

All-sky search for neutrino flares in the ANTARES legacy data



PoS(ICRC2025)1066



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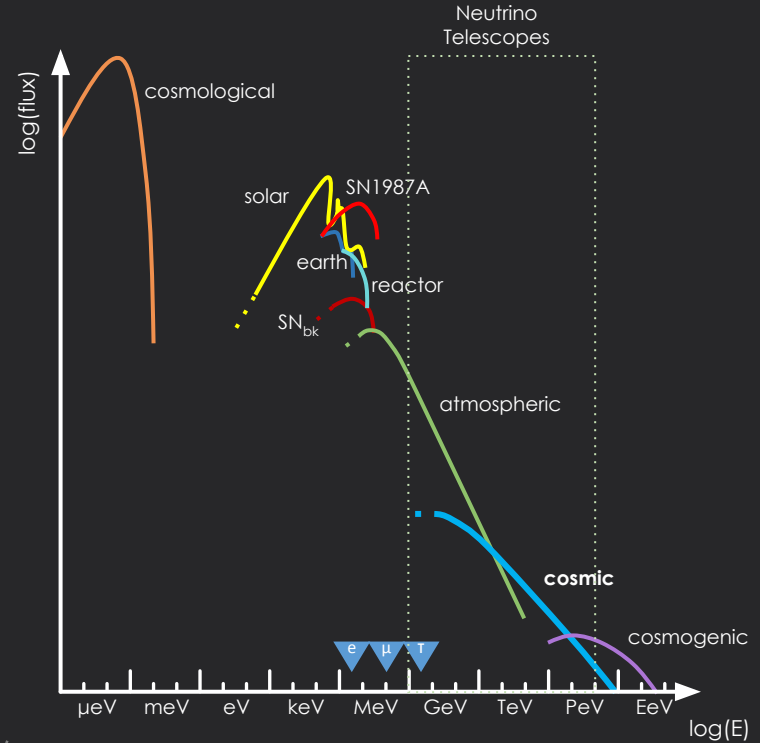
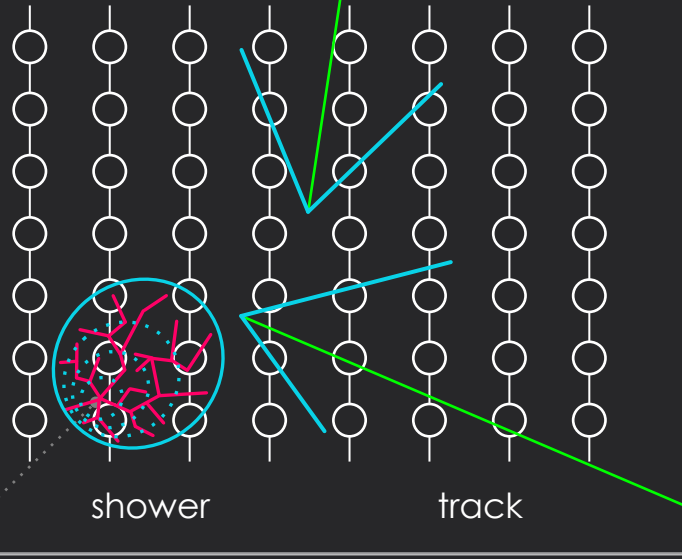
on behalf of the ANTARES Collaboration





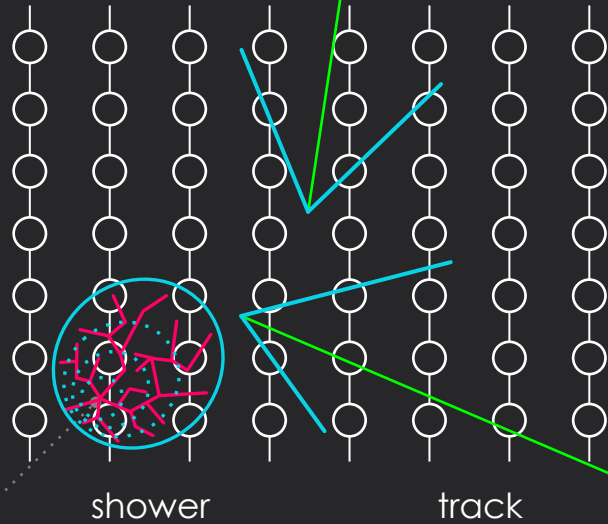
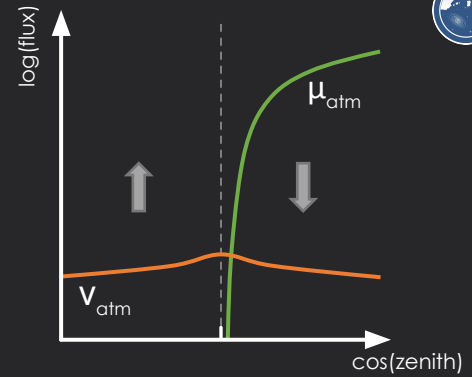
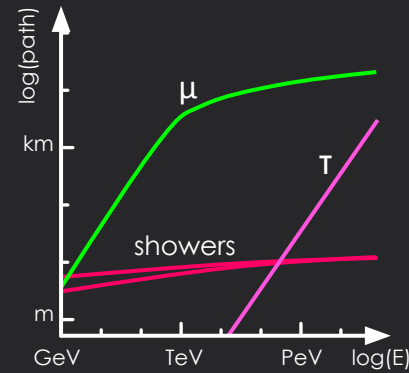
A Neutrino Telescope

“We propose setting up apparatus in an underground lake or deep in the ocean in order to separate charged particle directions by Cherenkov radiation”, **Markov 1960**

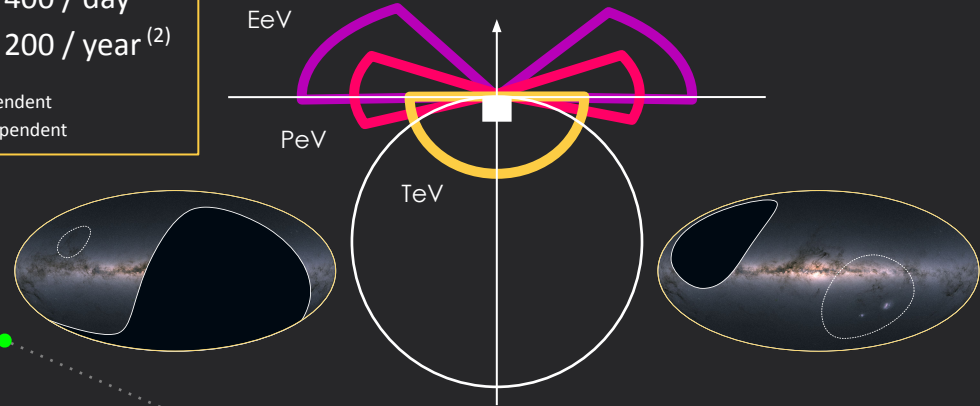




A Neutrino Telescope



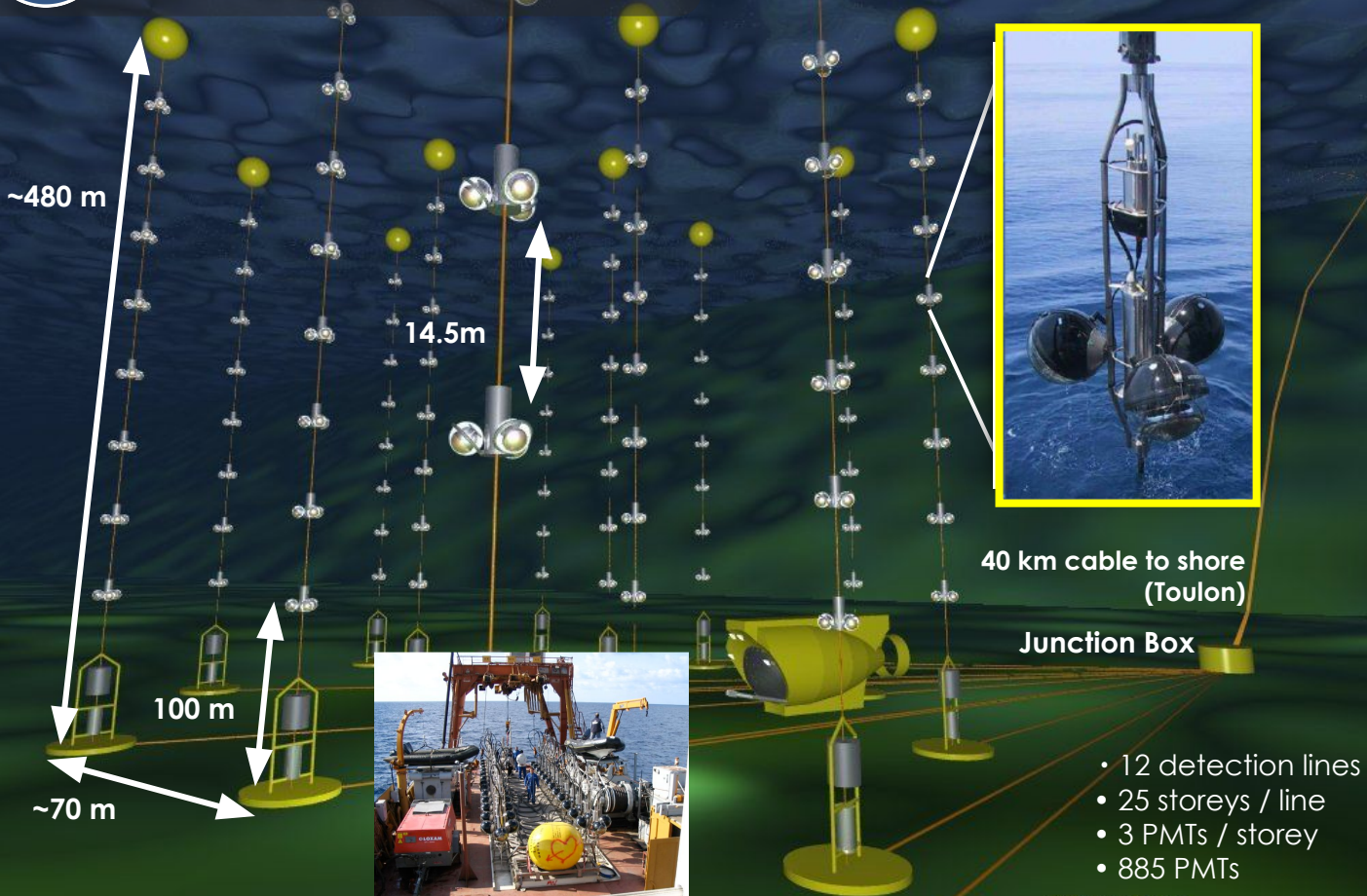
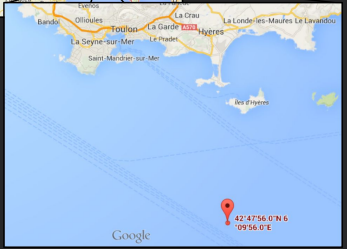
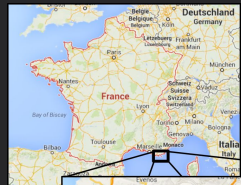
	1 km^3
μ_{atm}	$\sim 2000 / \text{s}^{(1)}$
ν_{atm}	$\sim 400 / \text{day}^{(2)}$
ν_{cos}	$\sim 200 / \text{year}^{(2)}$
(1): depth dependent	
(2): analysis dependent	





ANTARES

- String-based detector
- Downward-looking (45°) PMTs
- 2475 m deep



40 km cable to shore (Toulon)

Junction Box

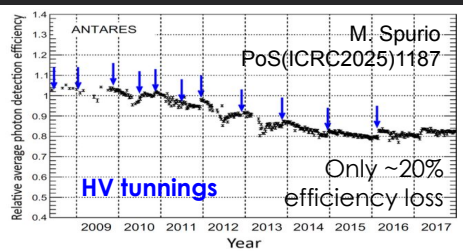
- 12 detection lines
- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs

More than 15 years taking data (2006-2022)

~0.01 km³
Largest NT on North Hemisphere for years

Medium angular resolution tracks: < 0.4° @ E > 10 TeV
showers: ~ 2°

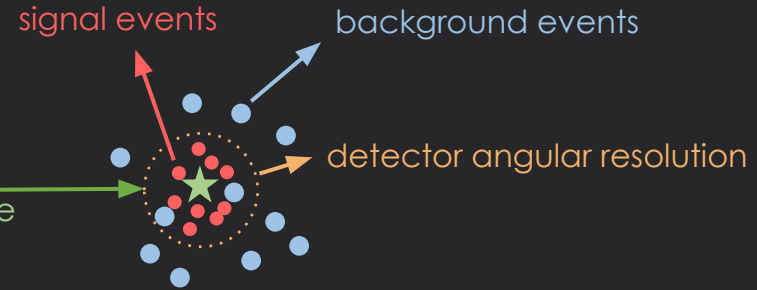
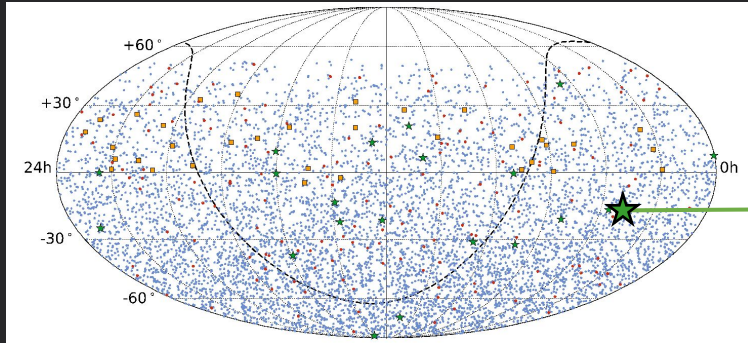
Hundreds of GeV to PeV range



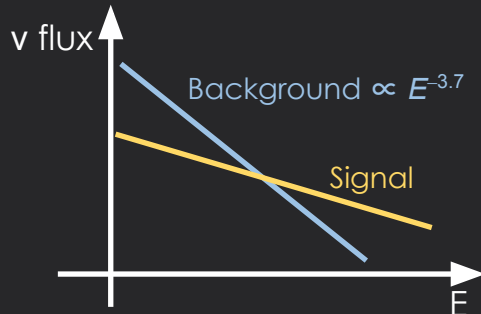


Statistical analyses on Direction-Energy-Time

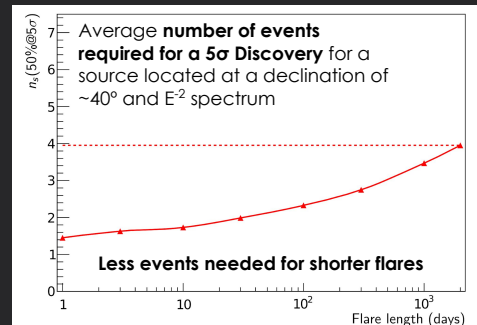
- **Spatial** distribution: compatible with point-like/extended sources?



- **Energy** spectrum: compatible with signal expectation?



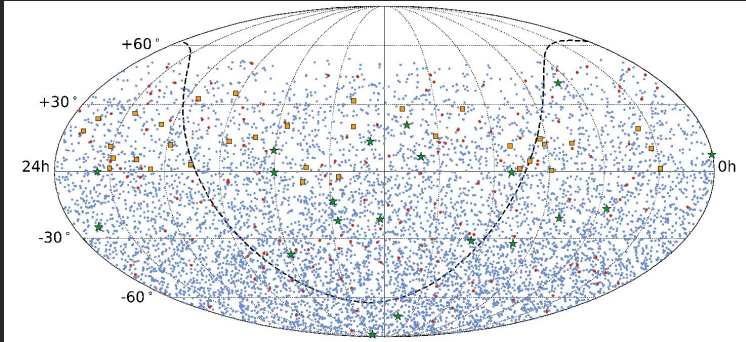
- **Arrival time**: limited to a transient signal hypothesis?





Untriggered full-sky point source neutrino search

- **Spatial** distribution: compatible with point-like/extended sources?

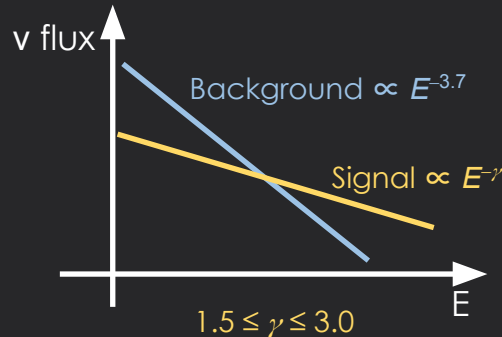


evaluate every point in the sky as potential source

$$\log \mathcal{L}(n_s, \gamma, T_0, \sigma_t) = \sum_i \log [n_s S_i(\gamma, T_0, \sigma_t) + NB_i]$$

number of detected signal events $\rightarrow n_s$
 spectral index $\rightarrow \gamma$
 flare time $\rightarrow T_0, \sigma_t$
 $S_i, B_i: PDF_{space} \times PDF_{energy} \times PDF_{time}$

- **Energy** spectrum: compatible with signal expectation?



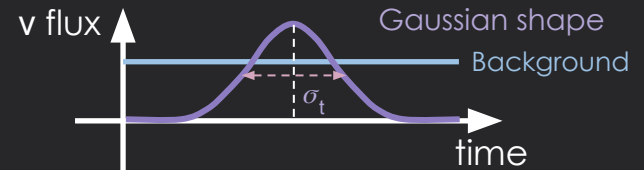
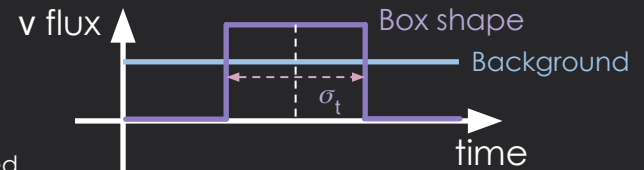
$T_0 \in \text{ANTARES}$ (range 5495 days)

$1 \leq \sigma_t \leq 1000$ days (half flare)

Shorter flares easier to accommodate:
likelihood ratio test statistic bias compensated

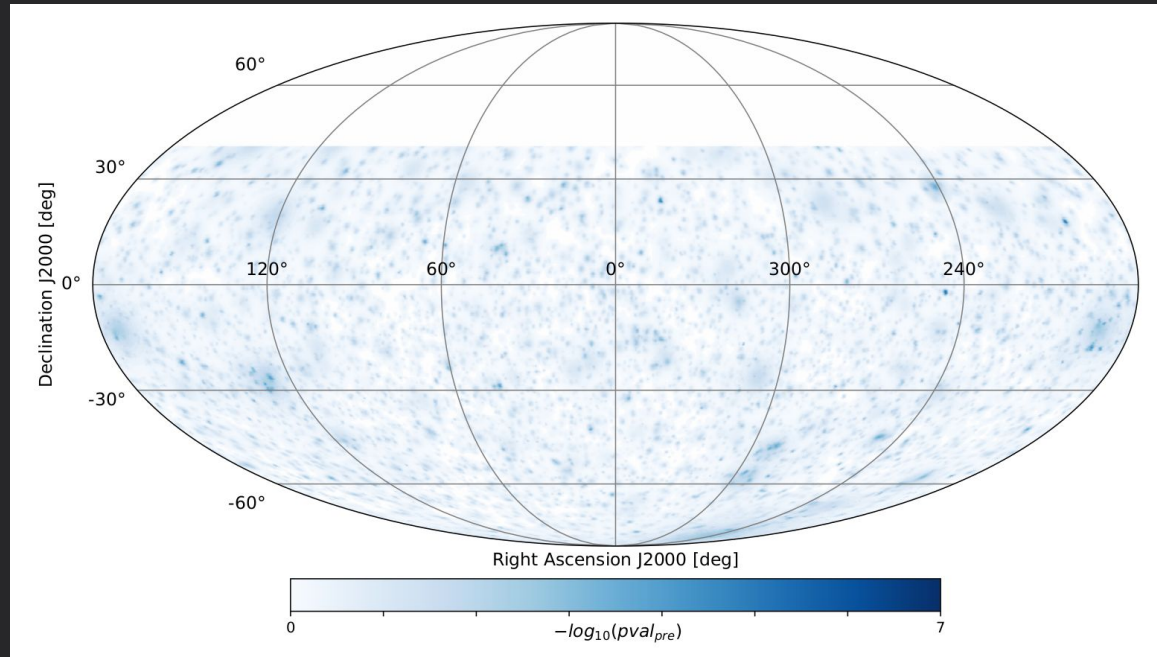
$$Q = -2 \log \left(\frac{\Delta T}{\sigma_t} \times \frac{\mathcal{L}(n_s = 0)}{\mathcal{L}(n_s = n_s^{max})} \right)$$

- **Arrival time**: limited to a transient signal hypothesis?





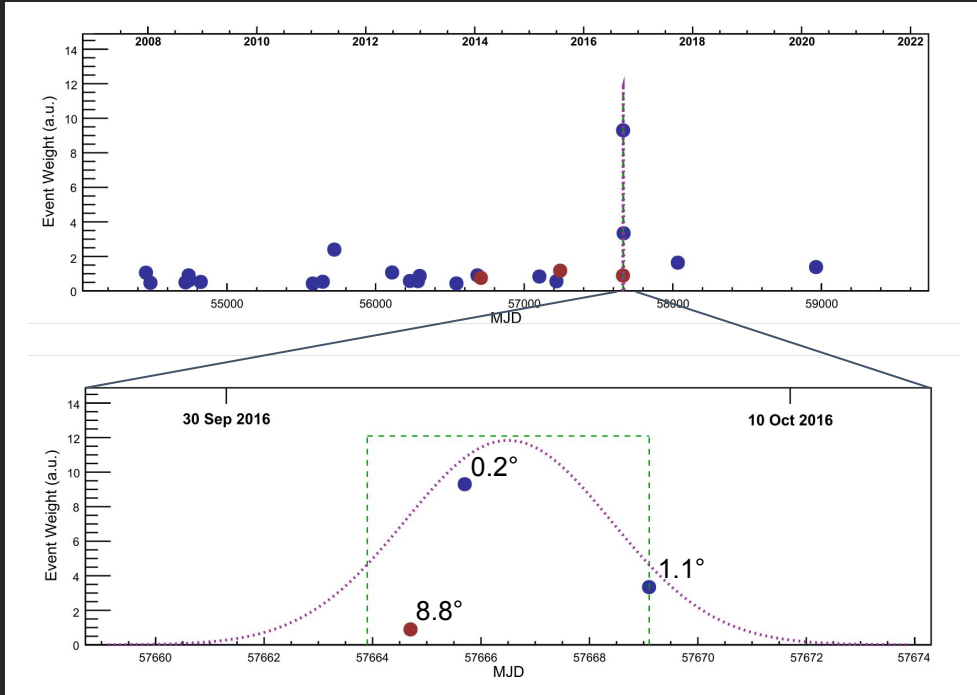
Example ANTARES full-sky p-value map



PoS(ICRC2025)1191
PO-1 ID 122



Hotspot: the most significant flare



track-like events within 5° and shower-like events within 10°

Gaussian-like flare

\square [$^\circ$]	α [$^\circ$]	T_0 [MJD]	σ_t [days]	n_s	γ	p-val (pre-trial)
9.8	141.3	57666	2	3.0	2.4	8.3×10^{-6} 4.3σ (1-sided)

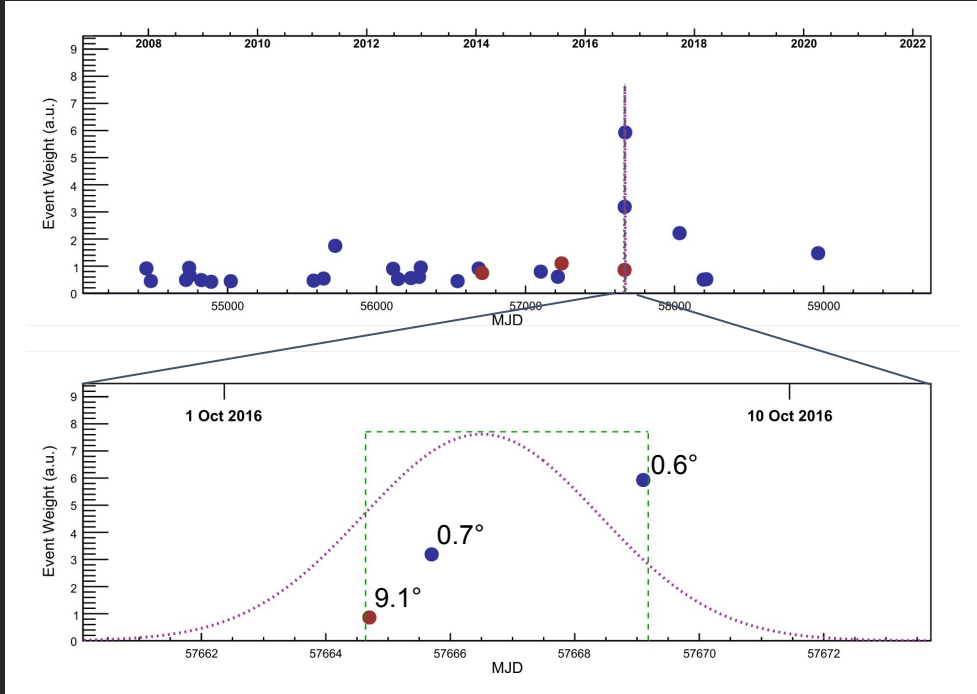
Post-trial significance: 30%

A posteriori

- **No significant lightcurve variation** spotted with Fermi All-sky Variability Analysis (FAVA) tool
- **No counterpart in GCN** circulars in a ± 1 week time window
- Some sources around but further $>1.5^\circ$



Hotspot: the most significant flare



track-like events within 5° and shower-like events within 10°

Box-like flare

\square [$^\circ$]	α [$^\circ$]	T_0 [MJD]	σ_t [days]	n_s	γ	p-val (pre-trial)
9.4	141.1	57667	2	3.2	2.4	8.8×10^{-6} 4.3σ (1-sided)

Post-trial significance: 28%

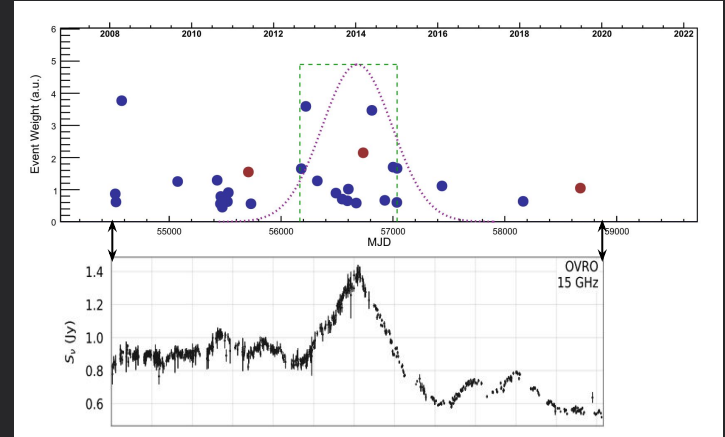
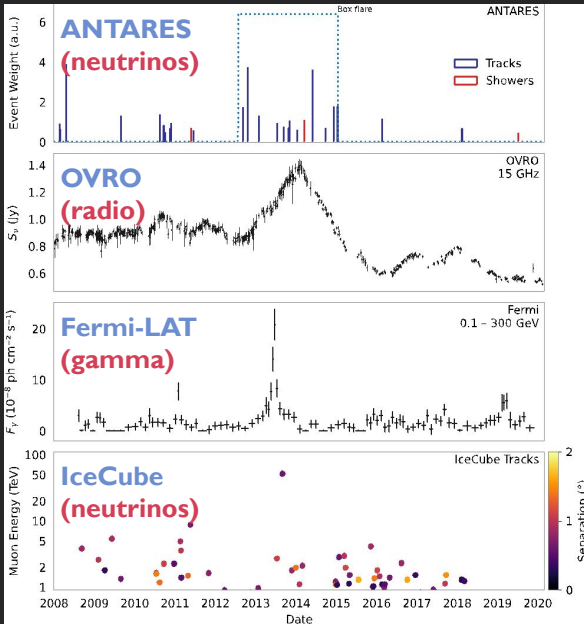
Same events as for the Gaussian-like flare

$\sim 0.5^\circ$ from Gaussian hotspot



Some a posteriori cases: PKS 0239+108 (J0242+1101)

Box				
T_0 [MJD]	σ_t [days]	n_s	γ	p-val (pre-trial)
56603	434	5.6	2.3	8.2×10^{-3}



Recap:

- 3411 radio-bright blazars ANTARES neutrino flare search
- 18 cases with $>3\sigma$ (2-tailed) ...including J0242+1101
- J0242+1101 coincidences estimated to be 0.5%

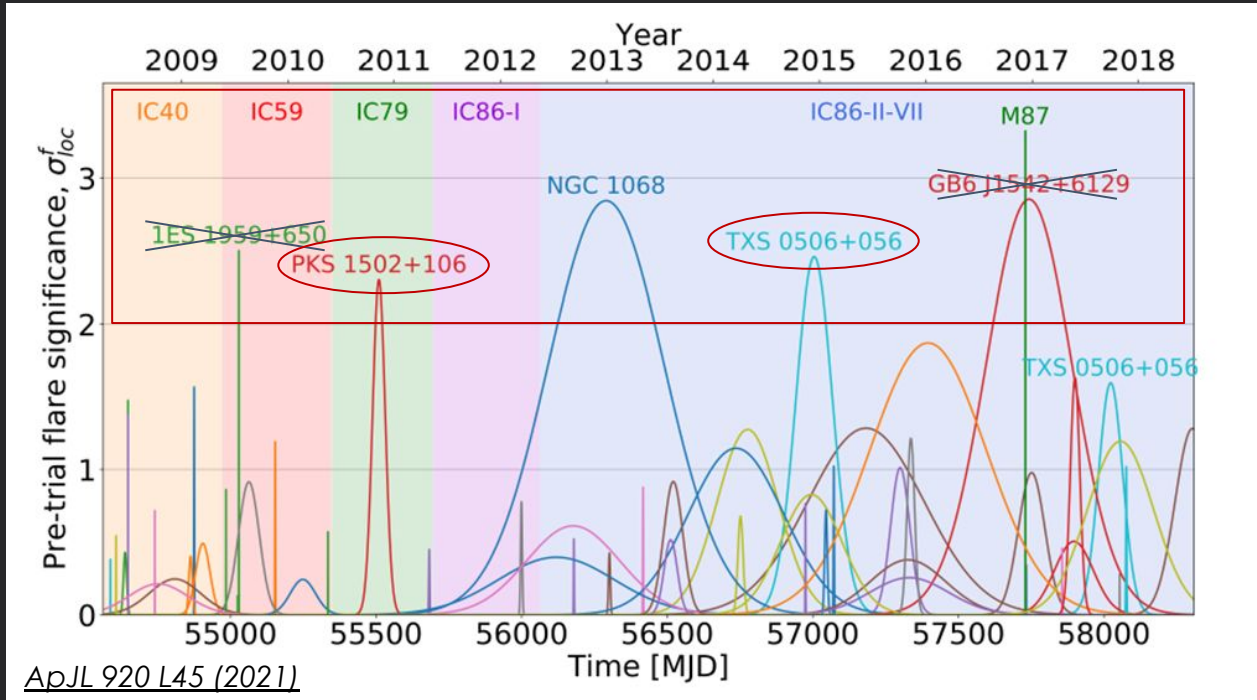
Now:

- overlap confirmed with last data selection
- although significance decreased: $3.1\sigma \rightarrow 2.6\sigma$

Astrophys.J. 964 (2024) 1, 3



Some *a posteriori* cases: IceCube flares



Having a look to the most significant IceCube flares:

- Significance $>2\sigma$
- Declination $<40^\circ$

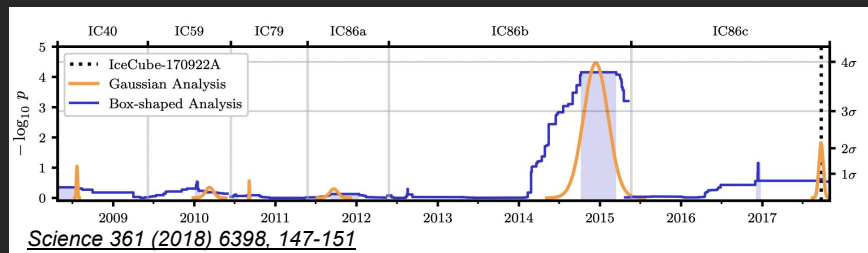


Two significant ($>2\sigma$) ANTARES flares: (+overlapping)

- TXS 0506+056
- PKS 1502+106



Some a posteriori cases: TXS 0506+056

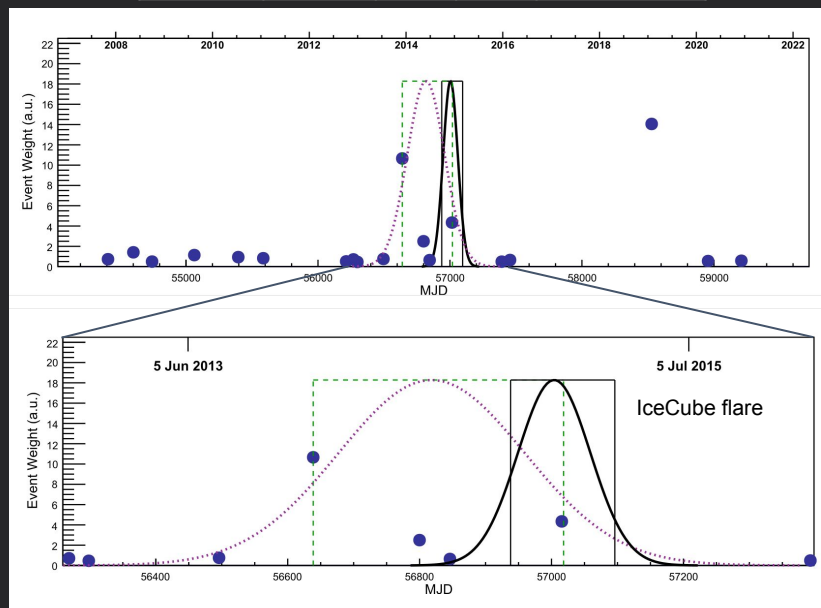


Box				
T_0 [MJD]	σ_t [days]	n_s	γ	p-val (pre-trial)
56828	190	3.4	3.2	2.2×10^{-2}

Both 2-3 σ excesses but with time overlap (80 days) with the so-called orphan IceCube flare

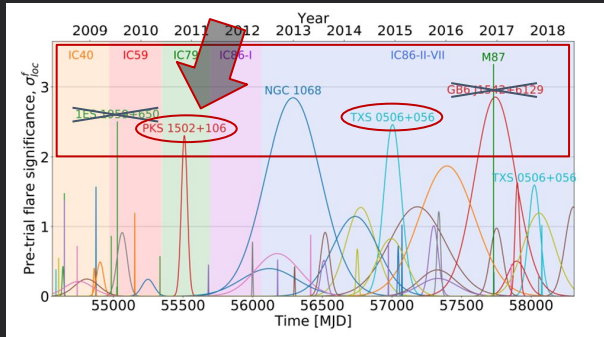
Box-shaped comparisons:

- ~21% of ANTARES flare overlaps with IceCube one
- ~51% of IceCube flare overlaps with ANTARES one
- Chances of ANTARES >2 σ and >21% overlapping: ~0.2%





Some a posteriori cases: PKS 1502+106

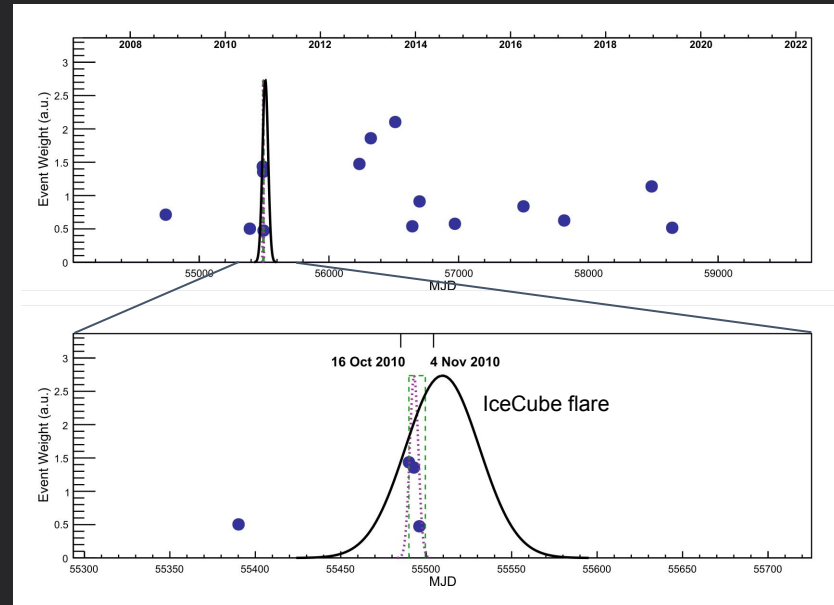


Gaussian				
T_0 [MJD]	σ_t [days]	n_s	γ	p-val (pre-trial)
55493	2	3.0	3.4	1.1×10^{-2}

Both 2-3 σ excesses with time overlap but different lengths

Gaussian-shaped comparisons, overlapping assuming $T_0 \pm 3\sigma_t$:

- 100% of ANTARES flare overlaps with IceCube one
- ~12% of IceCube flare overlaps with ANTARES one
- Chances of ANTARES >2 σ and >12% overlapping: ~0.3%





Summary

- All ANTARES sky investigated for neutrino flares
- Gaussian-like or box-like lasting 1–2000 days within 15 years data taking period (2006-2022)
- Most significant flare: 2 days with 28% post-trial probability with no counterpart
- Some *a posteriori* interesting cases
- PKS 0239+108 flare from previous ANTARES searches confirmed
- IceCube flares overlap: TXS 0506+056 orphan flare and PKS 1502+106
- Further studies about the chances of such coincidences are on-going

Thanks for

your attention

