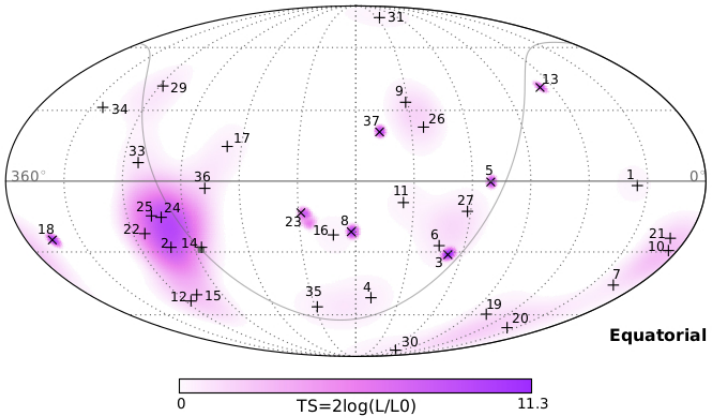
On the Detection Potential of Short Blazar Flares for Current Neutrino Telescopes

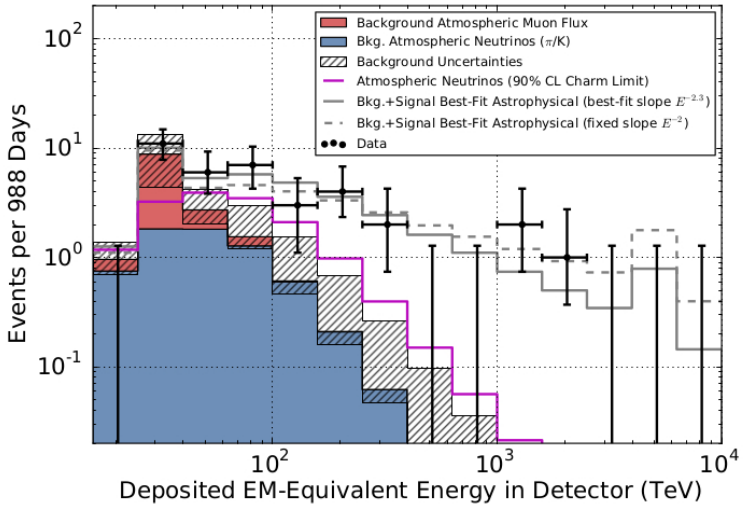
Michael Kreter, Matthias Kadler, Felicia Krauss,
Roopesh Ojha, Sara Buson
on behalf of the Fermi-LAT Collaboration,
Karl Mannheim, Joern Wilms

Half a Century of Blazars and Beyond
June 14th, 2018

Fermi
Gamma-ray
Space Telescope

Evidence for an extraterrestrial high-energy neutrino signal





Credit: IceCube Collaboration 2014, **Physical Review Letters** 113, 101101

- Also for Muon Neutrinos from the Northern Sky

  (IceCube Collaboration 2015, **Physical Review Letters** 115, 8)

- But: No clear source identification possible

Blazars as promising neutrino sources

Neutrino output of blazars estimated based on

- Mannheim 1993, **A&A** 269, 67–76
- Mannheim 1995, **Astroparticle Physics**, 3, 295

$$p + nucleus \rightarrow \pi + X \quad (\pi = \pi^{\pm}, \pi^0)$$

$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} \pi^0 + p \\ \pi^+ + n. \end{cases}$$

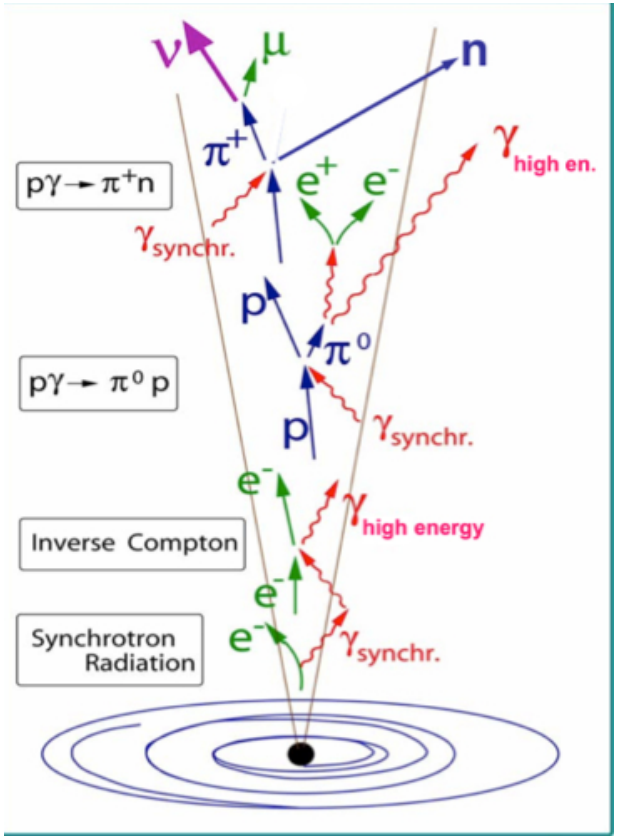
Resulting pions decay:

$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} \text{ (or } \bar{\nu_{\mu}})$$

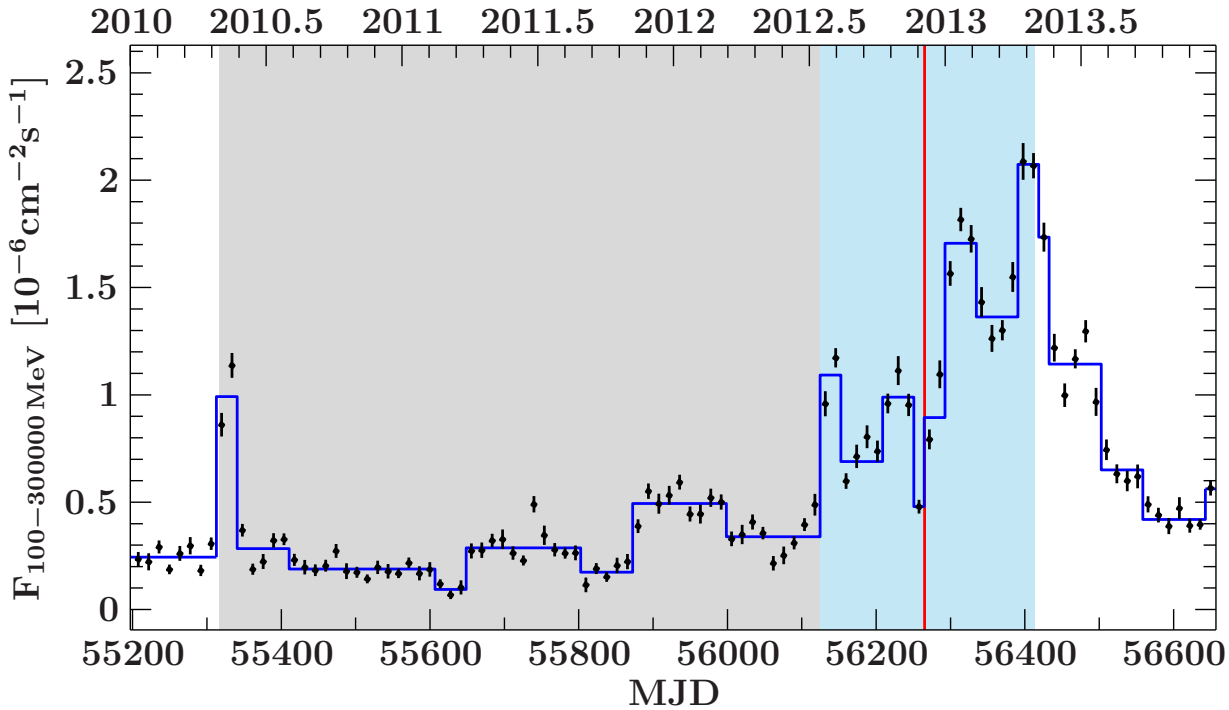
$$\mu^+ \rightarrow e^+ + \bar{\nu_{\mu}} + \nu_e$$

$$\mu^- \rightarrow e^- + \nu_{\mu} + \bar{\nu_e}$$



Credit: Katz & Spiering 2012, **Progress in Particle and Nuclear Physics**, 67, 651

Coincidence of a high-fluence blazar outburst with a PeV neutrino event

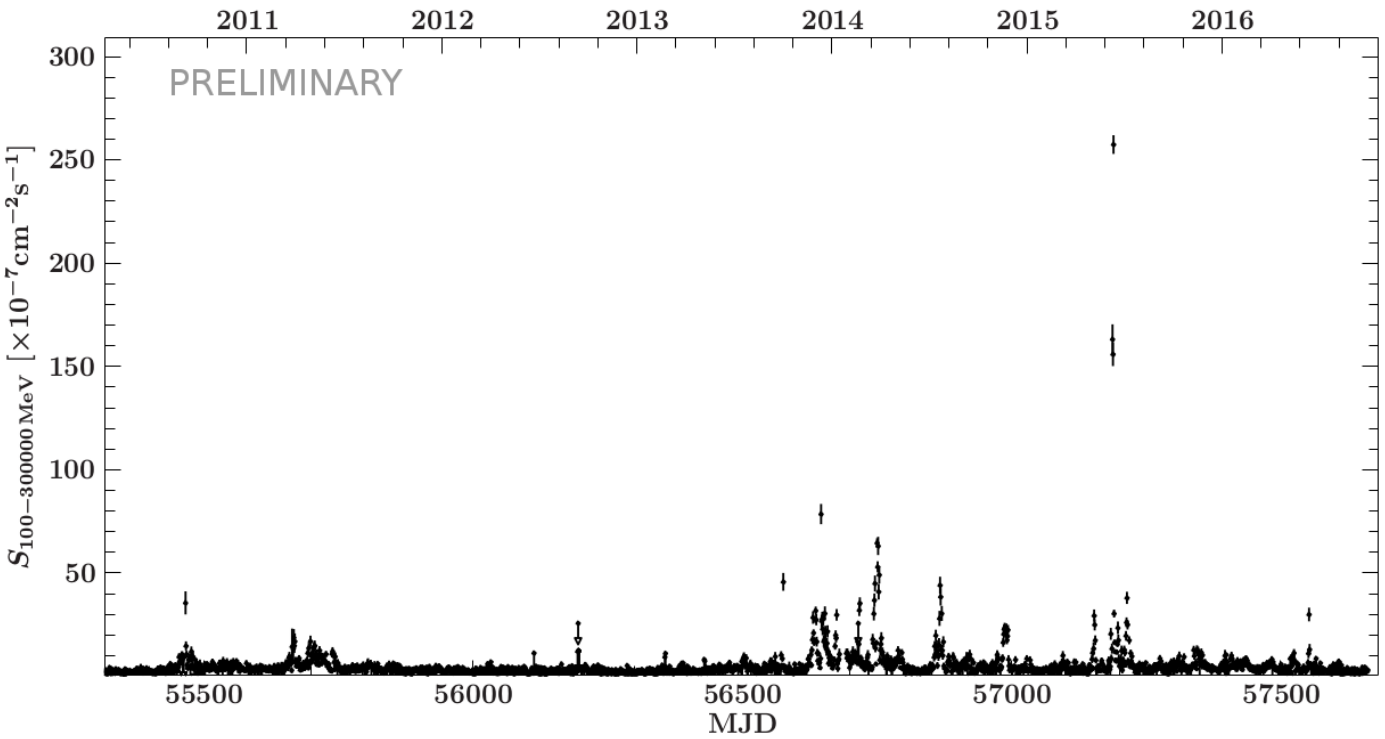


Credit: Kadler et al. 2016, **Nat Phys** 12, 807

$\Rightarrow$ Calorimetric Output in BigBird field dominated by PKS B1424-418

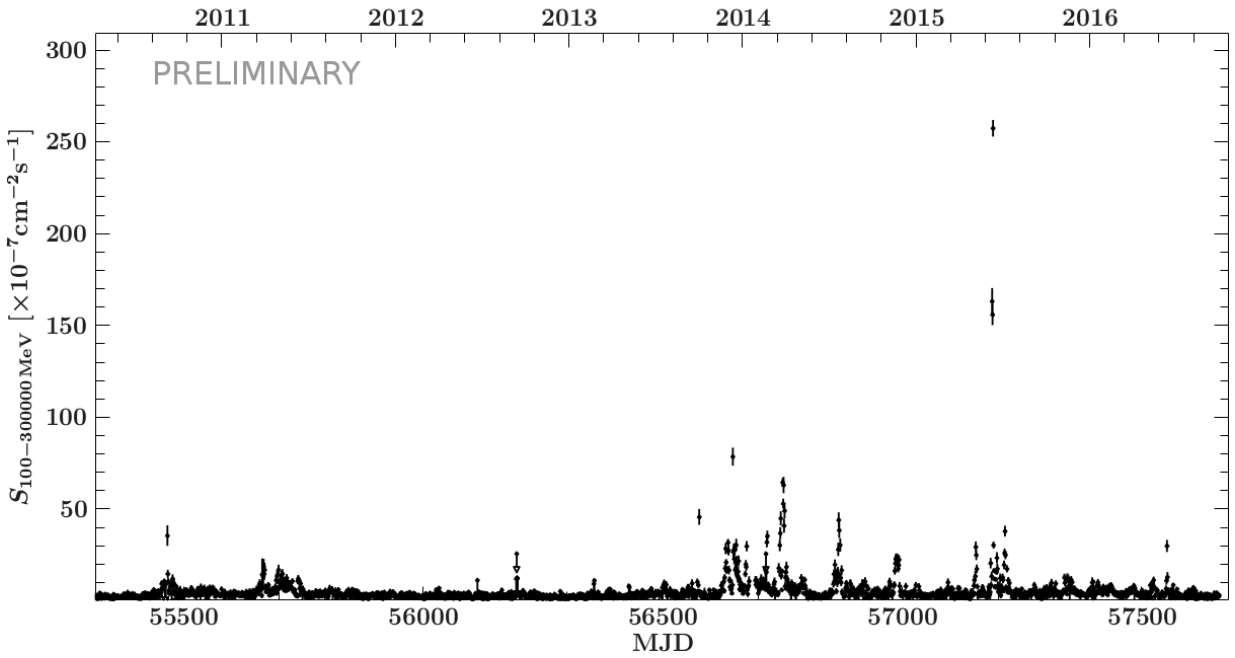
$\Rightarrow$ But: Chance Coincidence $\approx 5\%$

Blazars are rapidly variable sources



- Blazars show bright flares on timescales of minutes to months

$\Rightarrow$ But: How to define a flare?



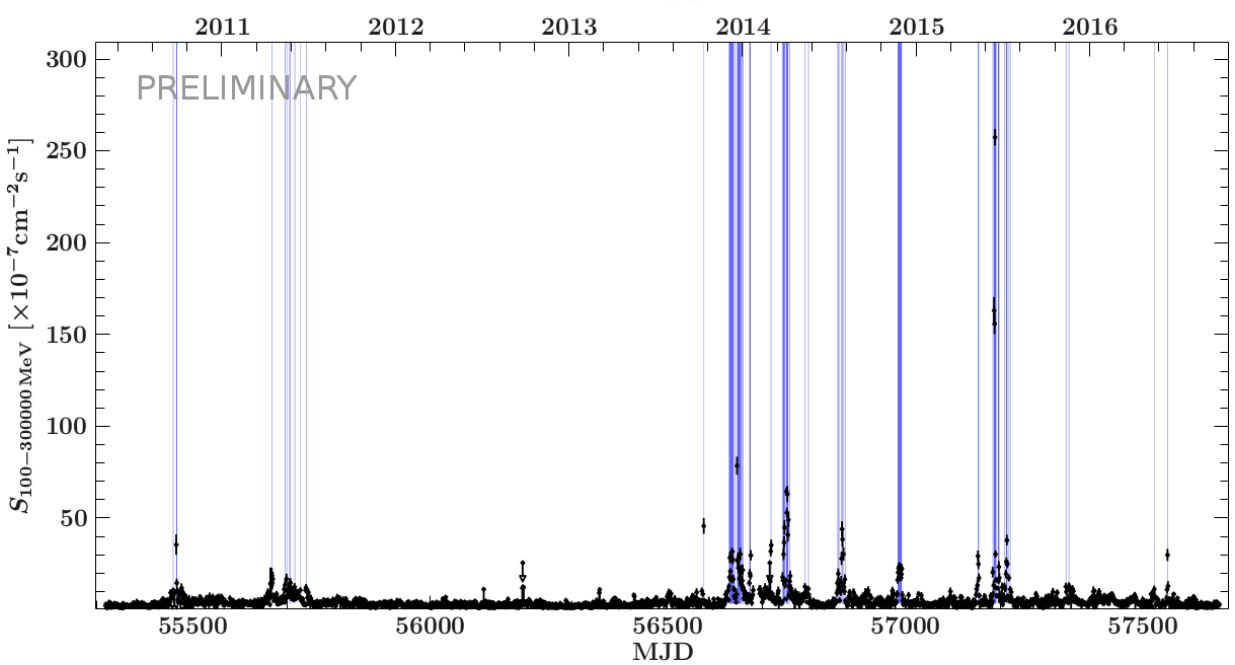
Define:

$$\sigma_i = (\text{Flux} - 3 \times \text{Flux err}) \times A_{\text{eff}} - G$$

Select continuous time ranges i that fulfill:

$$\sigma_i \geq 3 \times \sigma$$

- G: Flux Ground Level
- σ: Intrinsic source variation
- A_{eff}: IceCube effective area



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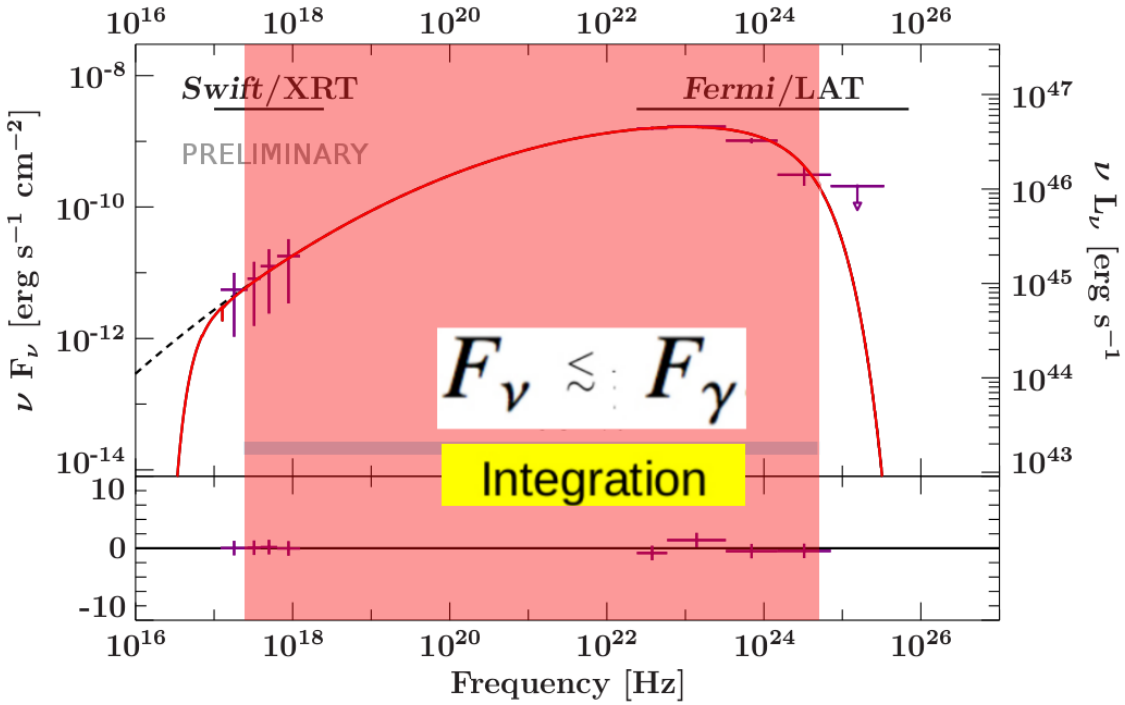
Estimate maximum neutrino output

Pion Photoproduction:

Maximum Neutrino Output:

$$F_\gamma = F_\nu$$



$$N^{max}_{\nu,PeV} = A_{eff,e_\nu} \times \left(\frac{F_\gamma}{E_\nu}\right) \times \Delta t$$

Flare sample

Source	Flare Number	Duration in Days	N_ν^{max}	$N_\nu^{pred} \times 10^{-2}$
3C 279	1	6	0.797	1.99
PKS 1510-089	2	5	0.306	0.764
PKS 1510-089	3	11	0.586	1.46
PKS 1510-089	4	1	0.0405	0.101
3C 279	5	1	0.0272	0.0681
3C 279	6	5	0.214	0.535
PKS 1510-089	7	10	0.393	0.982
3C 279	8	2	0.0993	0.248
PKS 1510-089	9	4	0.159	0.398
PKS 1510-089	10	2	0.0605	0.151
3C 454.3	38	240	11.71	29.28

- Detection probability of short flares $\sim$ days is small
- Reasonable association only for very bright short flares or long outbursts

TXS 0506+056

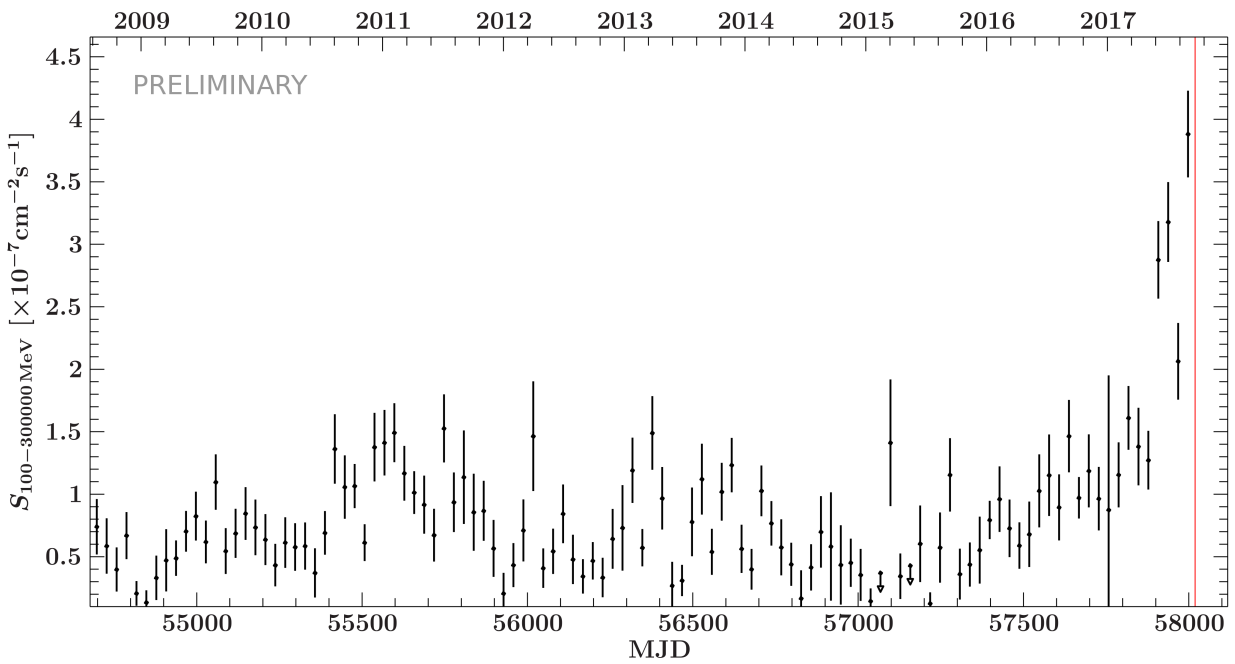
Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; ***Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration***
on ***28 Sep 2017; 10:10 UT***
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

- First track-like IceCube EHE event consistent with a flaring LAT source
- What is the expected neutrino output?

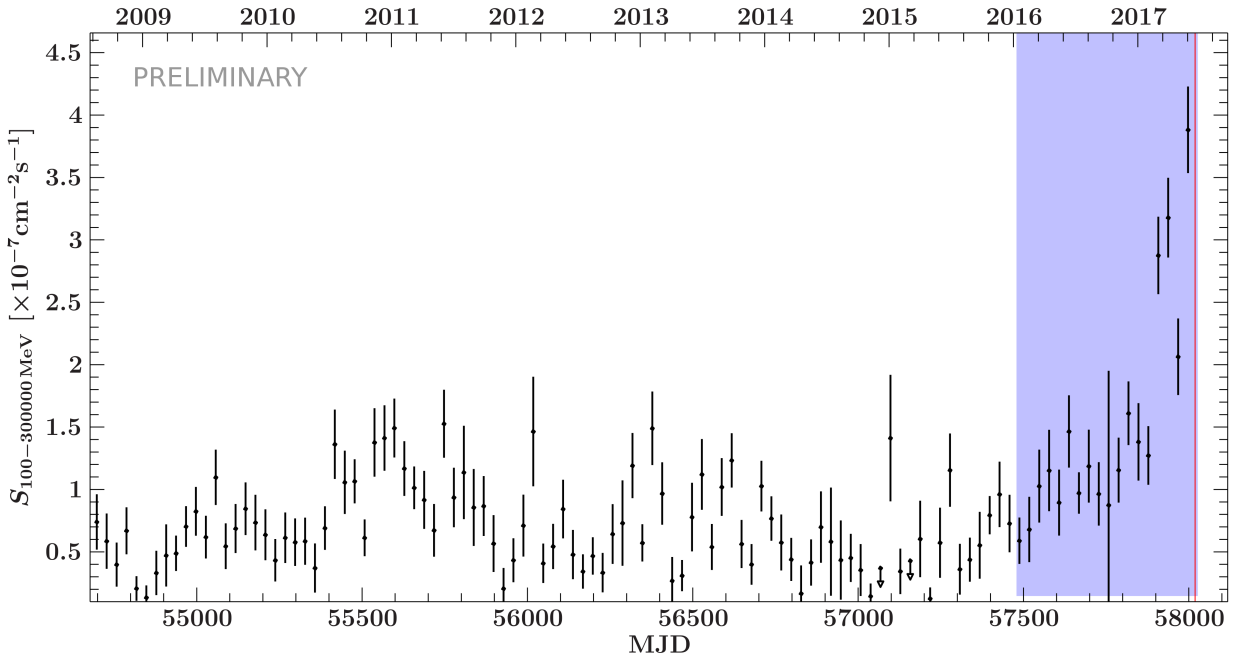
γ-ray light curve of TXS 0506+056



- Outburst already going on since early 2016

$\Rightarrow$ No short-flare period identified, according to our criteria

γ-ray light curve of TXS 0506+056

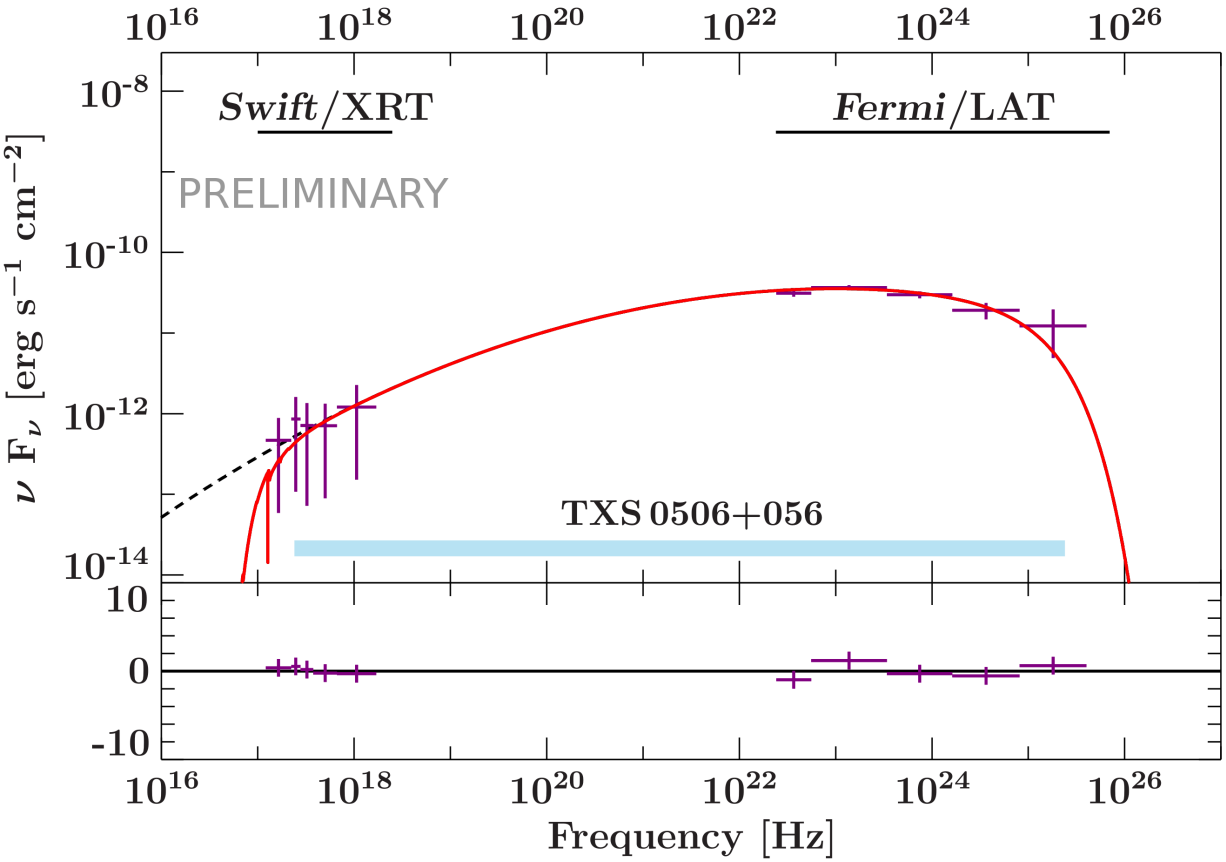


- Outburst already going on since early 2016

$\Rightarrow$ No short-flare period identified, according to our criteria

$\Rightarrow$ Calculate neutrino expectation for long-term outburst

Long-term outburst SED of TXS 0506+056



- select time range from early 2016 through Sep 2017
- $N_\nu^{\text{pred}} \approx 0.02$

$\Rightarrow$ Long-term association is plausible

Summary

- Short blazar flares yield only a small neutrino detection probability
- Long-term outbursts are required to provide enough fluence
- Association of EHE neutrino with TXS 0506+056 is calorimetrically plausible

Backup

Estimate maximum neutrino output

Scaling Factor:

$$N^{pred}_{\nu,PeV} = f \times N^{max}_{\nu,PeV}$$
$$f = 0.5 \times 0.05 \approx 0.025 \quad (1)$$

Things to consider:

- Different neutrino flavors
- UV seed photons needed (FSRQs)
- PeV peaks might be smeared out to $\approx (0.03 - 10)$ PeV

$\Rightarrow$ See Kadler et al. 2016 for details

Light curve ground level calculation