# Correlation between γ-rays and PeV Neutrinos in Blazar PKS B1424-418 ?

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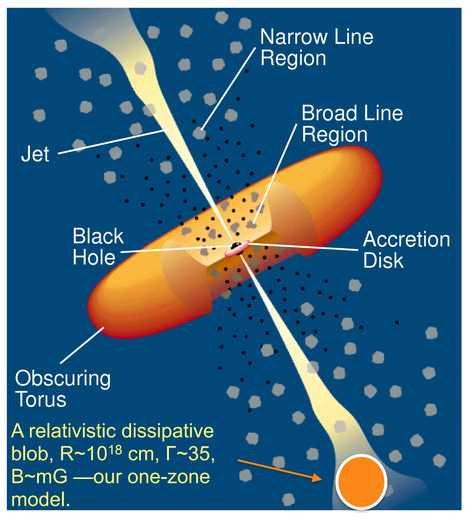
## Abstract

A potential correlation between an IceCube PeV-neutrino event and the gamma-ray burst phase of the flat spectrum radio quasar PKS B1424-418 was recently suggested. In this study, we simulate both the multi-wavelength photon and the neutrino emission from this source using a self-consistent radiation model. Using analytical arguments and numerical studies of the large parameter space we find that a simple hadronic model cannot adequately describe the spectral energy distribution for this source, but a lepto-hadronic model with sub-dominant hadronic component can reproduce the multi-waveband photon spectrum observed during various activity phases of the blazar. Up to about 0.4 neutrino events may coincide with the outburst, and tension with spectral energy distribution arises for larger neutrino event rates. We point out that simply assuming a direct relation between the neutrino fluence and the γ-ray fluence in a certain waveband ignores the leptonic contribution in that energy band which may in fact dominate the emission.

## Motivations




### Why blazars

- Contribute to the most of extra-glactic background γ-rays which may be neutrino counter-parts
- Relativistic Beaming: boosts luminosity & point-source identification possible

### Why PKS B1424-418 (by Kadler *et al*. 2016)

- Sufficient energy budget for a PeV ν event, if $L_\nu \sim L_\gamma$
- Spatial and temporal consistency with IC35 (2-PeV ν event)

### Why this work

- Needs a self-consistent model for this source
- The assumption $L_\nu \sim L_\gamma$ must be critically reviewed
- Parameter scan & model analysis, taken full advantage of multi-wavelength observation

ν produced by accelerated p via pγ interaction:
$p+\gamma \rightarrow \pi$, where $\pi^0 \rightarrow 2\gamma$ and
$\pi^+(\pi^-) \rightarrow \nu_\mu(\bar{\nu}_\mu)+\mu^+(\mu^-) \rightarrow \nu_\mu+\bar{\nu}_\mu+\nu_e(\bar{\nu}_e)+e^+(e^-)$

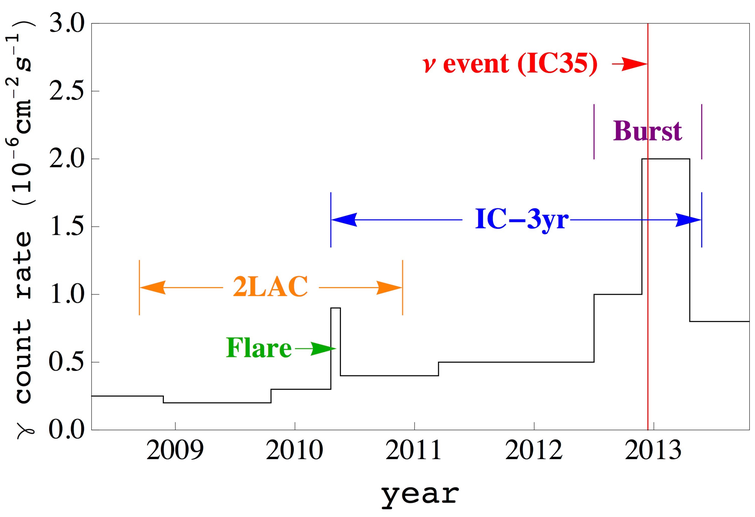



Illustration of γ-ray count rate and classifications of phases of PKS B1424-418, reconstructed according to (Kadler et al. 2016) : 2LAC, short flare, IceCube-3year exposure (IC-3yr) and outburst (Burst) phase.

## General Analysis

### General Assumptions

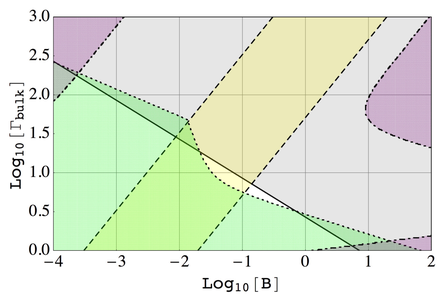
- Isotropic, homogeneous spherical blob
- Single power-law injection of e and p
- No external photons

### List of 4 Models

| | 1st peak (eV-keV) | middle (keV-MeV) | 2nd peak (MeV-TeV) | |
|---|---|---|---|---|
| **Pure Leptonic** | **L** primary e-syn | **L** Synchrotron-Self Compton (**SSC**) | **L** SSC or External-IC | ✔ |
| **LH-SSC** (this work) | **L** primary e-syn | **H** secondary lep emission | **L** SSC | ✔ |
| **LHπ** (Conventional Hadronic) | **L** primary e-syn | **H** secondary lep emission | **H** $\pi^0$ decay or secondary | ✗ |
| **Pure Hadronic** | **H** proton-syn | **H** secondary lep emission | **H** $\pi^0$ decay or secondary | ✗ |

**L** = leptonic, **H** = hadronic, **LH** = lepto-hadronic

**Veto "LHπ" : Allowed parameter-regions in color, on bulk Lorentz factor Γ and magnetic field B**




p synchrotron limit; $E_{peak}$ agrees observation; IC to syn ratio; photo-pair production limit

No region has all four colors → LHπ not viable

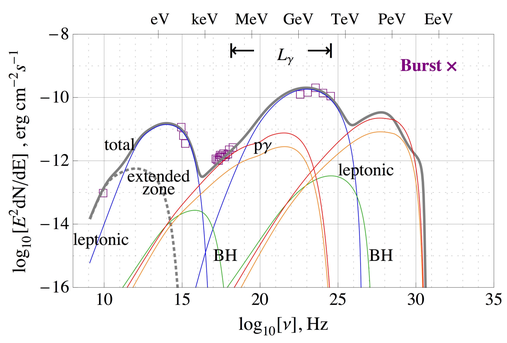
**Veto "pure hadronic":**
**1st (p-syn) and 2nd (pγ) peak requires different B**

**Conclusion: leptonic + sub-dominant hadronic, model 1 or 2 OK**

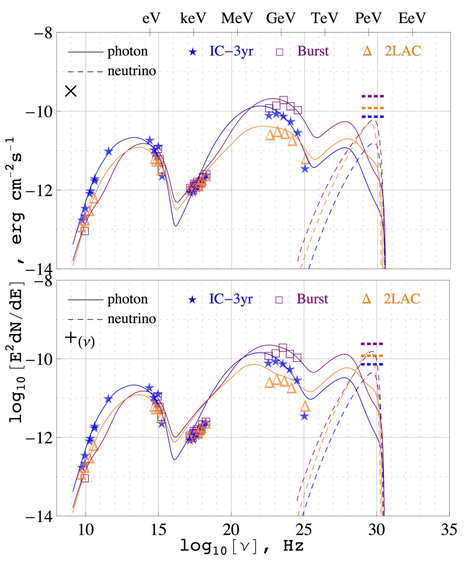
## Numerical Simulation

### Method:

- Solving the coupled time-dependent integro-differential kinematic equations for $e^+,e^-,p,n,\gamma,\nu$
- Find best-fit leptons first (syn. + SSC)
- Then add protons to obtain the full SED and ν



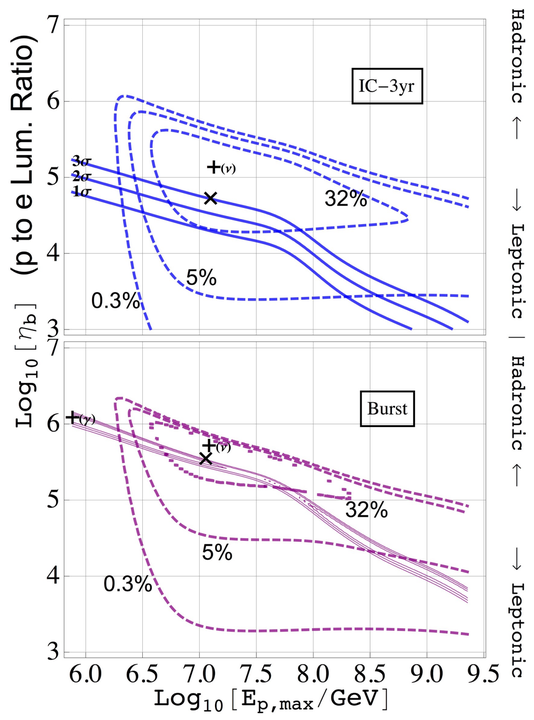

Contribution to the SED by interaction channels.
pγ : Emission by secondaries via EM cascades.
BH: Bethe-Heitler (photo-pair)
$L_\gamma$ : Integration range of γ-rays.

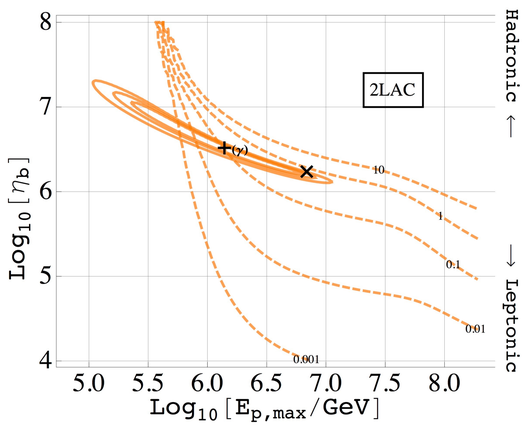



Top: max ν flux within SED consistency (3σ).
Bottom : ν best-fit only (violating SED).
Data points: from Kadler et al. 2016

## Conclusions

**Parameter Scan on $\eta_b$ (p to e⁻ luminosity ratio) and max p energy, and Fitting Qualities**




+(γ) : SED best-fit
+(ν) : neutrino best-fit only
× : max ν flux within 3σ SED-consistency
—— σ contours for SED ($\chi^2$)
- - - - } relative probability contours to observe IC35 during IC-3yr and Burst
- - - - expected number of PeV+ ν during 2LAC

- Our self-consistent one-zone model results in a far emission region of ~pc size and low magnetic field ~mG. Conventional hadronic LHπ model does not work for PKS B1424-418. Leptonic + sub-dominant hadronic viable.
- Relation $L_\nu \sim L_\gamma$ **no longer holds.** $L_\nu \sim 0.1 L_\gamma$ for this case ⇒ an additional correction factor needs to be considered in future neutrino searches with blazars.
- With SED consistency, up to ~5% chance to reproduce observation (IC35 + null in other energies) in either IC-3yr or Burst phase. Predicting up to ~0.4 events during the IC-3yr or Burst, or 0.6 in 2LAC phase, for a total >PeV all-flavor ν-count.