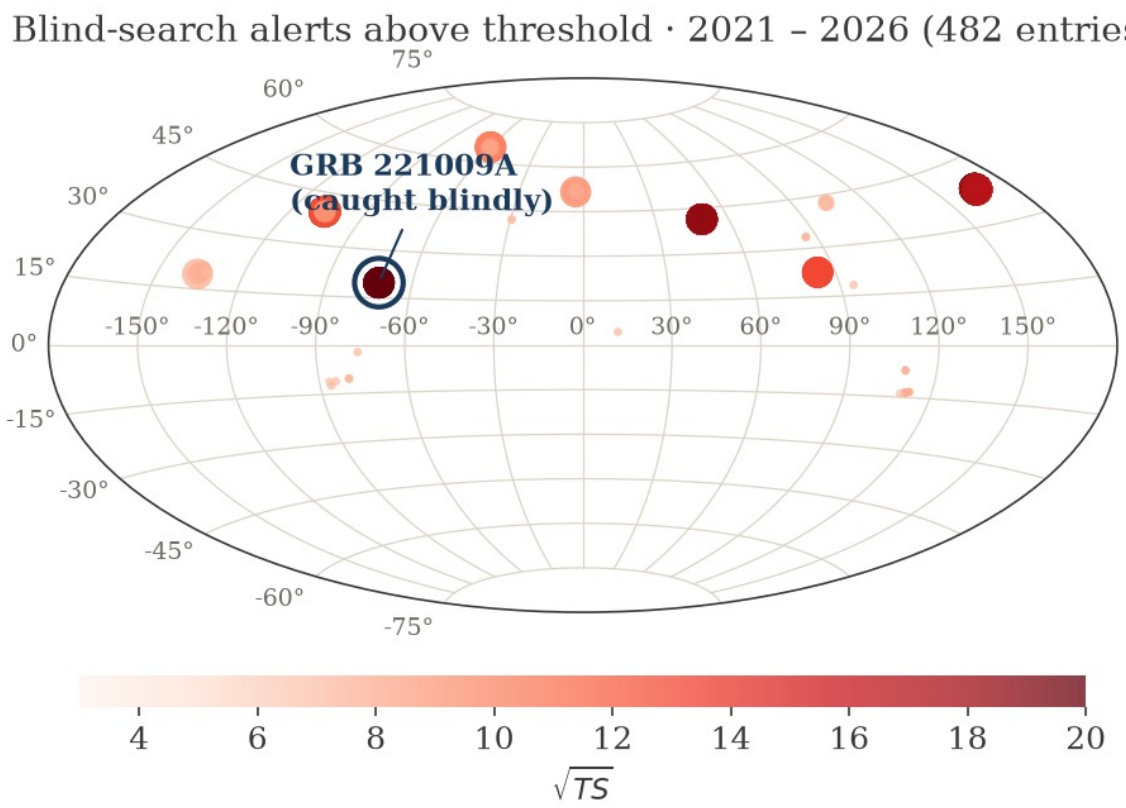
Sliding windows

0.5 -1 - 2– 4 transits.

False Alarm Rate=1 /year

Calirbrate by MC

All-sky Blind Search for TeV Transients



Alert thresholds: ≈10 / year and ≈1 / year, trial-factor-aware

All-sky search

-15 deg < Decl. < 75 deg

Sliding windows

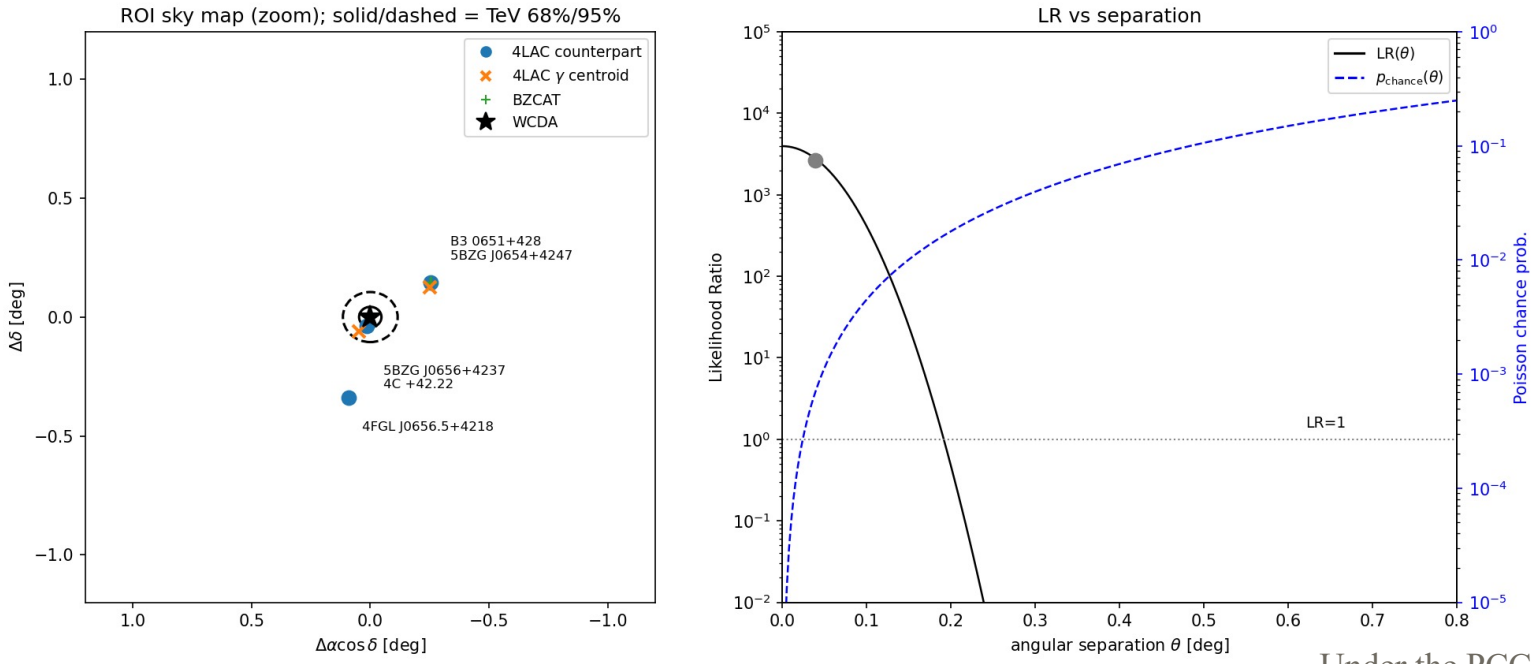
1 -2 - 4– 8 -16- 32 days

FAR=1 /year

Calirbrate by MC, sub threshold FAR=10/year

Discovery by the Pipeline: New TeV Transient 4C+42.22

Caught independently by both the all-sky blind search and the targeted monitoring



Under the PCC Discussion

Left: ROI skymap (WCDA position vs 4LAC/BZCAT counterparts); right: likelihood ratio & chance-coincidence probability

~8-day extragalactic transient · ~40% Crab · offset 0.03° from blazar 4C+42.22 (z = 0.059)

From Community Alerts to Automatic Follow-up

— External alerts: GCN & ATel, parsed by LLM

GCN Kafka · ATel
30-min polling

→

LLM parsing
grouping of notices

→

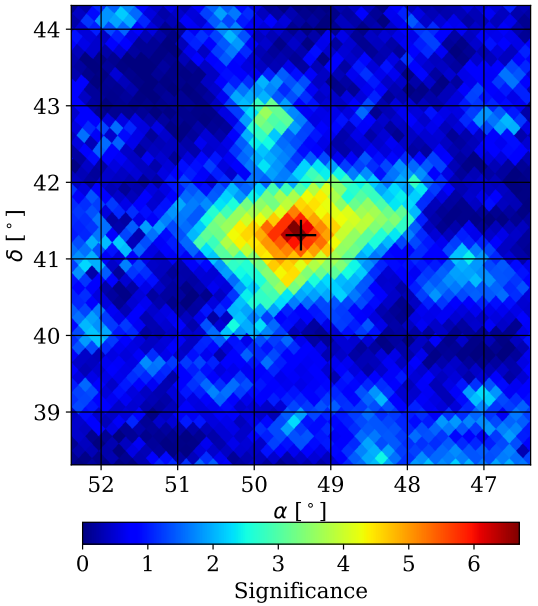
Smart trigger
in FoV · not retracted

→

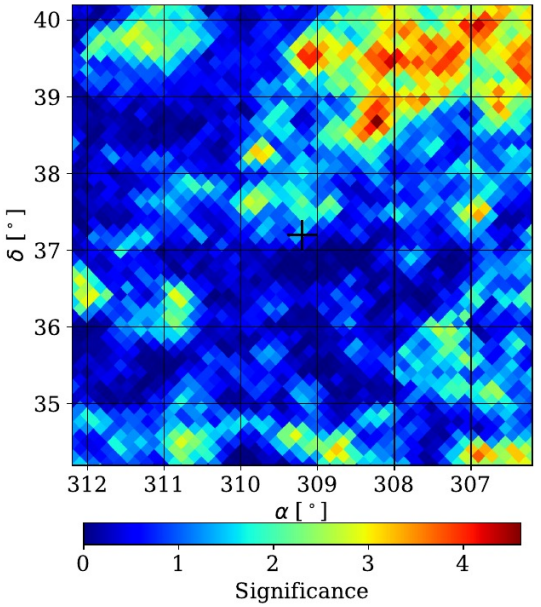
Follow-up analysis
cumulative significance

→

Results by e-mail
within hours



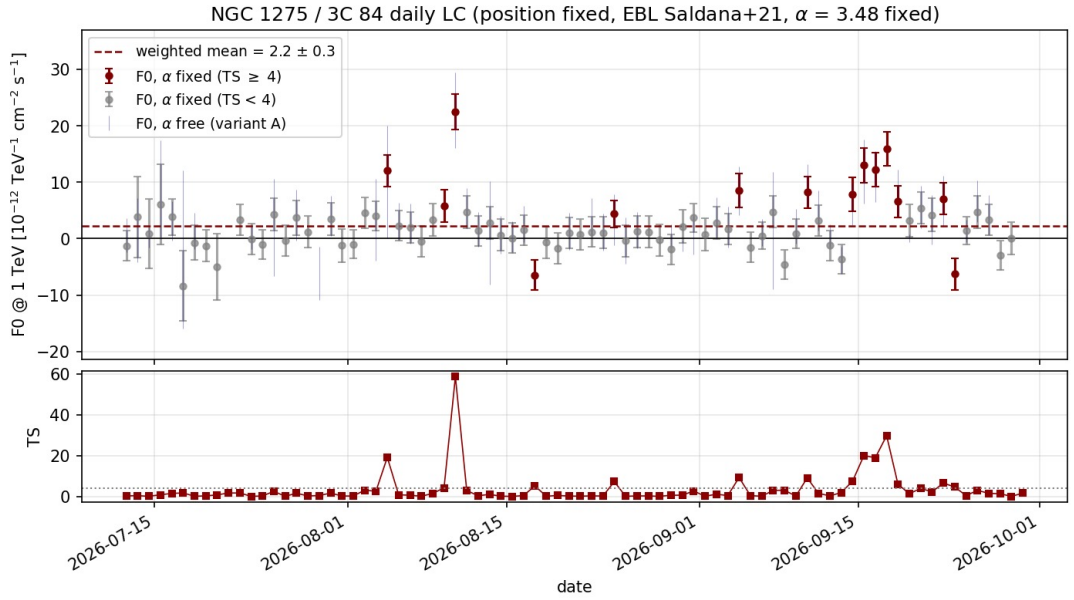
NGC 1275 flare, 2026-08-09~10: 6.7σ



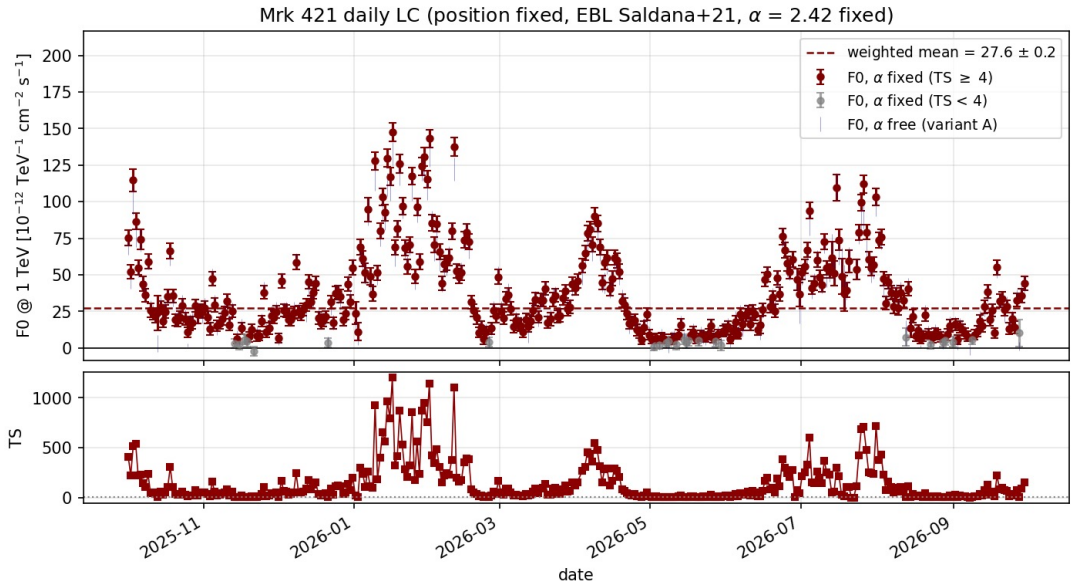
IceCube alert position (2026-05): no excess

Follow-up in Light Curves: NGC 1275 & Mrk 421

Daily maps · 3D likelihood · intrinsic PL × EBL



NGC 1275: flare on 2026-08-10, F0 = 22.5 ± 3.2 ×10⁻¹² — ≈10× baseline (TS = 58.7)



Mrk 421: giant flare Jan–Feb 2026, peak F0 = 132.7 ± 7.9 ×10⁻¹² (TS = 1224)

Long-term Monitoring of Neutrino Counterpart Candidates

Example: TXS0506+056 — candidate counterpart of IceCube-170922A

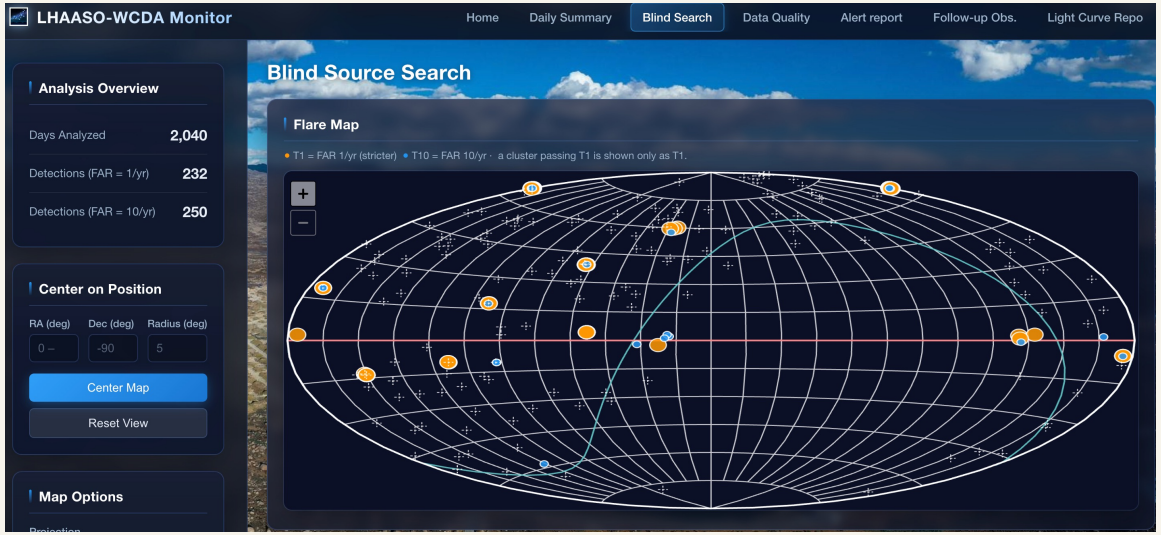


TXS0506+056: 30-transit significance & cumulative track, 2021–2026

- **Continuous TeV coverage of IceCube alert positions**
- **Weak-source trends via binning & cumulative tracking**
- **Auto follow-up ready for the next neutrino alert**

Data Portal: the LHAASO-WCDA Monitor Website

- **Blind-search flare map**
- **Light-curve repository (interactive)**

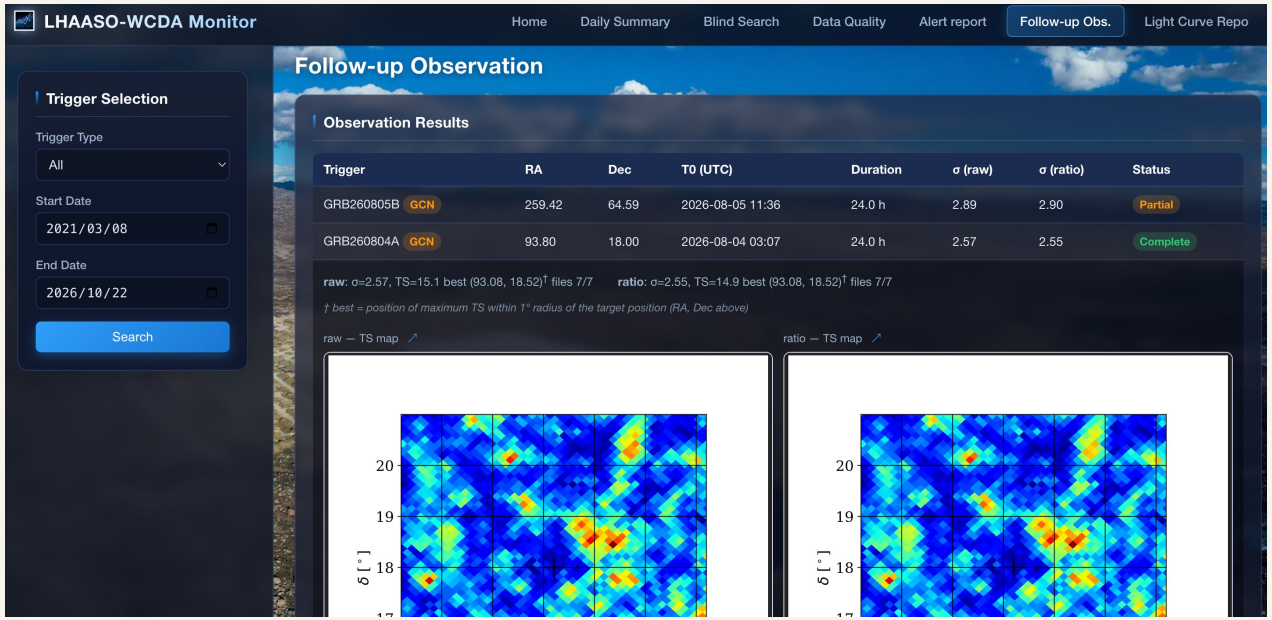




Data Portal: the LHAASO-WCDA Monitor Website

- **Daily summaries & flare alerts**
- **Data-quality trends · alert reports · follow-up results**





Summary & outlook

A Working Real-time System

WCDA monitoring is live 7×24: skymaps → blind search → alerts → follow-up

Science Delivered

Flaring activity from 16 AGNs; New TeV transient 4C+42.22;

Automated Follow-up(in test)

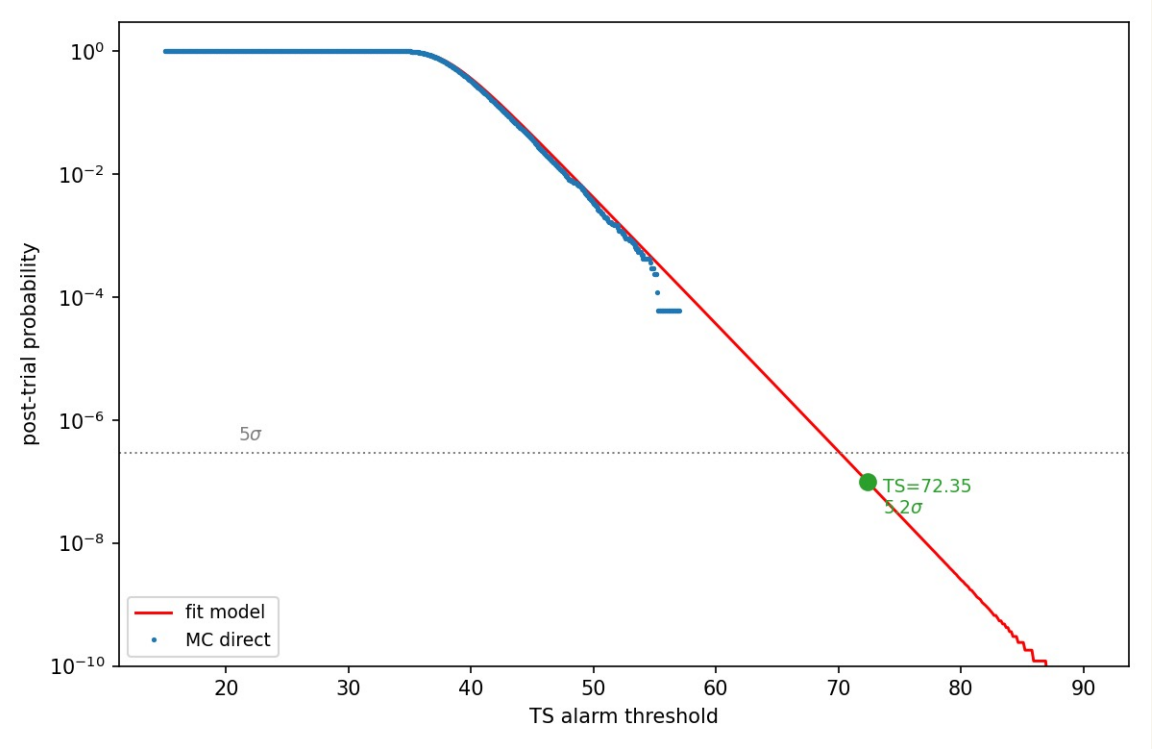
GCN / ATel ingested automatically · results within hours, no human in the loop · triggerless GRB follow-up

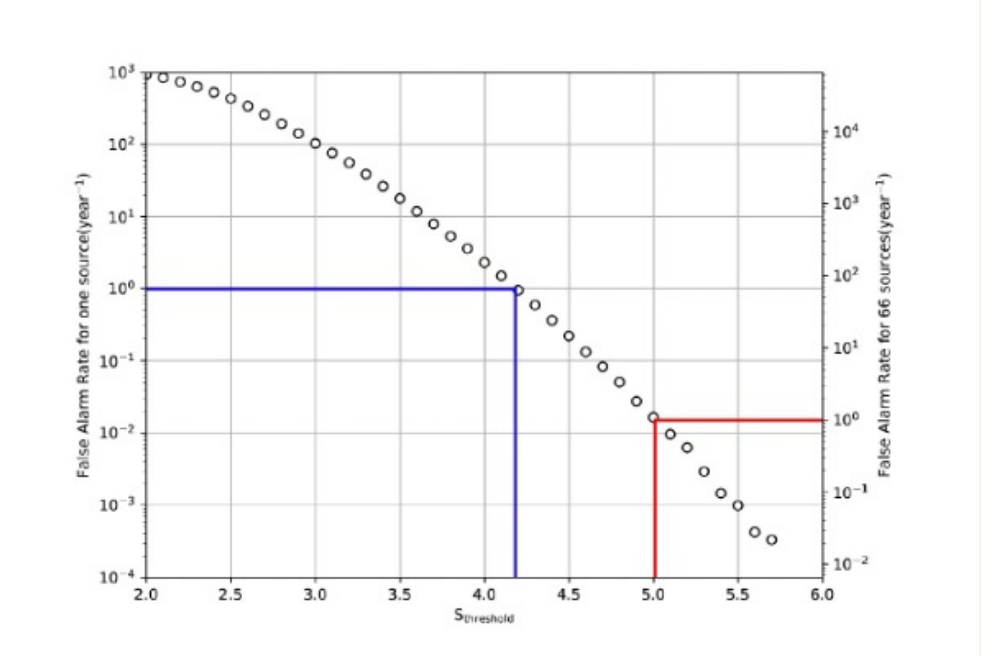
Connected to the Community

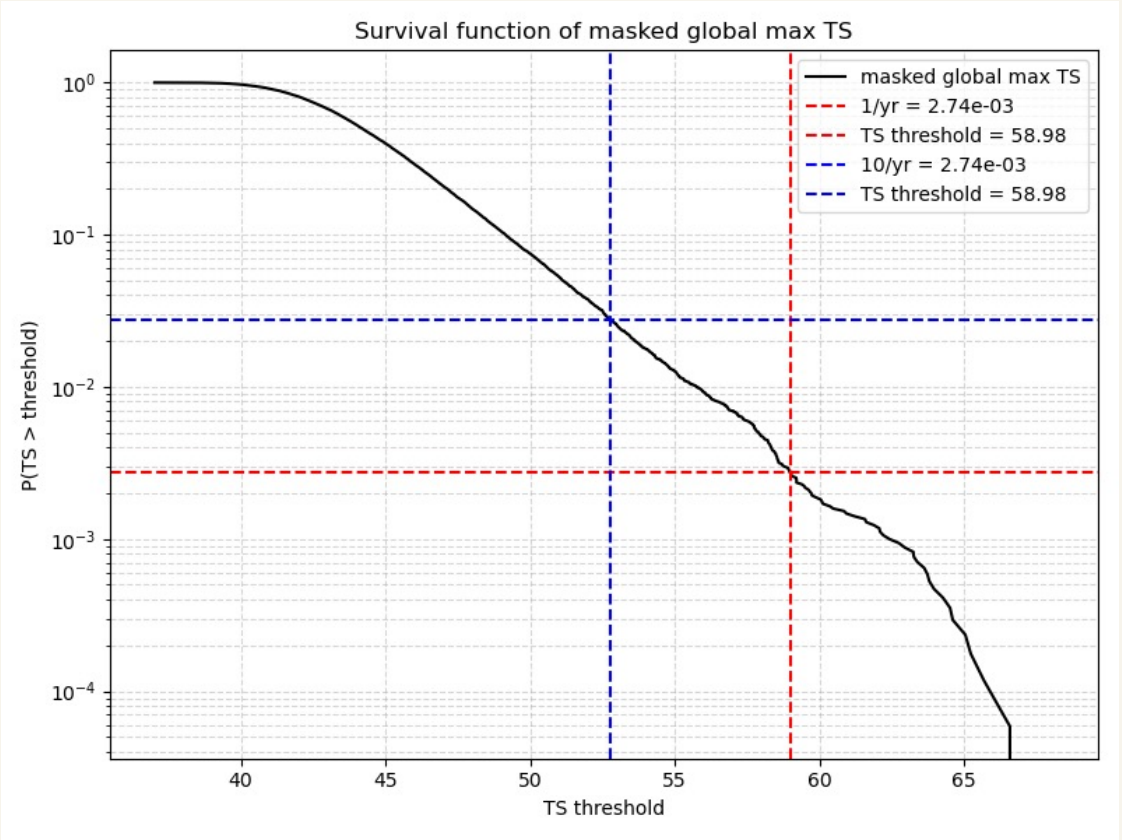
WCDA flare alerts are now publish ed via GCN / ATel, such as Astro-COLIBRI in preparation,

Thank you! — Questions & Comments

BACK UP


post-trial probability
TS alarm threshold
5σ
TS=72.35
5.2σ
fit model
MC direct


False Alarm Rate for one source(year⁻¹)
False Alarm Rate for 66 sources(year⁻¹)
S_threshold


Survival function of masked global max TS
masked global max TS
1/yr = 2.74e-03
TS threshold = 58.98
10/yr = 2.74e-03
TS threshold = 58.98
P(TS > threshold)
TS threshold
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
40
45
50
55
60
65

Outlook: LHAASO-LACT — Deep Follow-up of WCDA Alerts

Large Array of imaging atmospheric Cherenkov Telescopes · under construction at the LHAASO site

32 × 6 m
Cherenkov telescopes at LHAASO site

< 0.05°
angular resolution (5× LHAASO)

~2 km²
effective area above 10 TeV

2028
full array (first light 2026)

WCDA / KM2A
wide-FoV survey · real-time transient alerts

⬇

LACT
deep pointed follow-up · fine spectra & morphology

A self-triggered, wide-to-narrow transient facility:

WCDA finds and alerts — LACT zooms in