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

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Blazars as promising neutrino sources

Neutrino output of blazars estimated based on

- Mannheim 1995, Astroparticle Physics, 3, 295

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

\[ p + \gamma \rightarrow \Delta^+ \rightarrow \left\{ \begin{array}{c} \pi^0 + p \\ \pi^+ + n. \end{array} \right. \]

Resulting pions decay:

\[ \pi^0 \rightarrow \gamma + \gamma \]
\[ \pi^\pm \rightarrow \mu^\pm + \nu_\mu \quad (\text{or } \bar{\nu}_\mu) \]
\[ \mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e \]
\[ \mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e \]
Conidence of a high-fluence blazar outburst with a PeV neutrino event

Kadler et al. 2016, Nat Phys 12, 807

⇒ Calorimetric Output in BigBird field dominated by PKS B1424-418
⇒ But: Chance Coincidence ≈ 5%
Test neutrino detection potential for short blazar flares

Choose sources that:

- are highly variable
- show extreme bright short flares
Choose flares that fulfill:

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

$$\sigma_{\text{indi}} \geq 3 \times \sigma$$

- $G$: Flux Ground Level
- $\sigma_{\text{indi}}$: individual flux variation of each bin
- $\sigma$: Intrinsic source variation
- $A_{\text{eff}}$: Effective area
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- $\sigma$: Intrinsic source variation
- $A_{\text{eff}}$: Effective area
Which flares to select?

• Start from Fermi’s public bright-blazar list
• Identify flares according to flare selection method
• Run daily 6 year (Pass 8) light curves on sources responsible for 100 brightest short flares
• Re-run flare selection method on Pass 8 light curves

⇒ Select the best 50 flares according to their fluence
⇒ Calculate a neutrino expectation for all 50 flares
**ESTIMATE MAXIMUM NEUTRINO OUTPUT**

**Pion Photoproduction:**

Maximum Neutrino Output:

\[ F_\gamma = \frac{1}{3} F_\pi + \frac{1}{4} \cdot \frac{2}{3} F_\pi = \frac{1}{2} F_\pi \]

\[ F_\nu = \frac{2}{3} \cdot \frac{3}{4} F_\pi = \frac{1}{2} F_\pi \]

- Kadler et al. 2016, Nat Phys 12, 807

Credit: Mücke et al. 2000

\[ N_{\nu, \text{PeV}}^{\text{max}} = A_{\text{eff}, e\nu} \times \left( \frac{F_\gamma}{E_\nu} \right) \times \Delta t \]
**Estimate maximum neutrino output**

Scaling Factor:

\[ N_{\nu, \text{PeV}}^{\text{pred}} = f \times N_{\nu, \text{PeV}}^{\text{max}} \]

\[ f = 0.5 \times 0.05 \approx 0.025 \quad (1) \]

Things to consider:

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

\( \Rightarrow \) See Kadler et al. 2016 for details

Suggestion of promising neutrino candidate
On the Detection Potential of Short Blazar Flares

Motivation

Method

Flare sample

Summary

- Suggestion of promising neutrino candidate
- Identify flare duration of 6 days
3C279

- Time resolved SED of 2015 flare
- Simultaneous Swift/XRT and Fermi/LAT observations
3C279

- $N_{\nu,\text{PeV}}^{\text{pred}} \approx 0.02$
- $\approx 5$ months of non flaring activity
**Flare Sample**

Table 1. Neutrino expectation for the 50 best ranked flares, sorted by the normalized fluence.

<table>
<thead>
<tr>
<th>Source</th>
<th>Flare Number</th>
<th>Normalized Fluence</th>
<th>( t_{\text{min}} ) in MJD</th>
<th>( t_{\text{max}} ) in MJD</th>
<th>( N_{\nu}^{\text{max}} )</th>
<th>( N_{\nu}^{\text{pred}} \times 10^{-2} )</th>
<th>Duration in Days</th>
<th>Normalized ( N_{\nu}^{\text{pred}} \times 10^{-3} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C 279</td>
<td>1</td>
<td>260238</td>
<td>57186</td>
<td>57192</td>
<td>0.797</td>
<td>1.99</td>
<td>6</td>
<td>3.32</td>
</tr>
<tr>
<td>PKS 1510-089</td>
<td>2</td>
<td>192902</td>
<td>55849</td>
<td>55854</td>
<td>0.306</td>
<td>0.764</td>
<td>5</td>
<td>1.53</td>
</tr>
<tr>
<td>PKS 1510-089</td>
<td>3</td>
<td>151569</td>
<td>55866</td>
<td>55877</td>
<td>0.586</td>
<td>1.46</td>
<td>11</td>
<td>1.33</td>
</tr>
<tr>
<td>PKS 1510-089</td>
<td>4</td>
<td>151262</td>
<td>55856</td>
<td>55857</td>
<td>0.0405</td>
<td>0.101</td>
<td>1</td>
<td>1.01</td>
</tr>
<tr>
<td>3C 279</td>
<td>5</td>
<td>138636</td>
<td>56717</td>
<td>56718</td>
<td>0.0272</td>
<td>0.0681</td>
<td>1</td>
<td>0.681</td>
</tr>
<tr>
<td>3C 279</td>
<td>6</td>
<td>128078</td>
<td>56749</td>
<td>56754</td>
<td>0.214</td>
<td>0.535</td>
<td>5</td>
<td>1.07</td>
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<td>PKS 1510-089</td>
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<td>125857</td>
<td>57241</td>
<td>57251</td>
<td>0.393</td>
<td>0.982</td>
<td>10</td>
<td>0.982</td>
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<tr>
<td>3C 279</td>
<td>8</td>
<td>119379</td>
<td>56866</td>
<td>56868</td>
<td>0.0993</td>
<td>0.248</td>
<td>2</td>
<td>1.24</td>
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<tr>
<td>PKS 1510-089</td>
<td>9</td>
<td>119033</td>
<td>56553</td>
<td>56557</td>
<td>0.159</td>
<td>0.398</td>
<td>4</td>
<td>0.995</td>
</tr>
<tr>
<td>PKS 1510-089</td>
<td>10</td>
<td>116956</td>
<td>55766</td>
<td>55768</td>
<td>0.0605</td>
<td>0.151</td>
<td>2</td>
<td>0.757</td>
</tr>
</tbody>
</table>

- 50 best flares are generated by a group of only seven different sources:
  3C 279, PKS 1510-089, PKS 0402-362, CTA 102, 3C 454.3, PKS 1424-418, PKS 1329-049
- 3C 279 and PKS 1510-089 responsible for 42 flares
Detection probability shows saturating tendency

⇒ Extending the sample size does not substantially increase the detection probability

⇒ Highest fluence flares provide by far the largest contribution
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

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Subjects: Gamma Ray, Neutrinos, AGN

Referred to by ATel #: 10792, 10794, 10799, 10801, 10817, 10830, 10831

- First track like IceCube EHE event consistent with a LAT source
Summary

• Short blazar flares yield only a small neutrino detection probability
• No substantial improvement by adding more (fainter) flares
• Top-ranked flares produced by only a handful of individual blazars
Backup
On the Detection Potential of Short Blazar Flares

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Summary

Light curve ground level calculation

![Graph showing light curve ground level calculation](image)
Light curve of 3C 279
Light curve of 3C 454.3

Motivation

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Light curve of PKS 1510-089

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Light curve of CTA 102
Light curve of PKS 0402-362
Light curve of PKS 1329-049
Light curve of PKS 1424-41