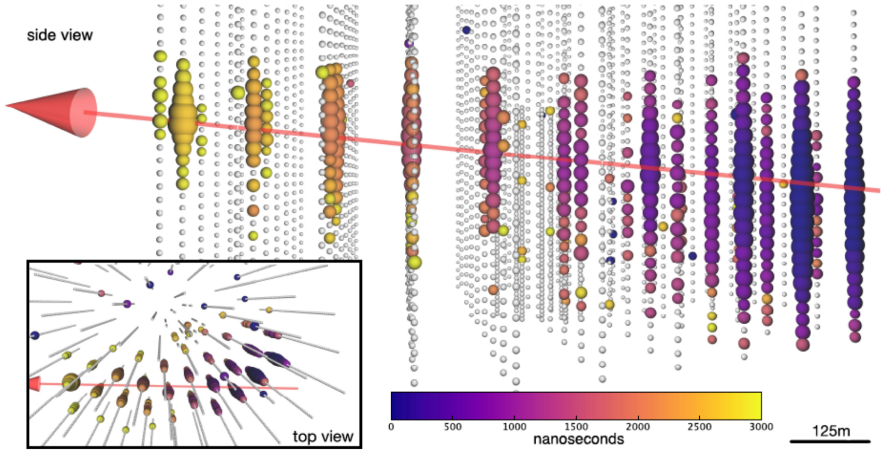
ANTARES search for neutrino flares from the direction of radio-bright blazars

Giulia Illuminati* **and Alexander Plavin** on behalf of the **ANTARES** Collaboration

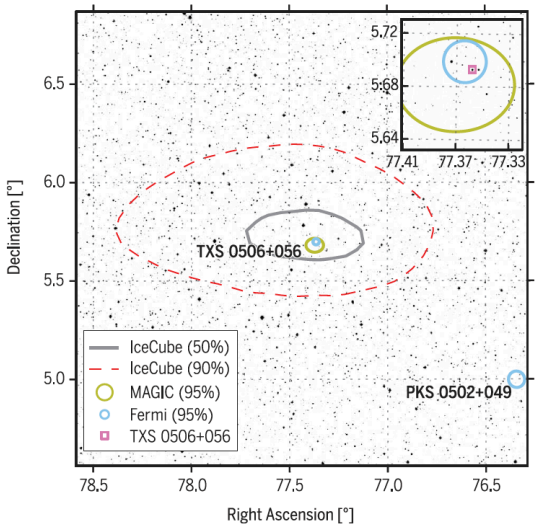
ICRC 2021

Neutrino flare from TXS 0506+056

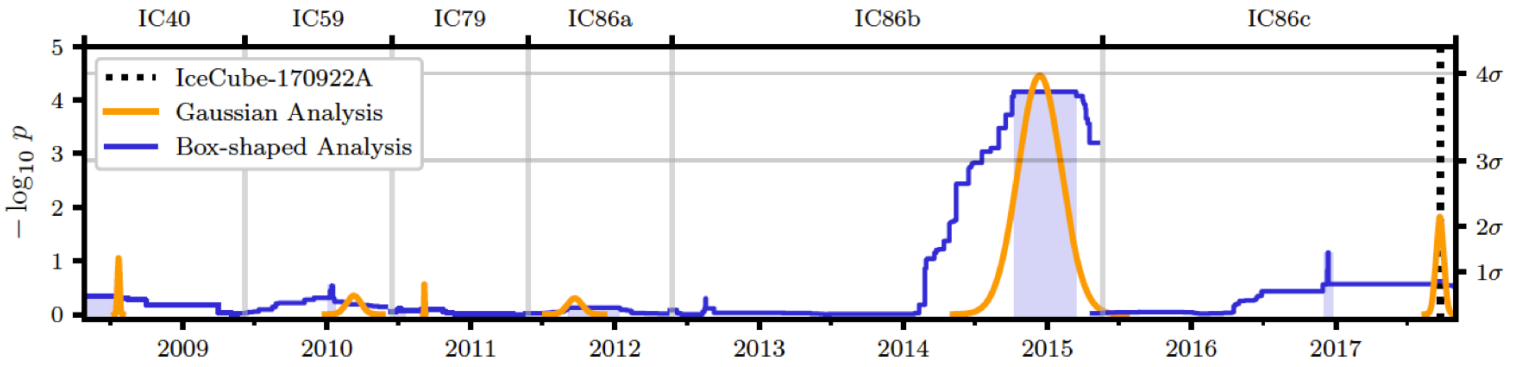


September 2017:
Multimessenger observations of a **flaring blazar coincident** with high-energy neutrino **IceCube-170922A**

[Science 361, eaat1378 (2018)]



~4-5 month-long neutrino flare from same blazar found in IceCube archival data **not accompanied by any observed electromagnetic activity**



[Science 361, 147-151 (2018)]

Similar IceCube time-dependent searches:

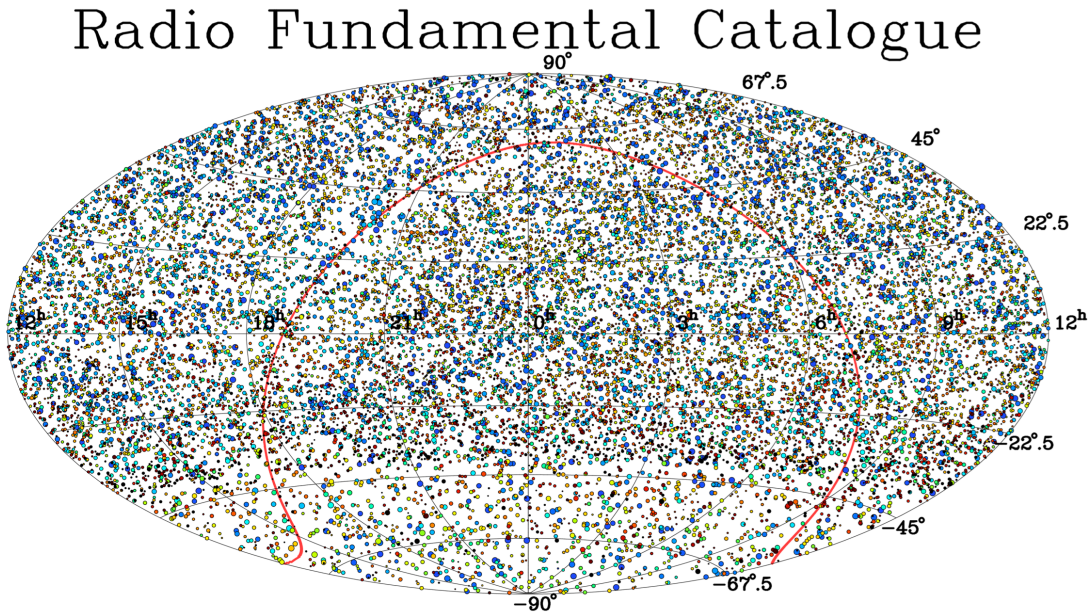
[Astrophys.J.744:1,2012]
[ApJ 807 (2015) 46]
[Astrophys.J. 911 (2021) 1, 67]

Target sources:
2774 radio-bright blazars

Recent **promising associations** between **IceCube neutrinos** and **radio-bright blazars**

ApJ 908 (2021) 157
ApJ 894 (2020) 101

🗣️ **Similar analysis** using **ANTARES data** presented in **J. Aublin and A. Pavlin**'s talk (**#1240**)



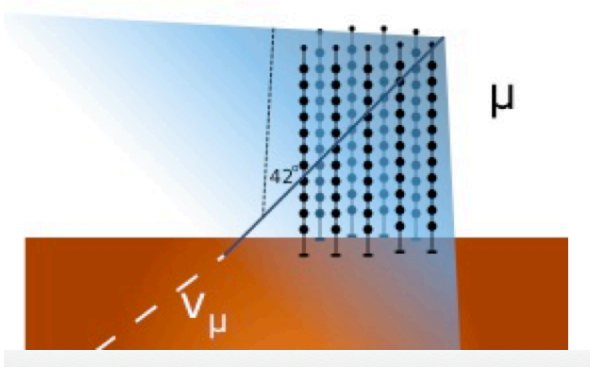
http://astrogeo.org/rfc/

Same blazar catalog:

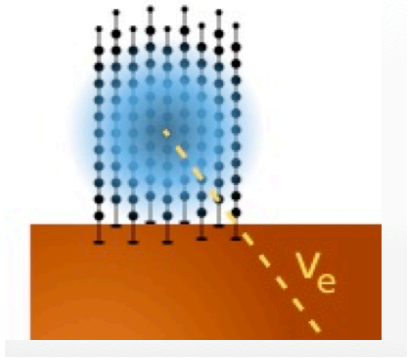
- all-sky sample of blazars
- selected on the basis of **very-long-baseline interferometry (VLBI) radio flux**
- flux density integrated over VLBI images at 8 GHz **> 150mJy**

- $\delta < 40° \rightarrow$ **2774 sources**

ANTARES data: tracks and showers

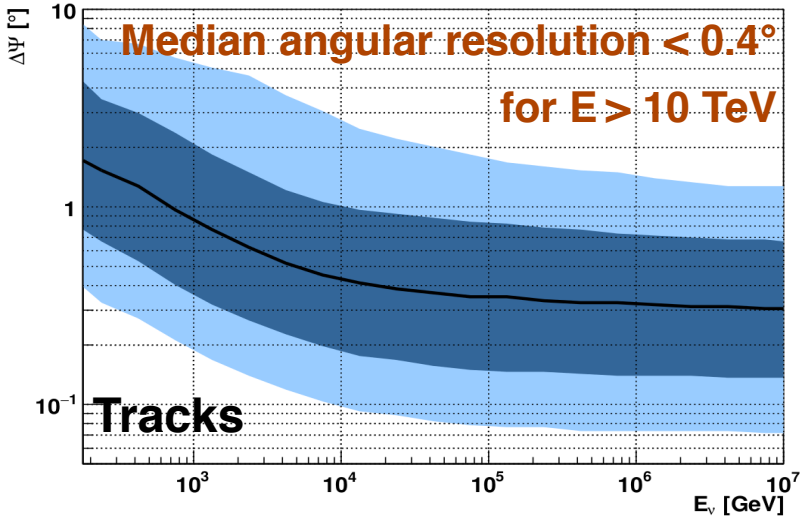


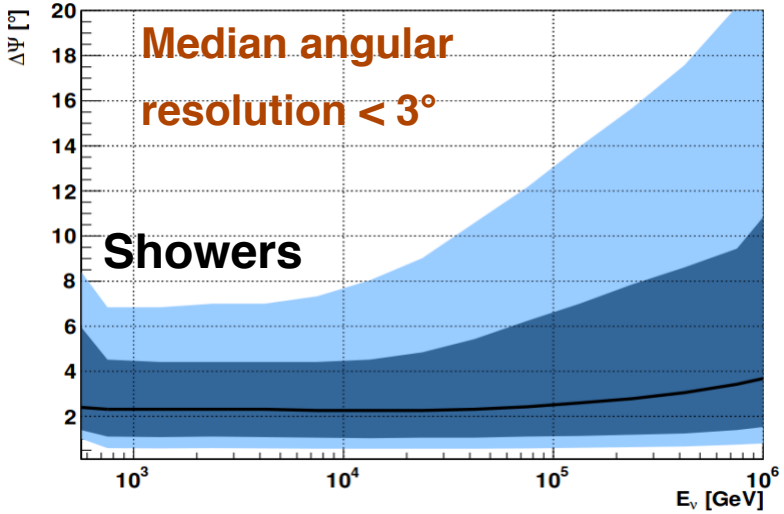
Track-like events:
ν_μ (ν_τ) neutrino CC interaction near the detector



Shower-like events:
all neutrinos NC, ν_e,ν_τ CC interaction inside or very close to the detector

Period: from Jan 2007 to Feb 2020
Livetime: 3845 days
Events: **10162 tracks** and **225 showers**





Unbinned likelihood: PDFs

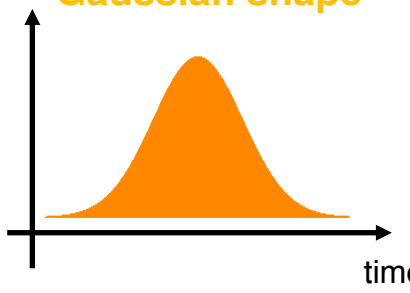
$$\log L(\underbrace{n_s, \gamma, T_0, \sigma_t}_{\text{free parameters}}) = \sum_{j \in \{tr,sh\}} \sum_{i \in j} \log \left[\frac{n_s^j}{N^j} S_i^j(\gamma, T_0, \sigma_t) + \frac{N^j - n_s^j}{N^j} B_i^j \right]$$

Signal PDFs

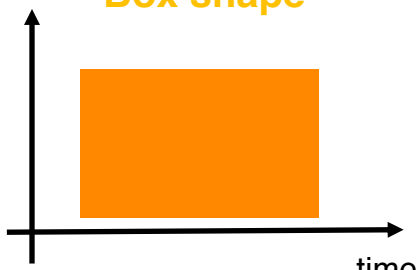
$$S_i = S^{space} \cdot S^{energy} \cdot S^{time}$$

Two assumptions for SIGNAL time profile

Gaussian shape



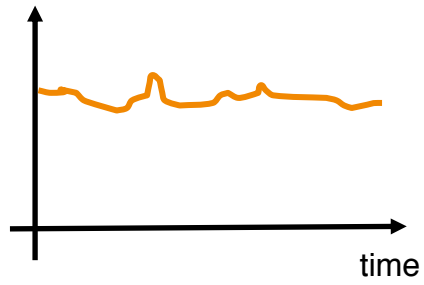
Box shape



Background PDFs

$$B_i = B^{space} \cdot B^{energy} \cdot B^{time}$$

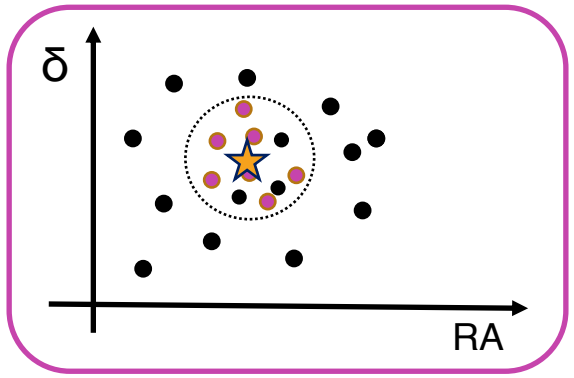
BACKGROUND time profile from data



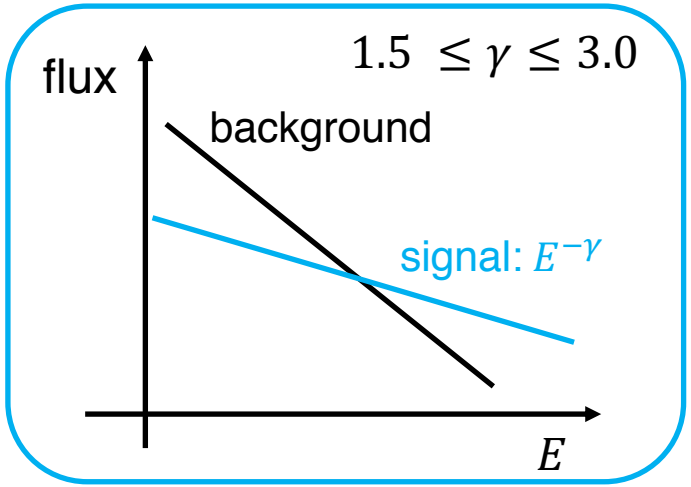
Unbinned likelihood: free parameters

$$\log L(n_s, \gamma, T_0, \sigma_t) = \sum_{j \in \{tr, sh\}} \sum_{i \in j} \log \left[\frac{n_s^j}{N^j} S_i^j(\gamma, T_0, \sigma_t) + \frac{N^j - n_s^j}{N^j} B_i^j \right]$$

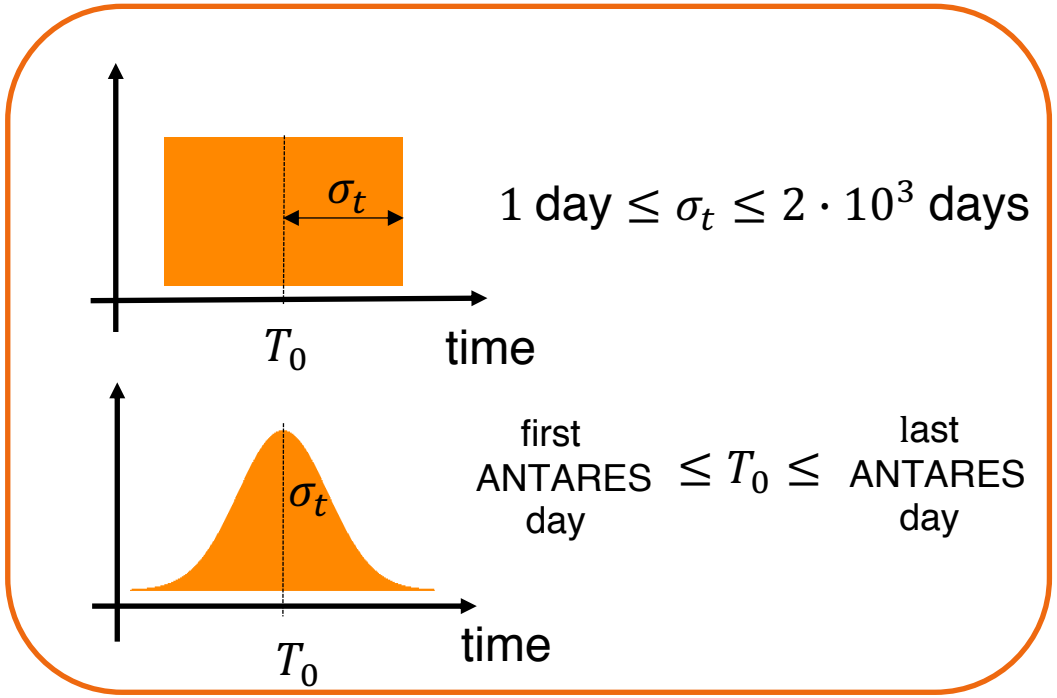
number of detected signal events



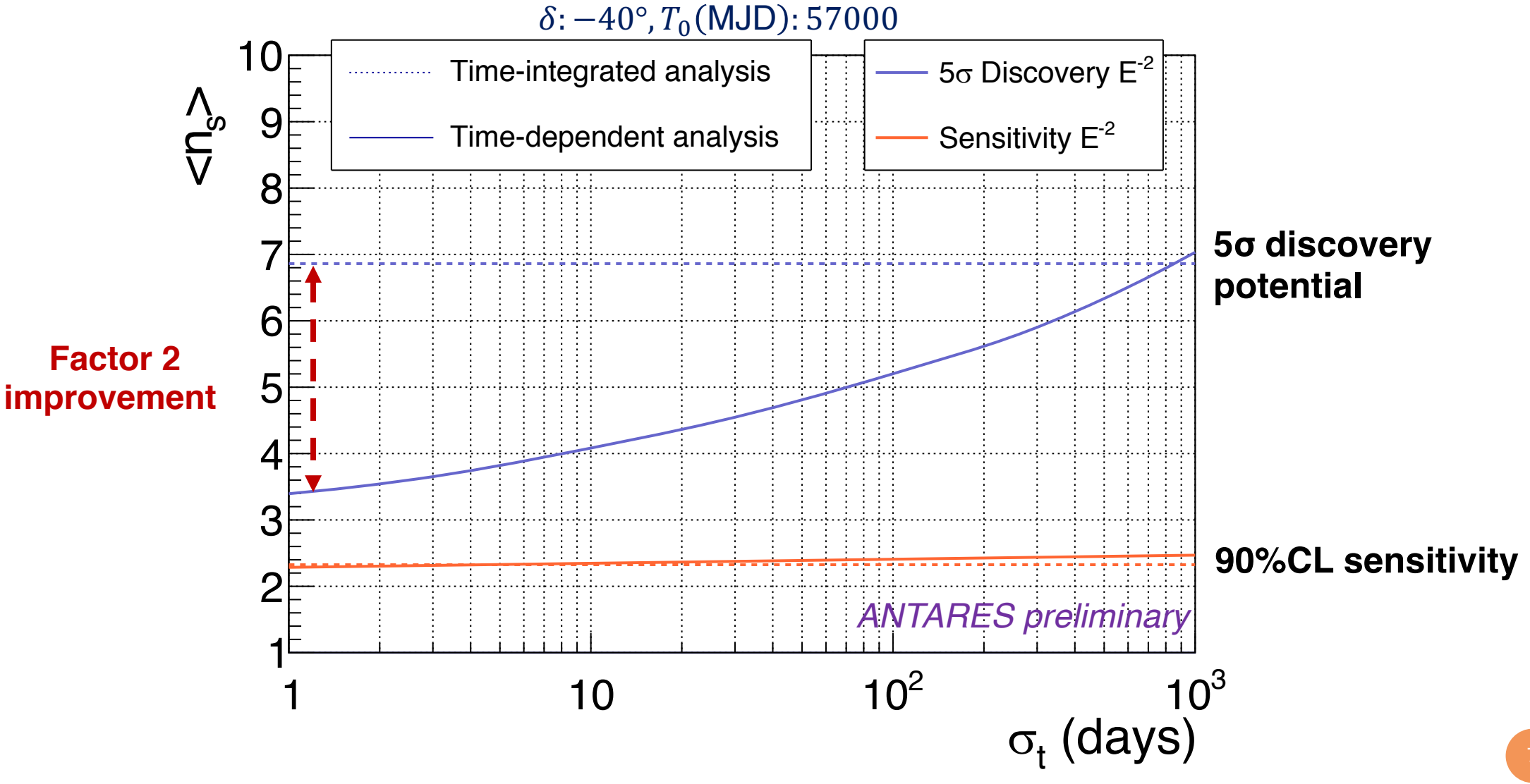
signal spectral index



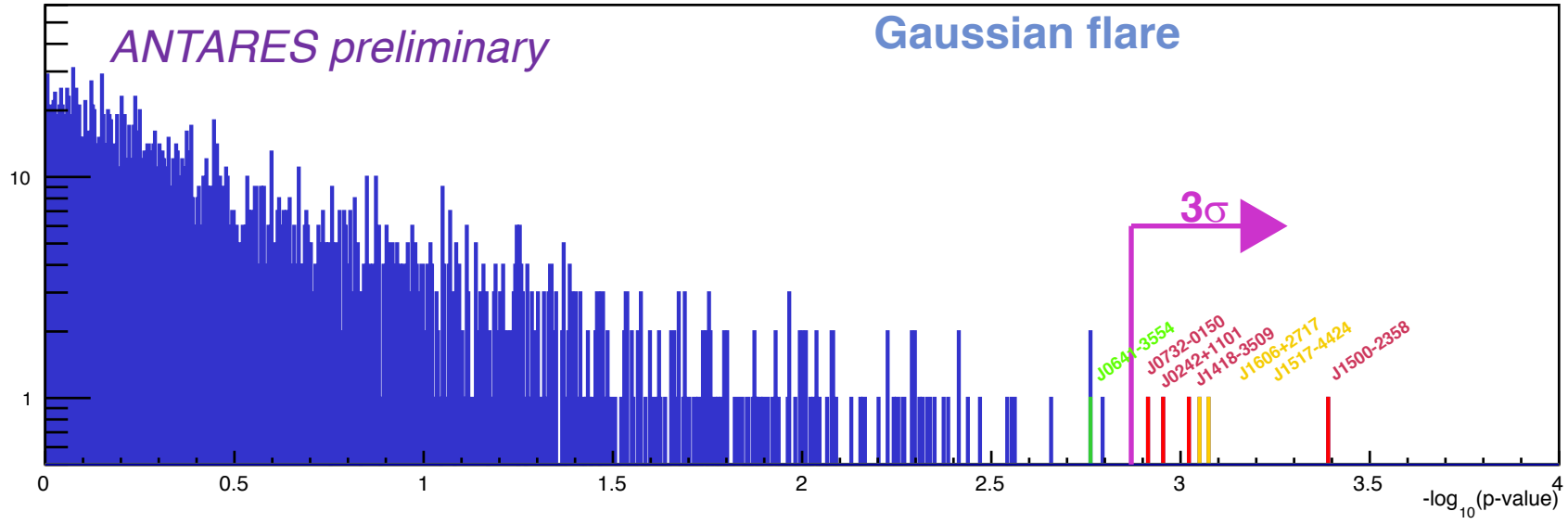
time-related parameters

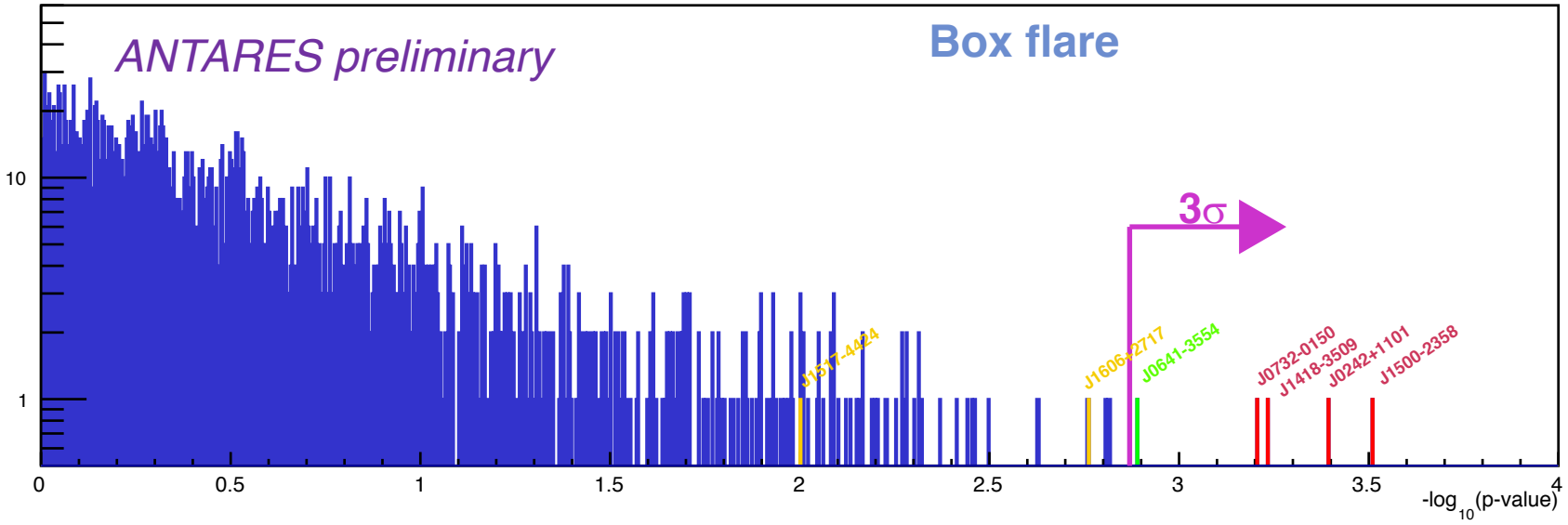


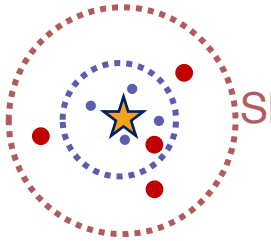
90%CL Sensitivity and Discovery@5σ



Obtained p-value distribution



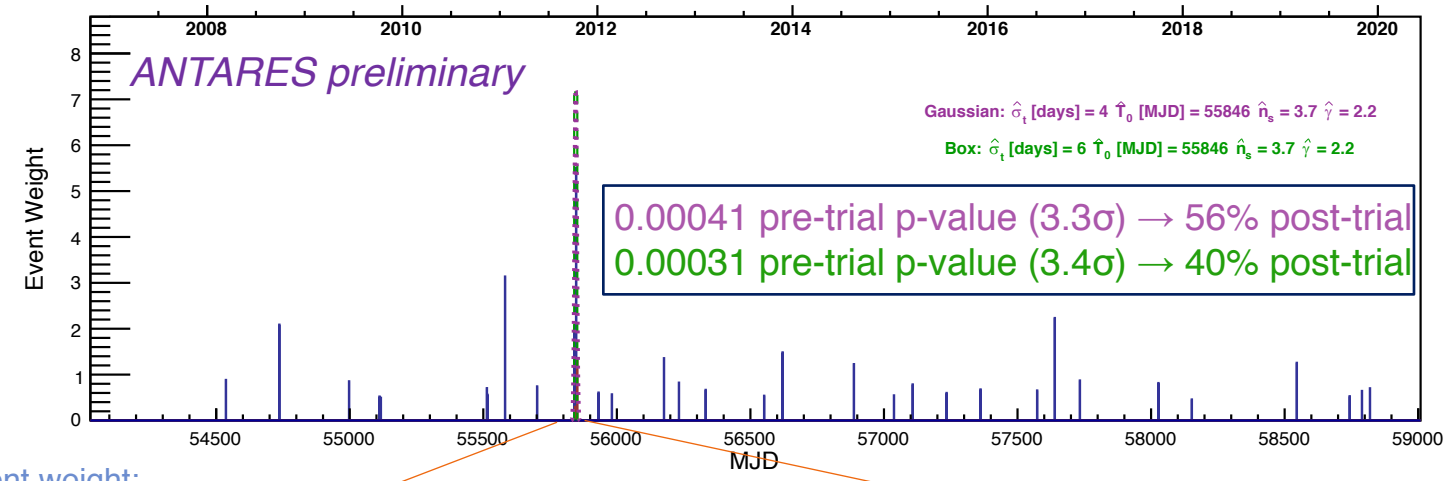




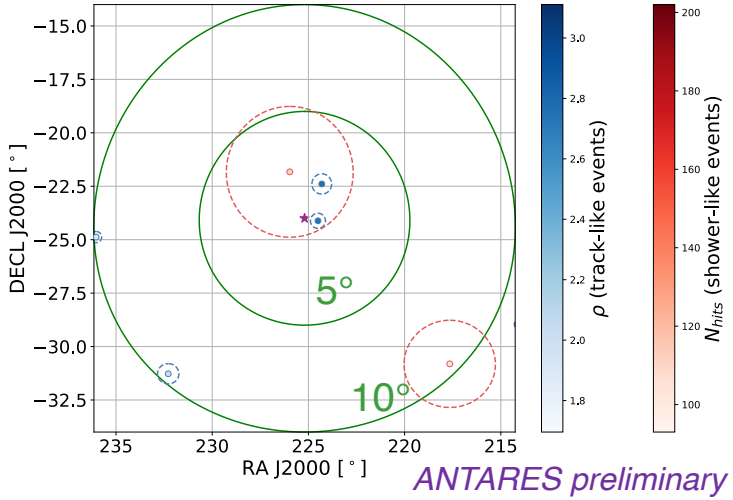
Tracks within 5°
Showers within 10°

J1500-2358

J1500-2358 (RA [deg], δ [deg]) = (225.2, -24.0)



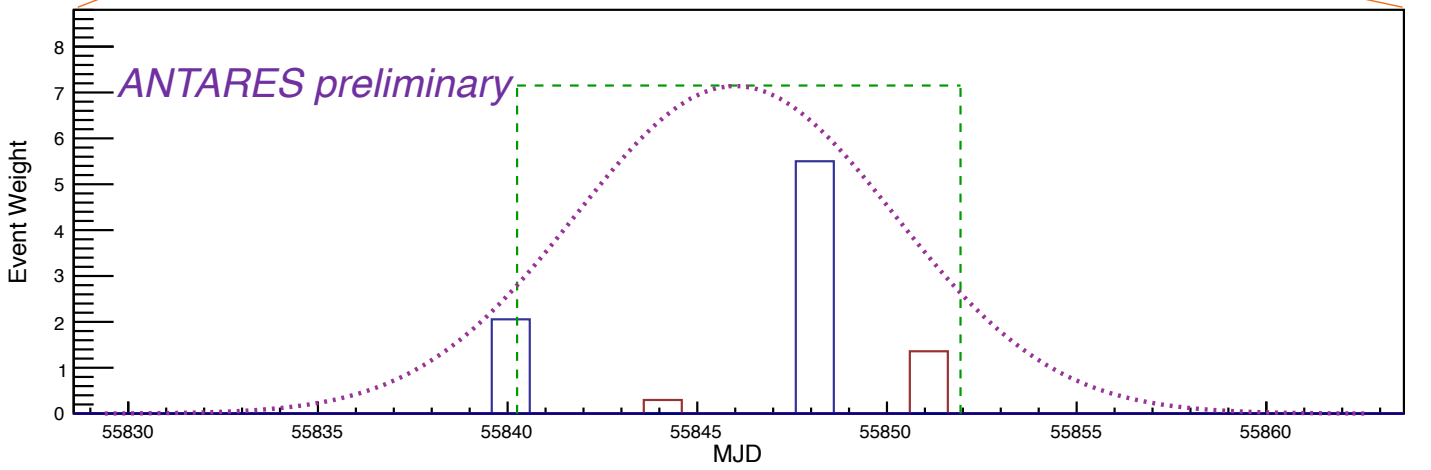
events within $3 \cdot \widehat{\sigma_t}^{Box}$

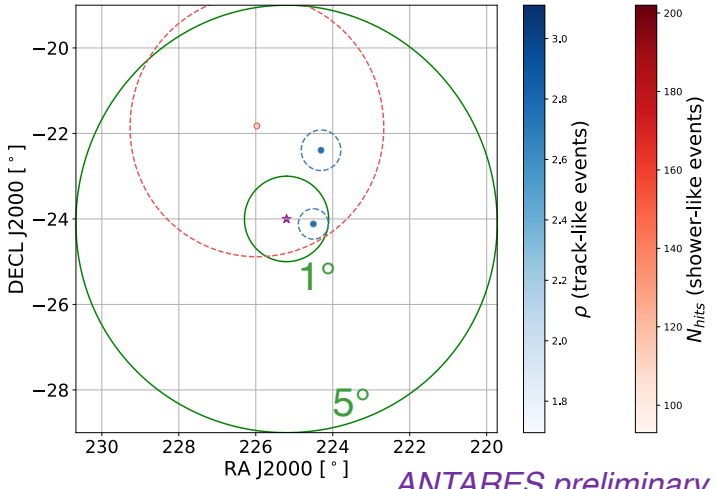


event weight:

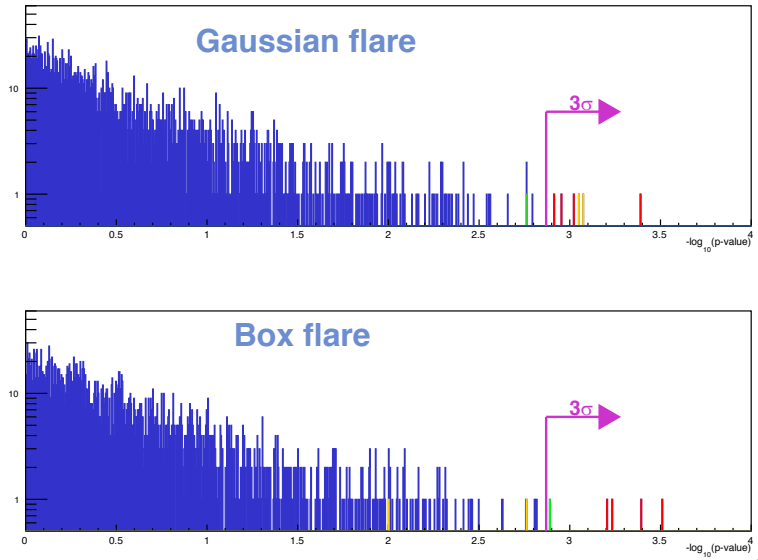
$$\frac{cone\ size}{\Delta\Psi_i} \frac{E_i}{E_{max}}$$

J1500-2358 (RA [deg], δ [deg]) = (225.2, -24.0)





Seven sources with >3σ pre-trial significance



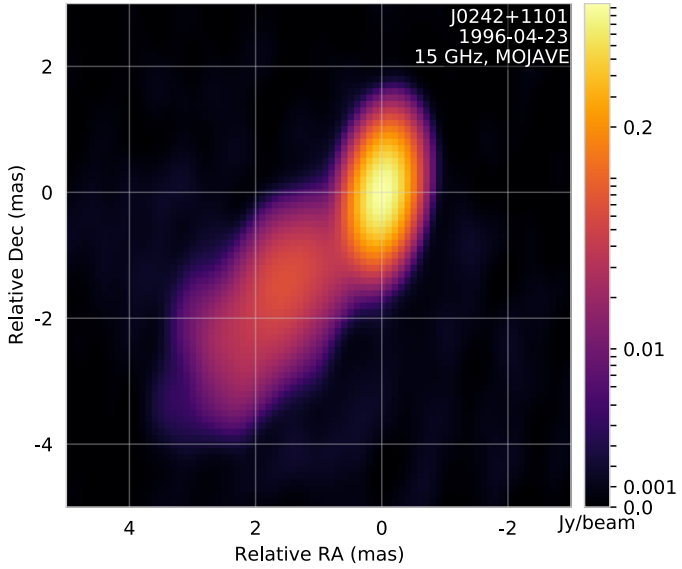
Source			Results									
Name	δ	α	Gaussian-shaped time profile					Box-shaped time profile				
			$\hat{T}_0$	$\hat{\sigma}_t$	$\hat{\mu}_{sig}$	$\hat{\gamma}$	p-value	$\hat{T}_0$	$\hat{\sigma}_t$	$\hat{\mu}_{sig}$	$\hat{\gamma}$	p-value
	[deg]	[deg]	[MJD]	[days]				[MJD]	[days]			
J1500-2358	**-24.0**	**225.2**	**55846**	**4**	**3.7**	**2.2**	**0.00041**	**55846**	**6**	**3.7**	**2.2**	**0.00031**
J1517-4424	-44.4	229.4	57761	361	7.2	3.5	0.00084	57366	529	5.3	3.5	0.0099
J1606+2717	27.3	241.7	58793	1	1.0	1.1	0.00089	58267	538	1.2	1.3	0.0017
J1418-3509	**-35.2**	**214.7**	**58119**	**12**	**3.6**	**3.3**	**0.00095**	**58119**	**14**	**3.8**	**3.3**	**0.00058**
J0242+1101	**11.0**	**40.6**	**56634**	**318**	**5.3**	**2.0**	**0.0011**	**56635**	**413**	**5.6**	**2.1**	**0.00040**
J0732-0150	**1.8**	**113.1**	**55794**	**82**	**4.9**	**3.5**	**0.0012**	**55813**	**117**	**5.2**	**3.5**	**0.00062**
J0641-3554	-35.9	100.3	58084	16	3.0	3.2	0.0017	58080	18	3.0	3.2	0.0013

Radio light-curves produced by the Owens Valley Radio Observatory (OVRO) checked for these sources (if available)

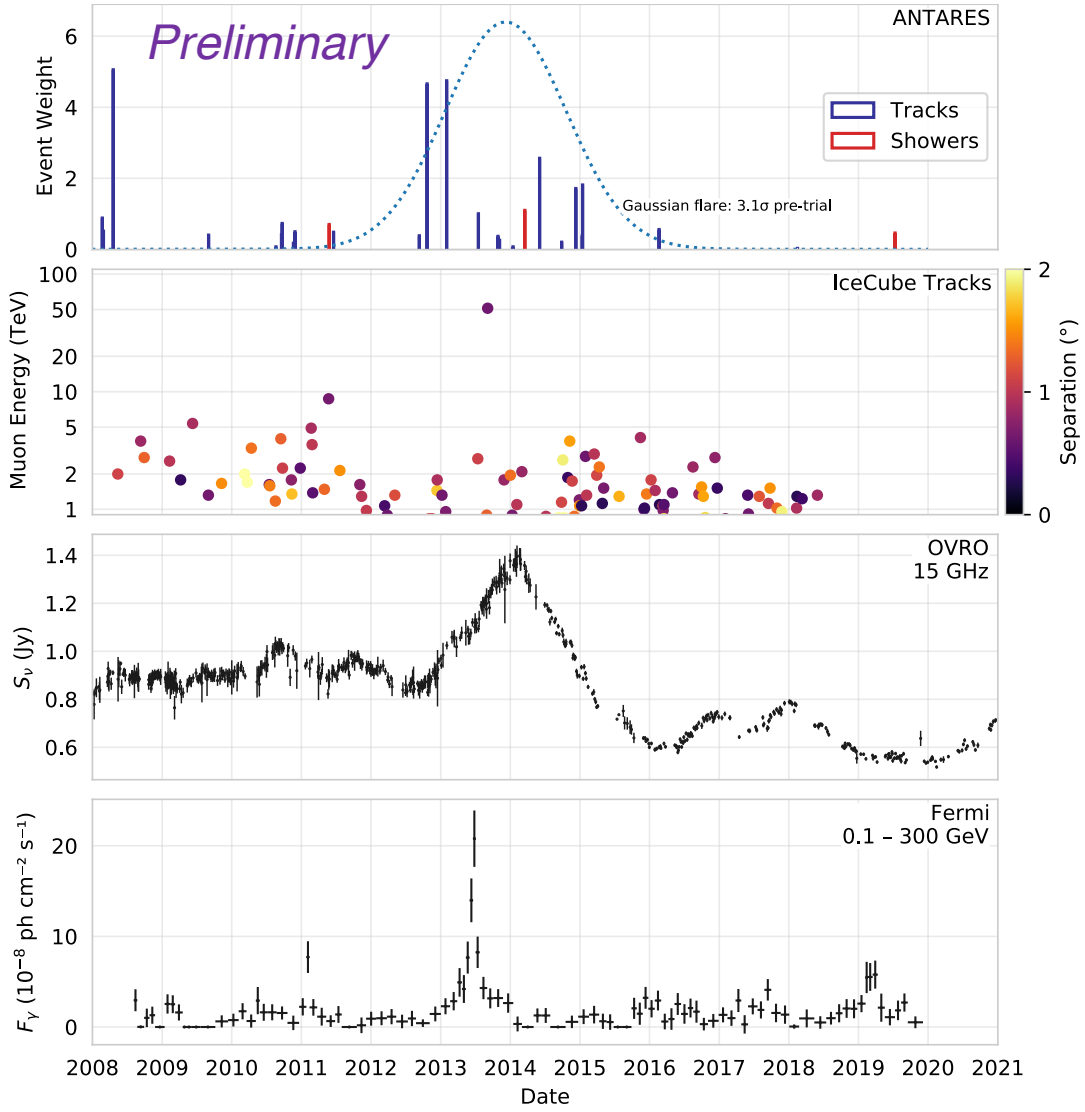
One notable case found: **J0242+1101(PKS 0239+108)**

J0242+1101(PKS 0239+108)

VLBI image at 15 GHz



Chance probability of the multi-messenger association under study



ANTARES best-fit flare for this source

IceCube tracks from 10-years point-source sample
- Tracks within 90% angular error from source
- angular error < 10deg^2

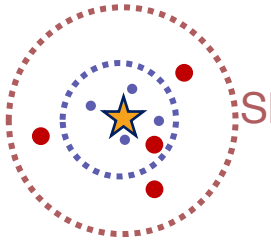
OVRO radio light-curve

Adaptive binned gamma-ray light-curve obtained from Fermi LAT data

Summary

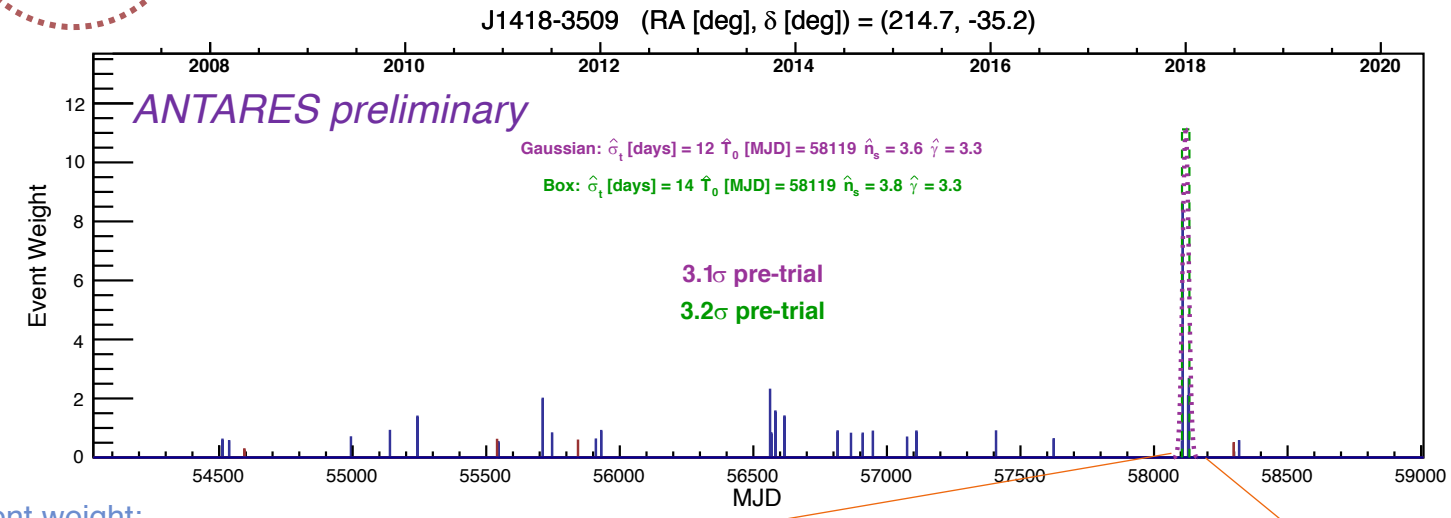
- A search for flaring neutrino emission from the direction of 2774 radio-selected blazars using 13 years of ANTARES data has been performed.
- Same radio catalog for which a promising directional correlation with IceCube events has been recently reported. A similar analysis by ANTARES presented in this Conference (see J. Aublin and A. Pavlin's talk, #1240).
- Most significant source: J1500-2358
  - Gaussian-flare: 3.3σ pre-trial → 56% post-trial
  - Box-flare: 3.4σ pre-trial → 40% post-trial
- Other 6 sources with >3σ pre-trial significance: J1517-4424, J1606+2717, J1418-3509, J0242+1101, J0732-0150, and J0641-3554
- Intriguing overlap in time of the flaring emission in radio, gamma-ray and neutrino for J0242+1101(PKS 0239+108) found. Further study to assess the chance probability of the association will follow.

Backup



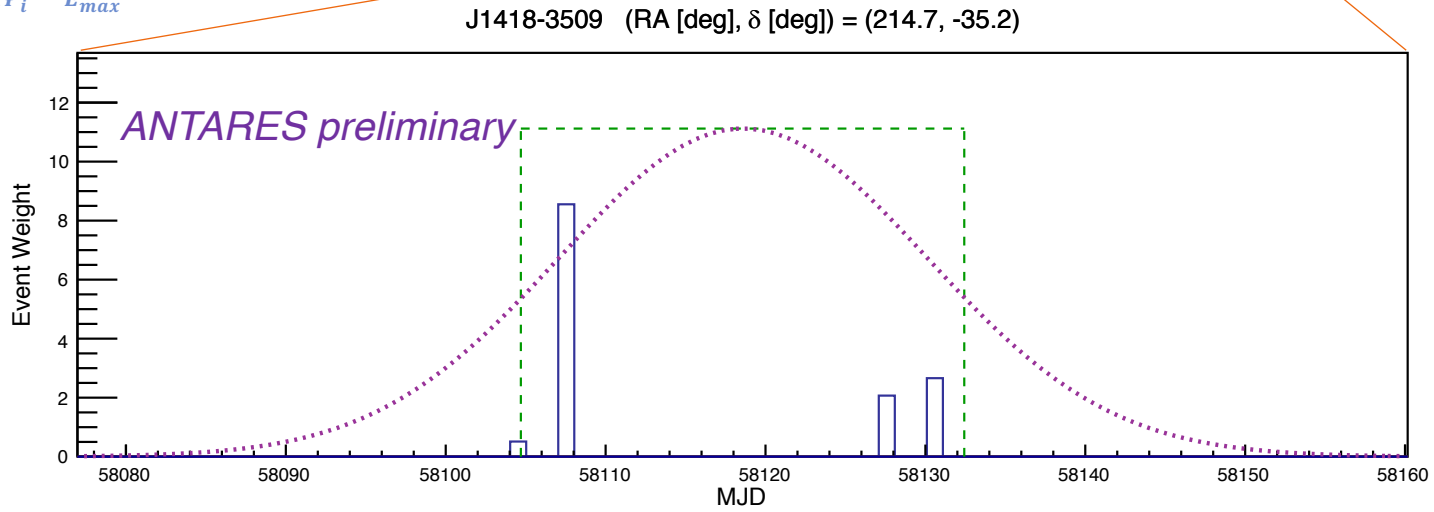
Tracks within 5°
Showers within 10°

J1418-3509

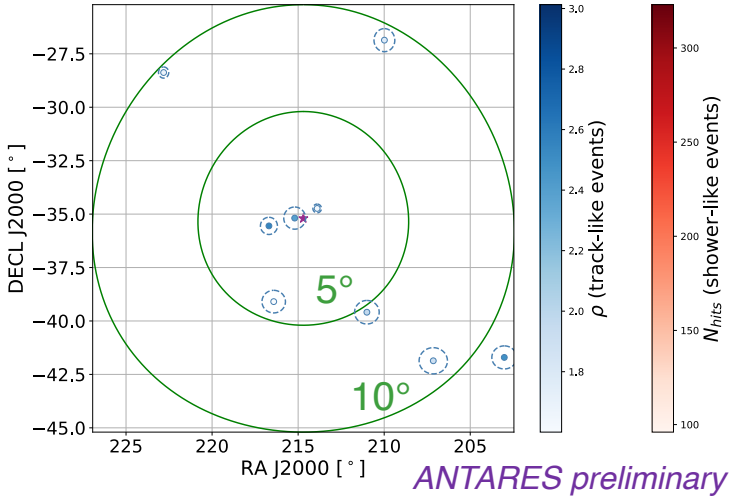


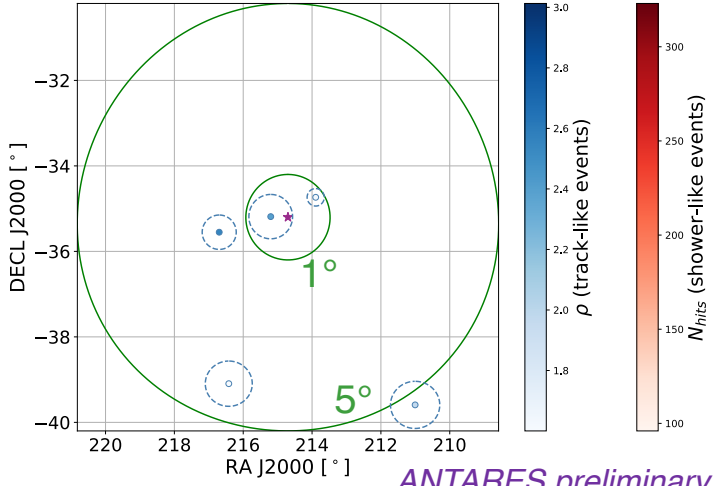
event weight:

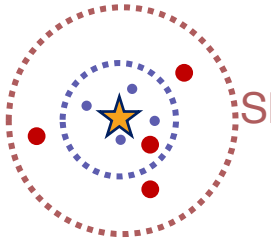
$$\frac{cone\ size}{\Delta\Psi_i}\,\frac{E_i}{E_{max}}$$



events within $3 \cdot \widehat{\sigma_t}^{Box}$



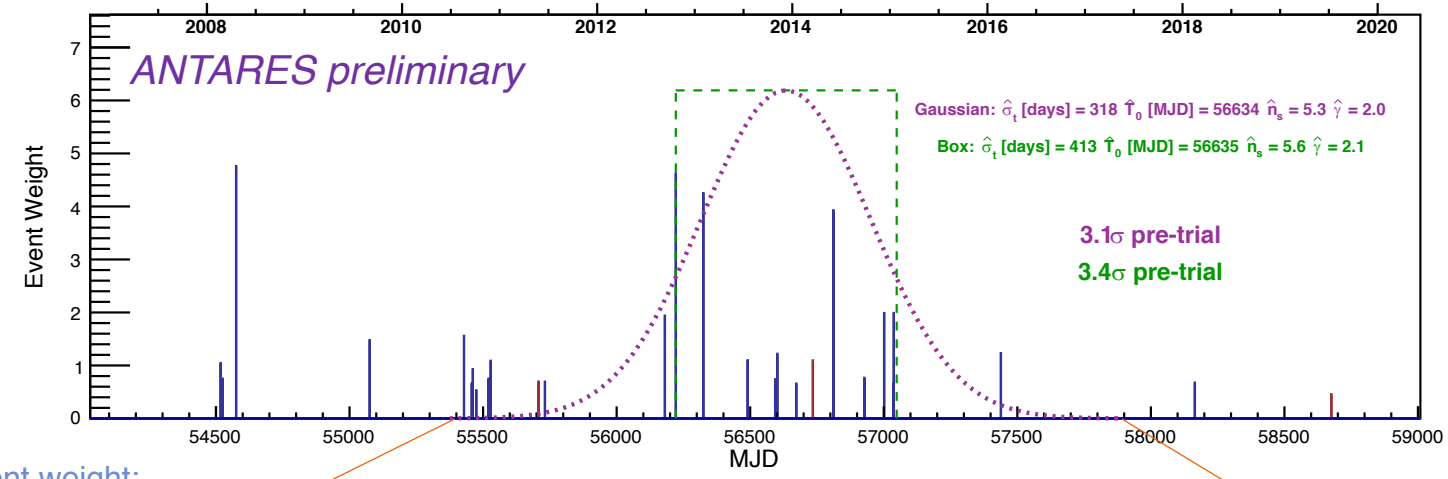




Tracks within 5°
Showers within 10°

J0242+1101

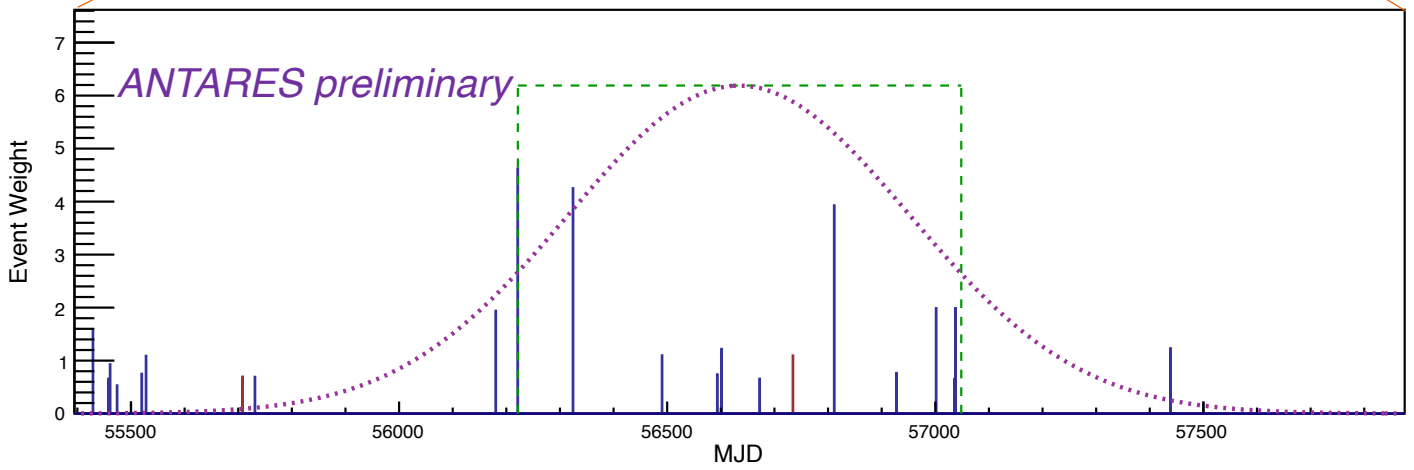
J0242+1101 (RA [deg], δ [deg]) = (40.6, 11.0)



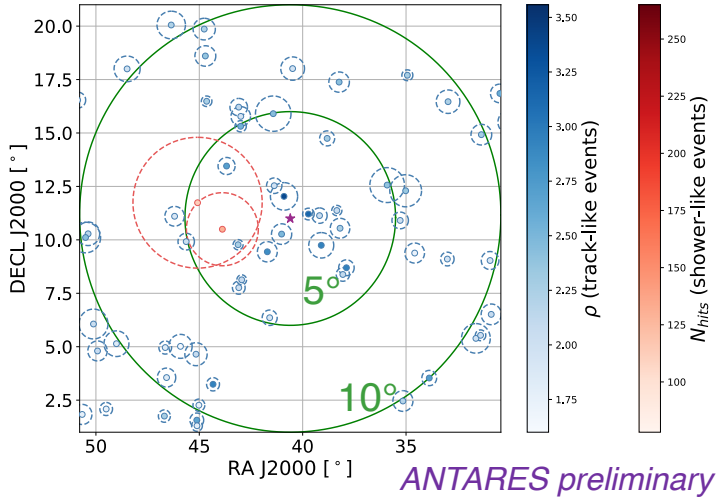
event weight:

$$\frac{cone\ size}{\Delta\Psi_i}\frac{E_i}{E_{max}}$$

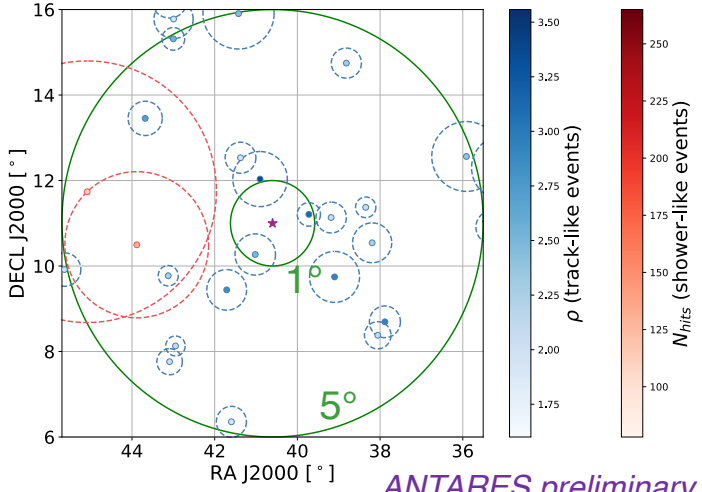
J0242+1101 (RA [deg], δ [deg]) = (40.6, 11.0)



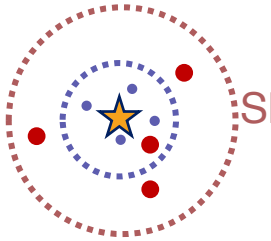
events within $3 \cdot \widehat{\sigma_t}^{Box}$



ANTARES preliminary



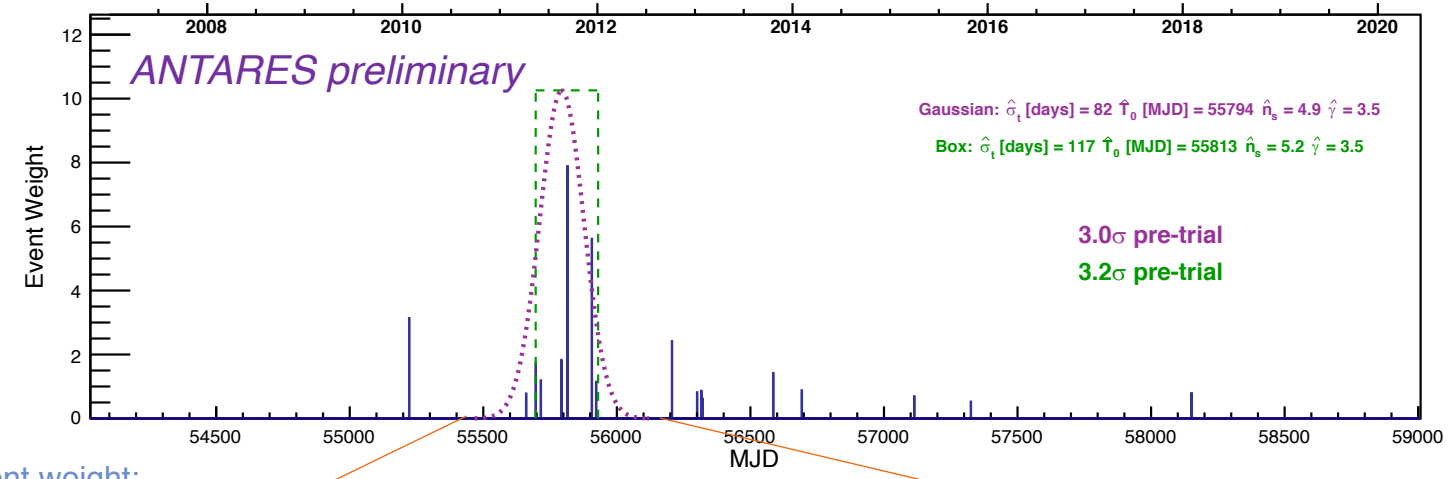
ANTARES preliminary



Tracks within 5°
Showers within 10°

J0732-0150

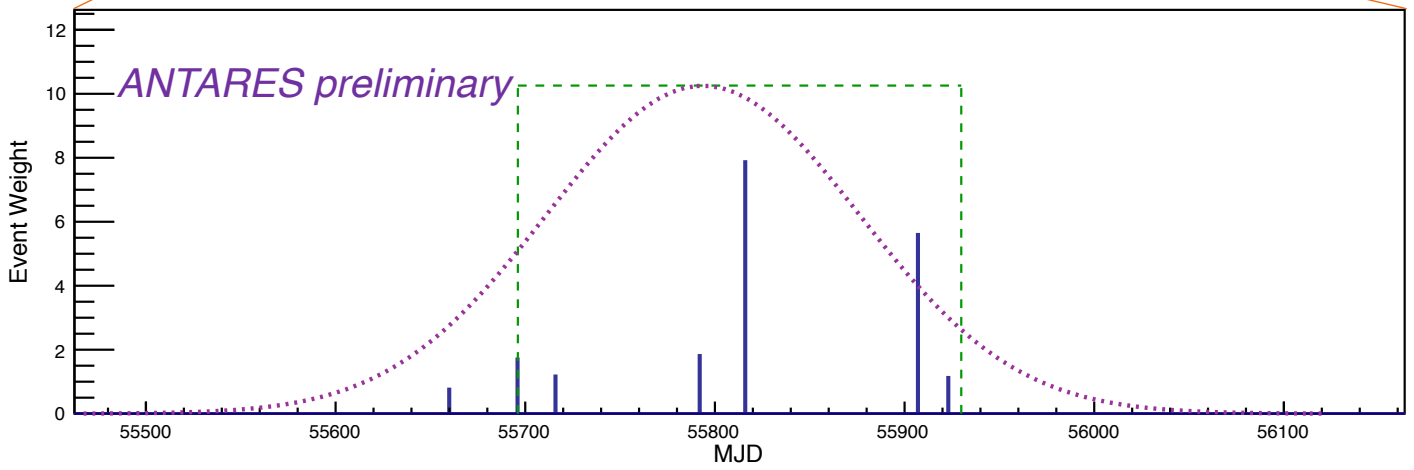
J0732+0150 (RA [deg], δ [deg]) = (113.1, 1.8)



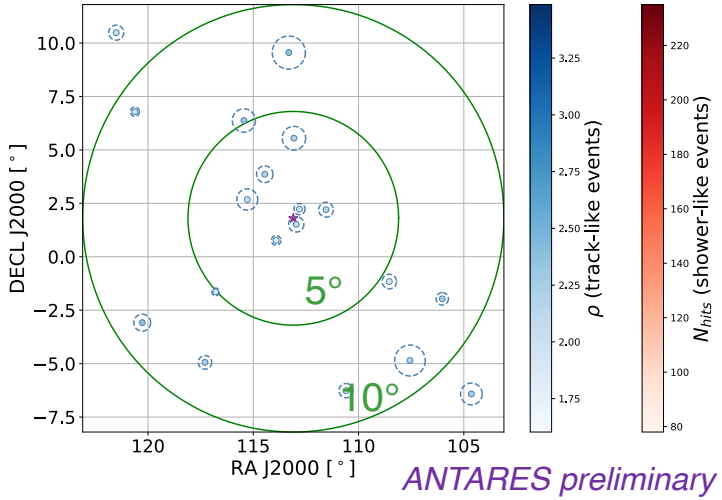
event weight:

$$\frac{cone\ size}{\Delta\Psi_i}\frac{E_i}{E_{max}}$$

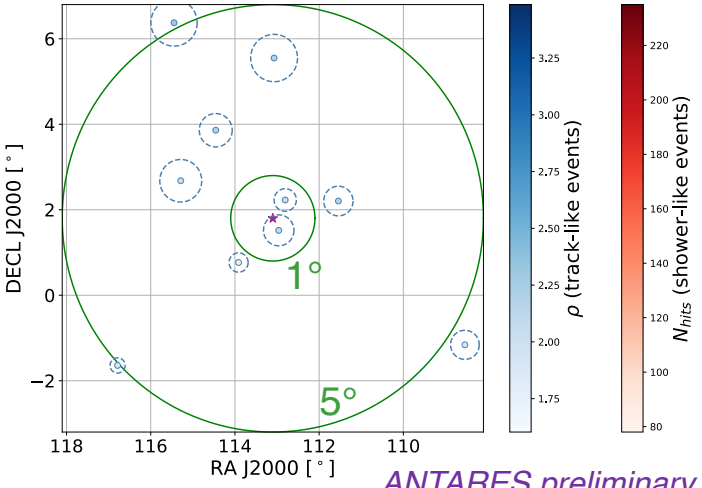
J0732+0150 (RA [deg], δ [deg]) = (113.1, 1.8)



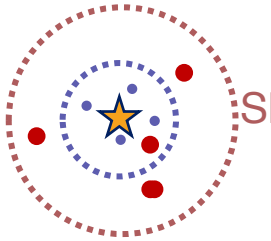
events within $3 \cdot \widehat{\sigma_t}^{Box}$



ANTARES preliminary

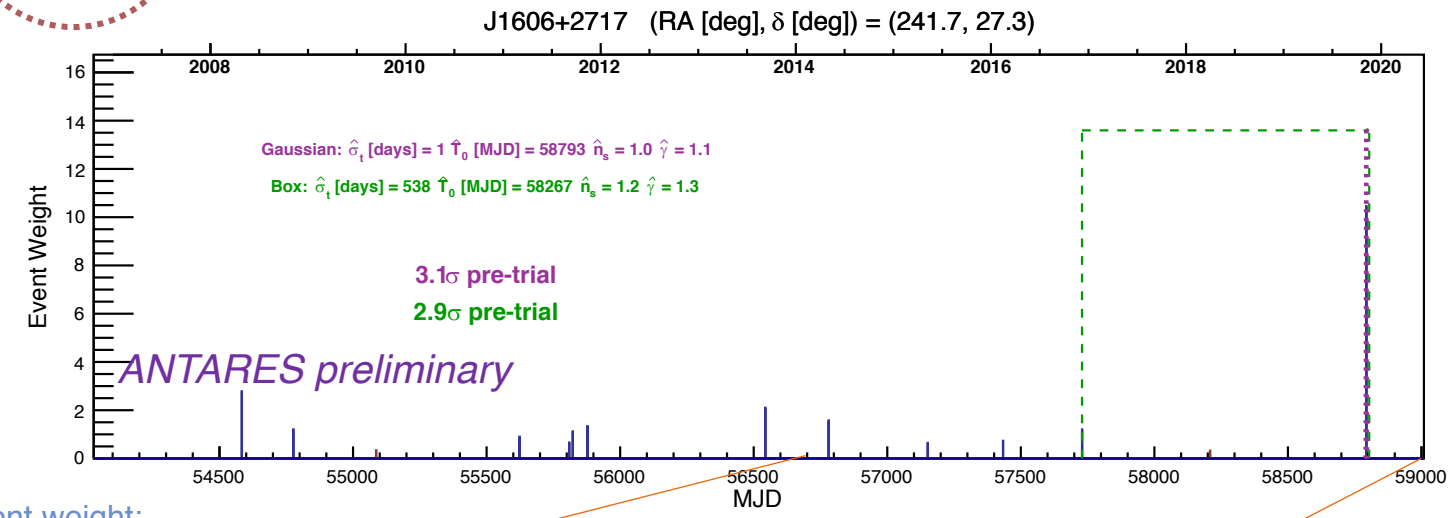


ANTARES preliminary



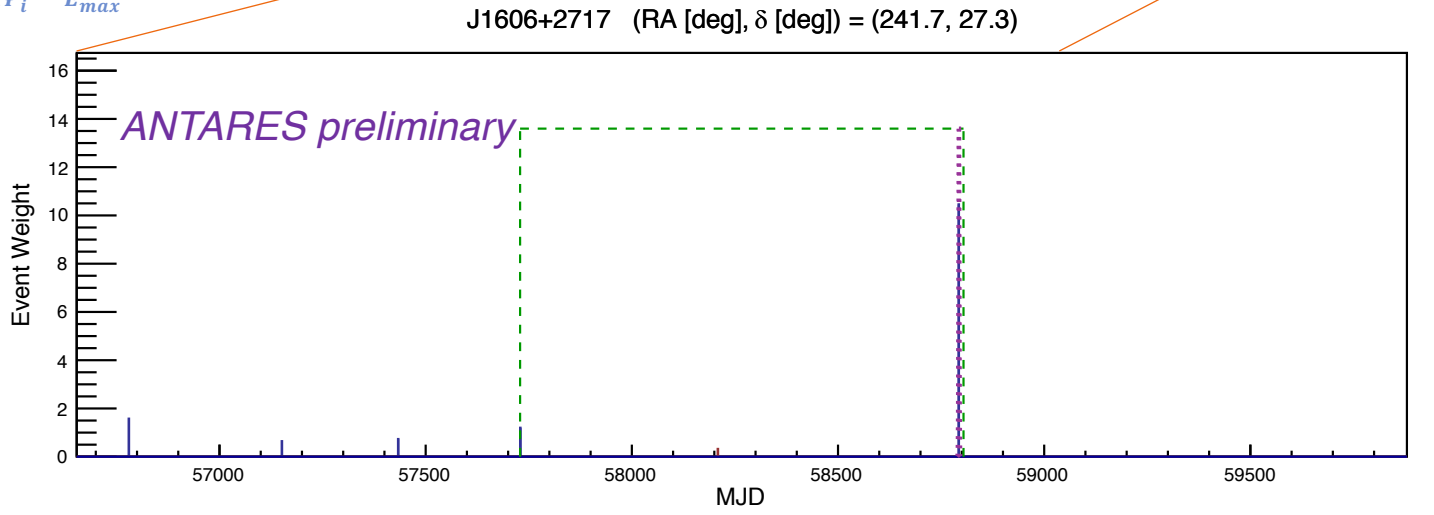
Tracks within 5°
Showers within 10°

J1606+2717

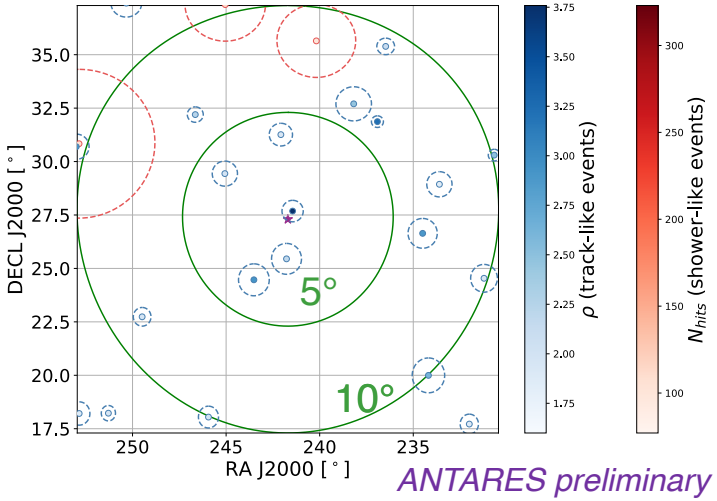


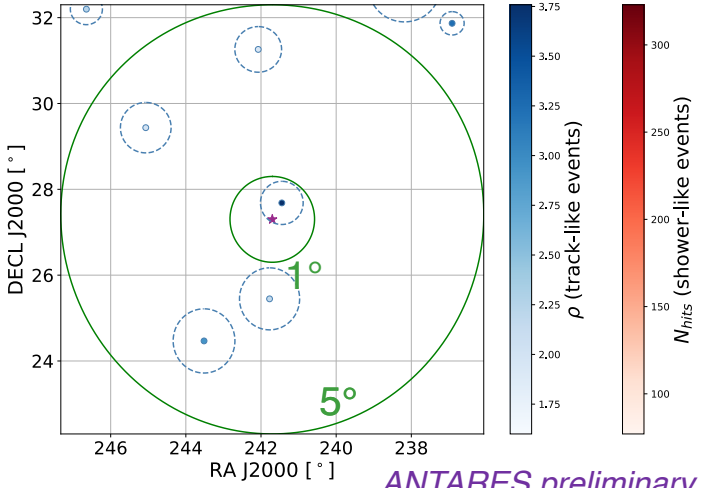
event weight:

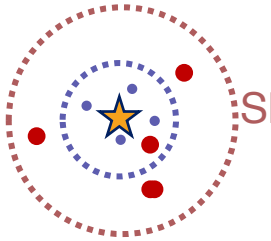
$$\frac{cone\ size}{\Delta\Psi_i}\frac{E_i}{E_{max}}$$



events within $3 \cdot \widehat{\sigma_t}^{Box}$

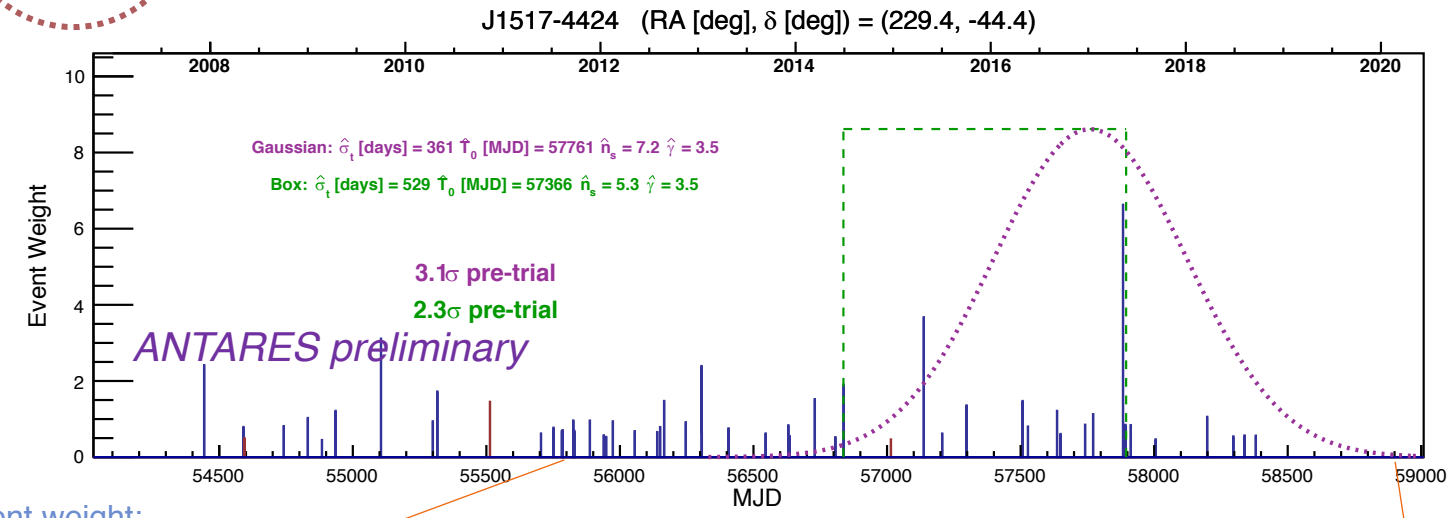




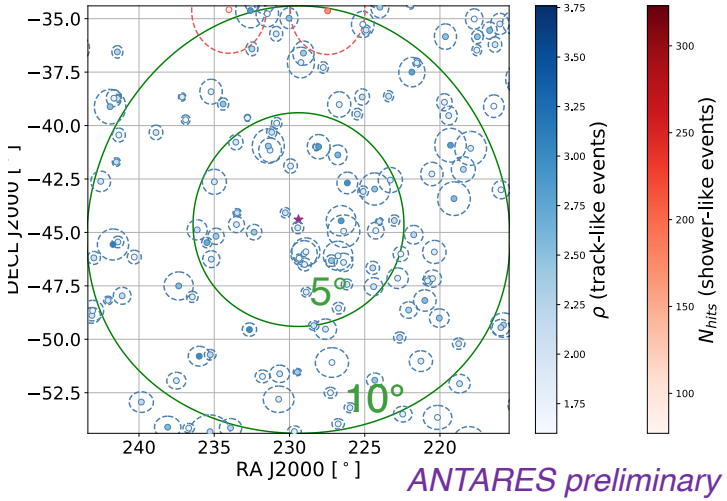


Tracks within 5°
Showers within 10°

J1517-4424

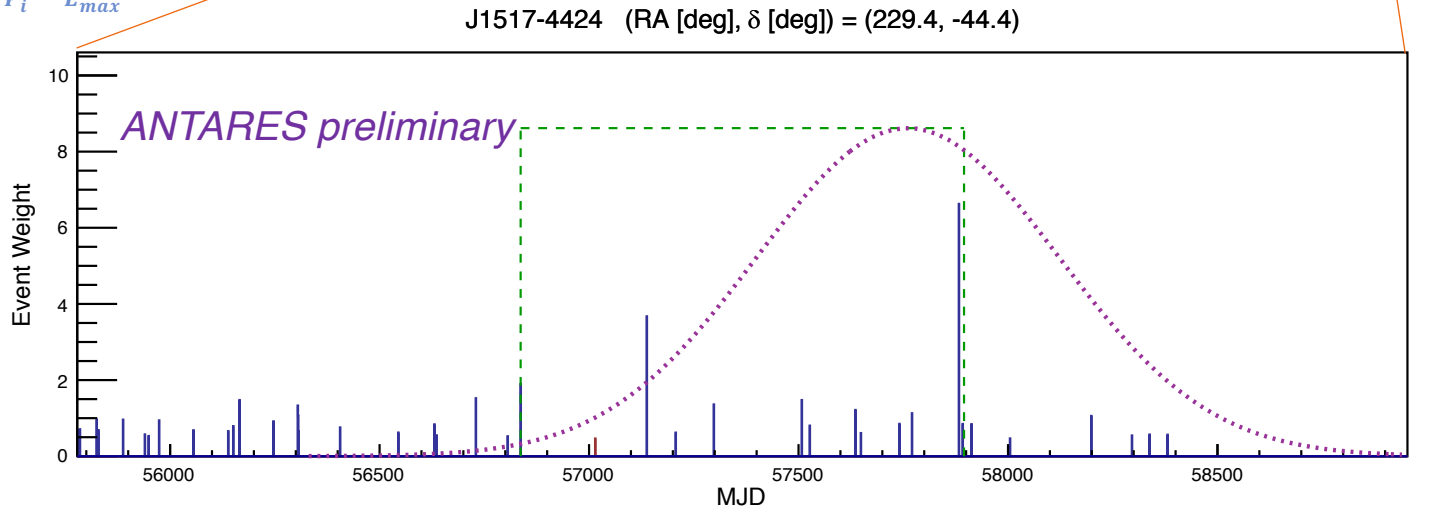


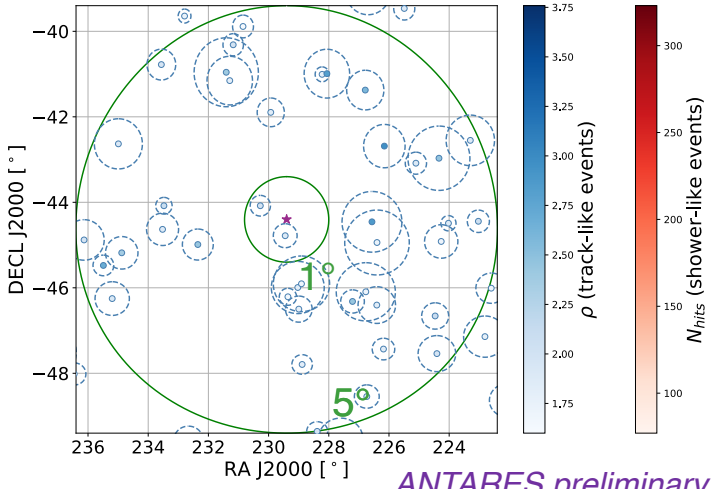
events within $3 \cdot \widehat{\sigma_t}^{Box}$

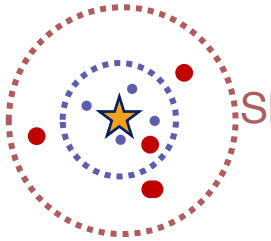


event weight:

$$\frac{cone\ size}{\Delta\Psi_i} \frac{E_i}{E_{max}}$$



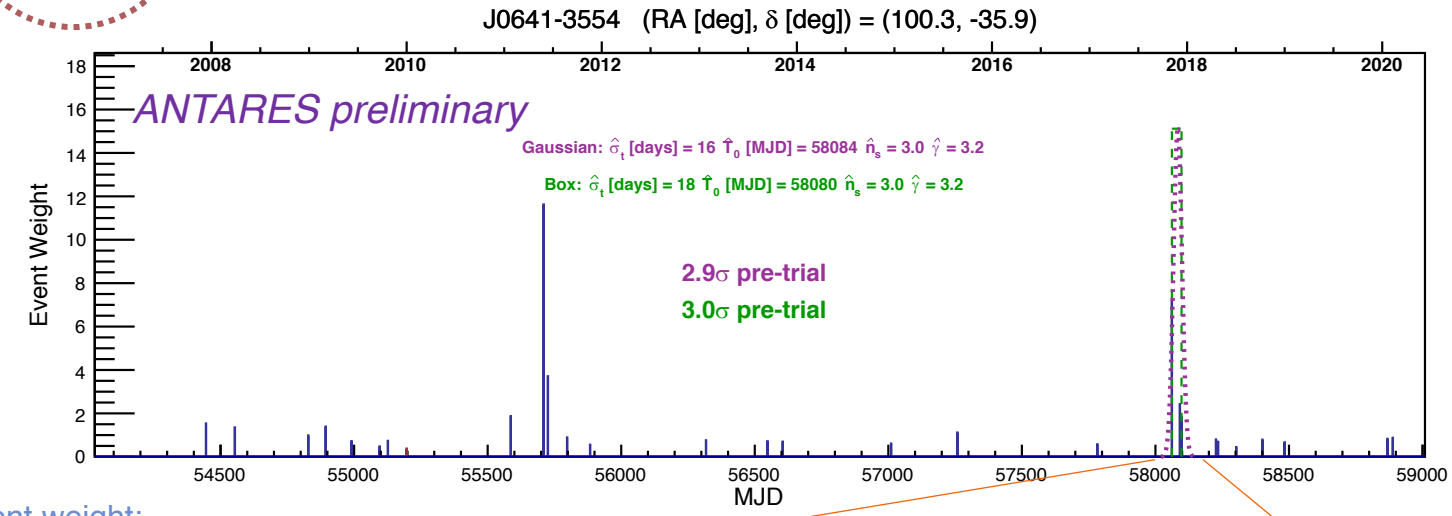


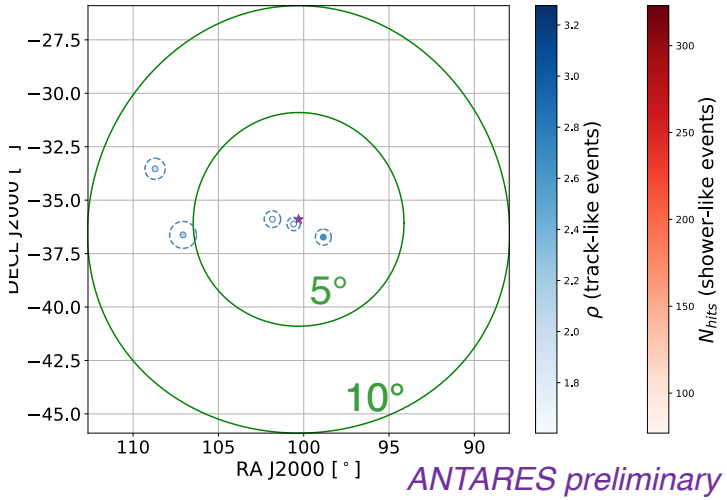


Tracks within 5°
Showers within 10°

J0641-3554

events within $3 \cdot \widehat{\sigma_t}^{Box}$

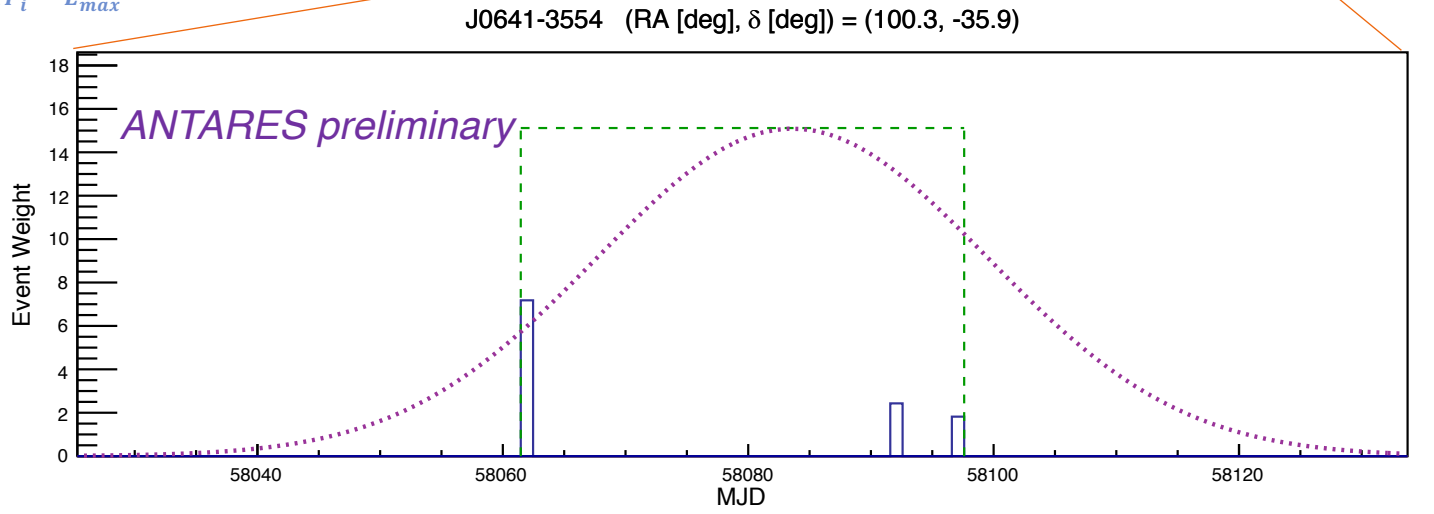


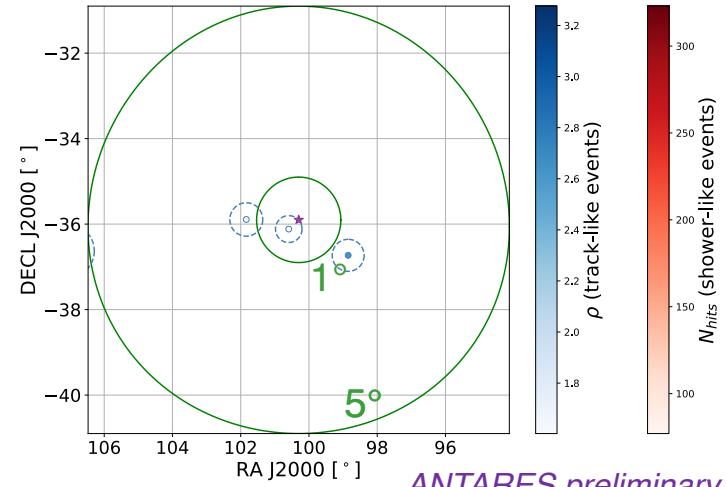


ANTARES preliminary

event weight:

$$\frac{cone\ size}{\Delta\Psi_i} \frac{E_i}{E_{max}}$$





ANTARES preliminary