Unresolved blazars as sources of the diffuse astrophysical neutrino flux

A. Palladino, XR, S. Gao, and W. Winter, arXiv:1806.04769 (2018)

Xavier Rodrigues

TeVPA 2018
Berlin

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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Outline

Source model

Based on XR, Fedynitch, Boncioli, and Winter, arXiv:1711.02091

Model ingredient list

Spherical radiation zone
$R = c \times t_{\rm flare} = c \times 1{\rm day}$

Magnetic field scaling as power law of L_γ

2nd order Fermi acceleration of protons

Low acceleration efficiency
$\eta_{\rm acc} = 10^{-3}$

different from the original model, where
$\eta_{\rm acc} = 1$

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Low-luminosity blazars

No evidence of external fields

↓

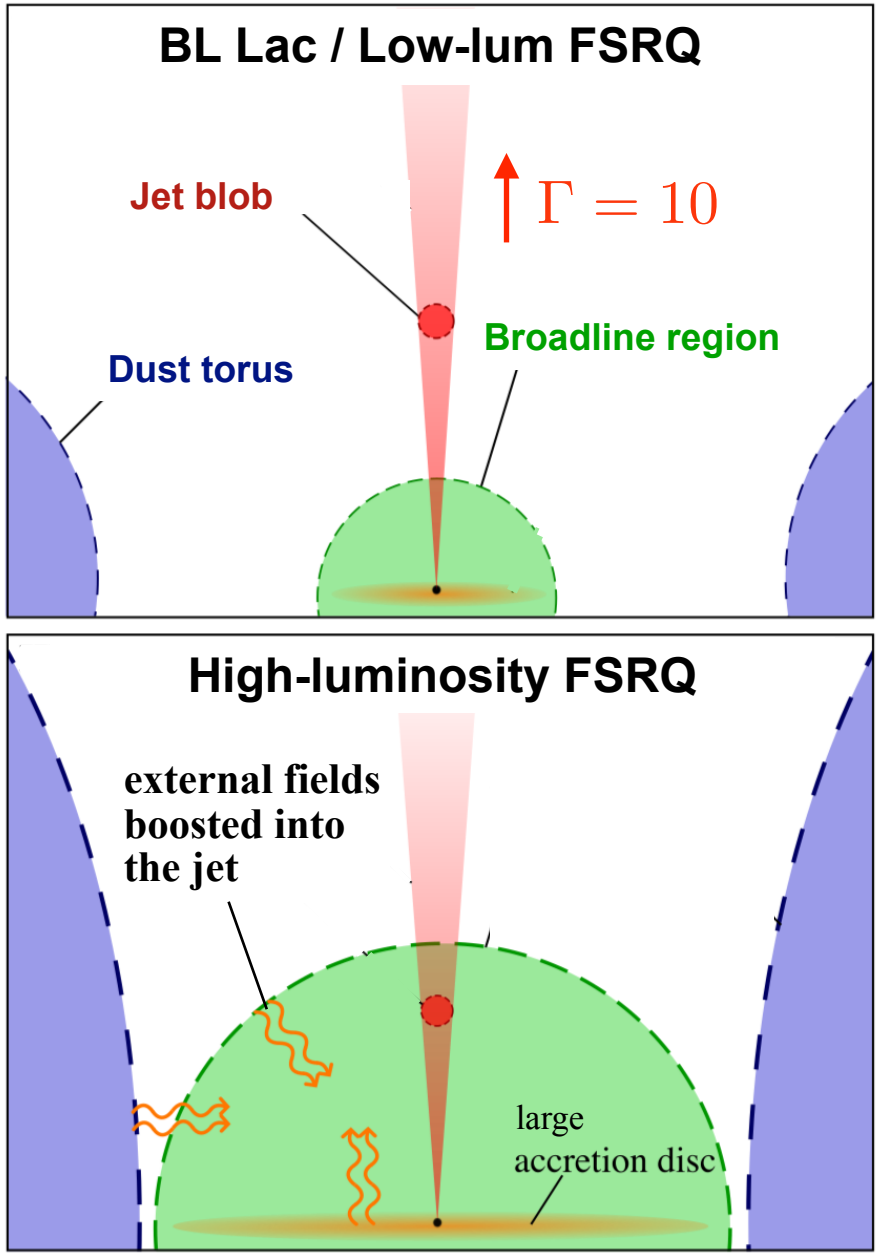
One-zone model

High-luminosity FSRQs

Large broadline region and dust torus

↓

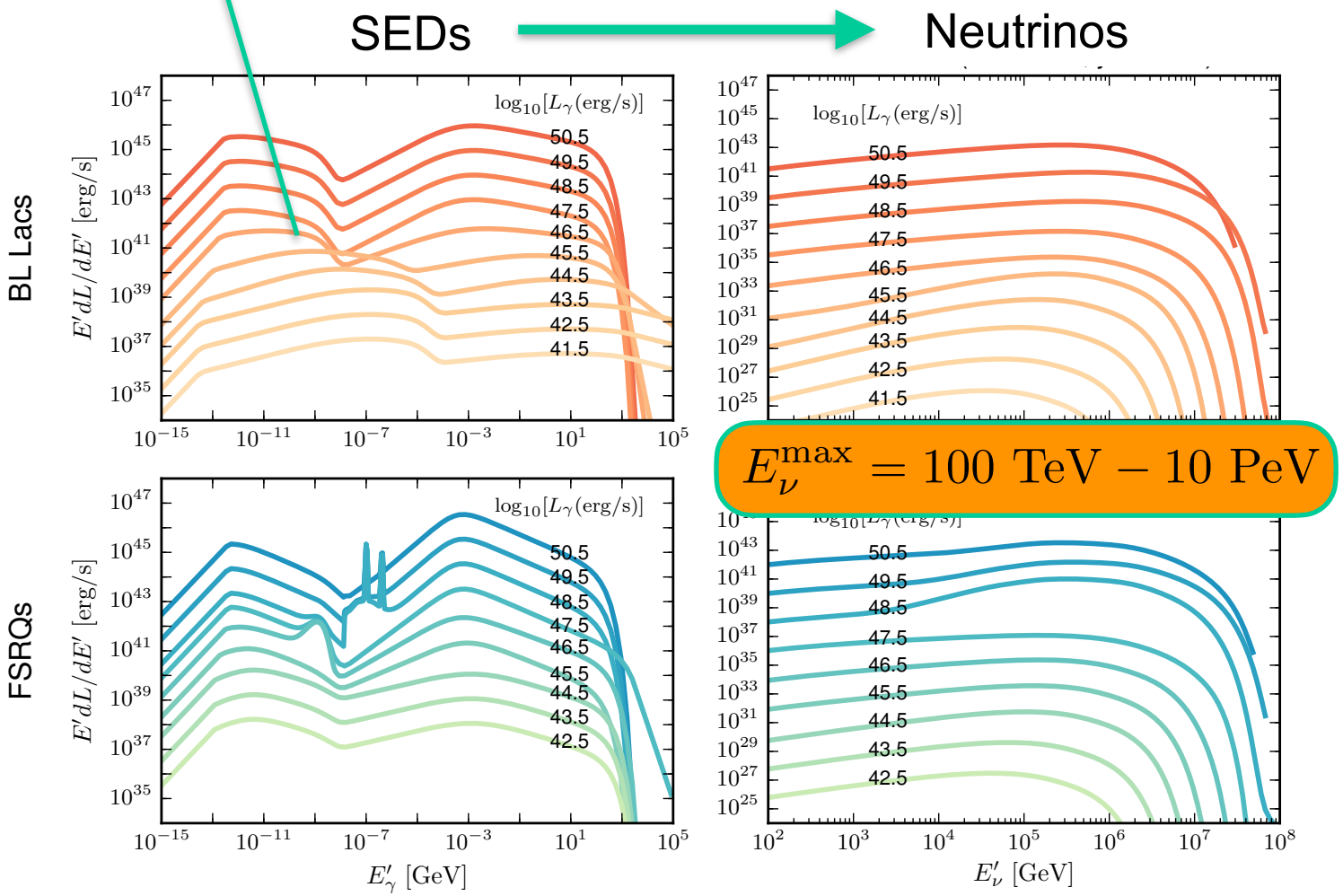
External contributions to the target photon field for CR interactions



Source model

Based on XR, Fedynitch, Boncioli & Winter, ApJ 2017 (1711.02091)

SEDs taken as **input** [Ghisellini+ 2017]



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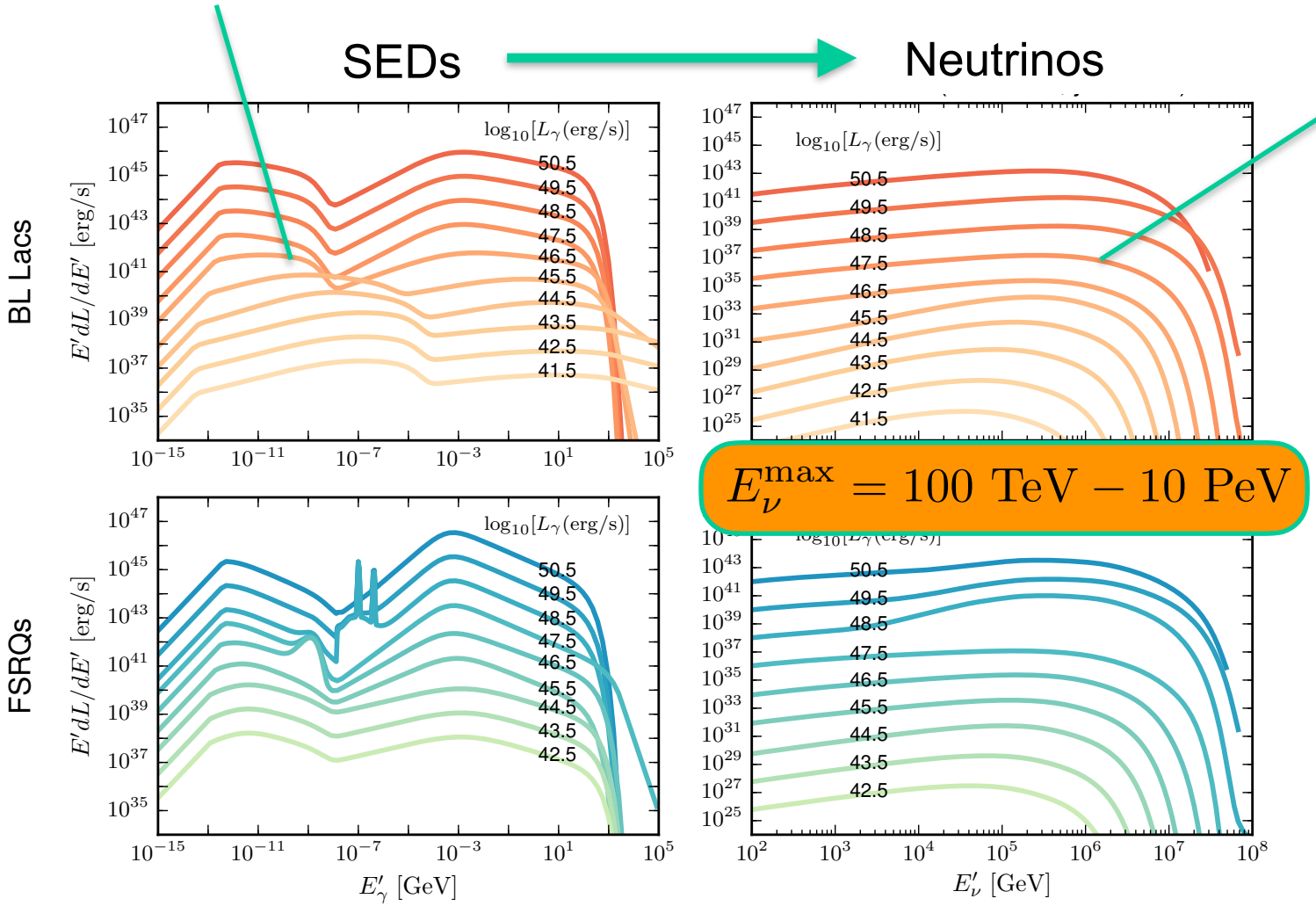

We can then calculate the **neutrino production efficiency** as a function of luminosity

$$L_\nu = \eta_\nu \times \xi_p \times L_\gamma$$

The **Baryonic loading** is a free parameter:

$$\xi_p = \frac{L_{\mathrm{CR}}}{L_\gamma}$$

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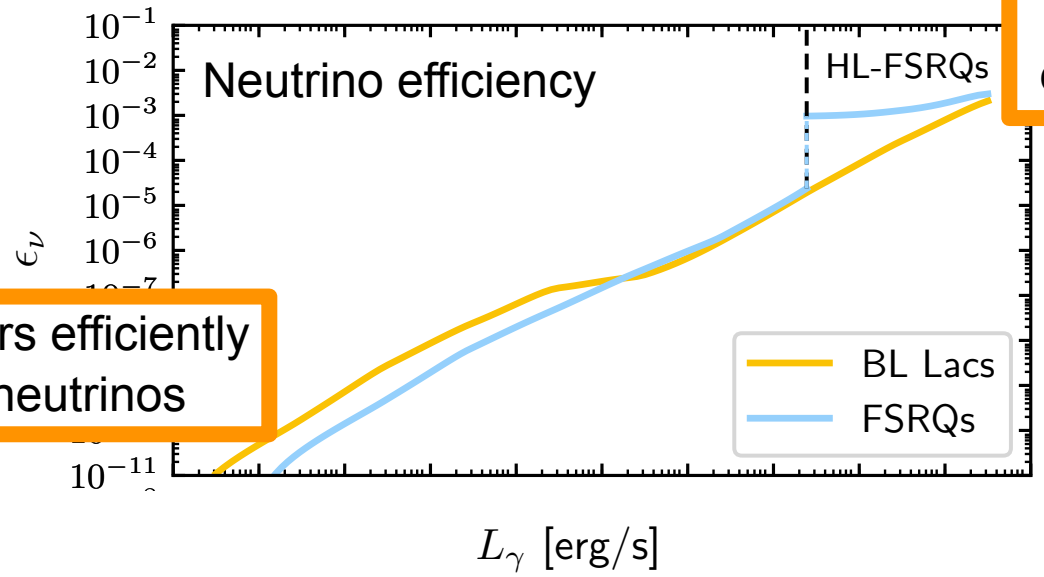
High-luminosity blazars have **high neutrino efficiency** due to strong photon fields



Low-luminosity blazars efficiently emit CRs but not neutrinos

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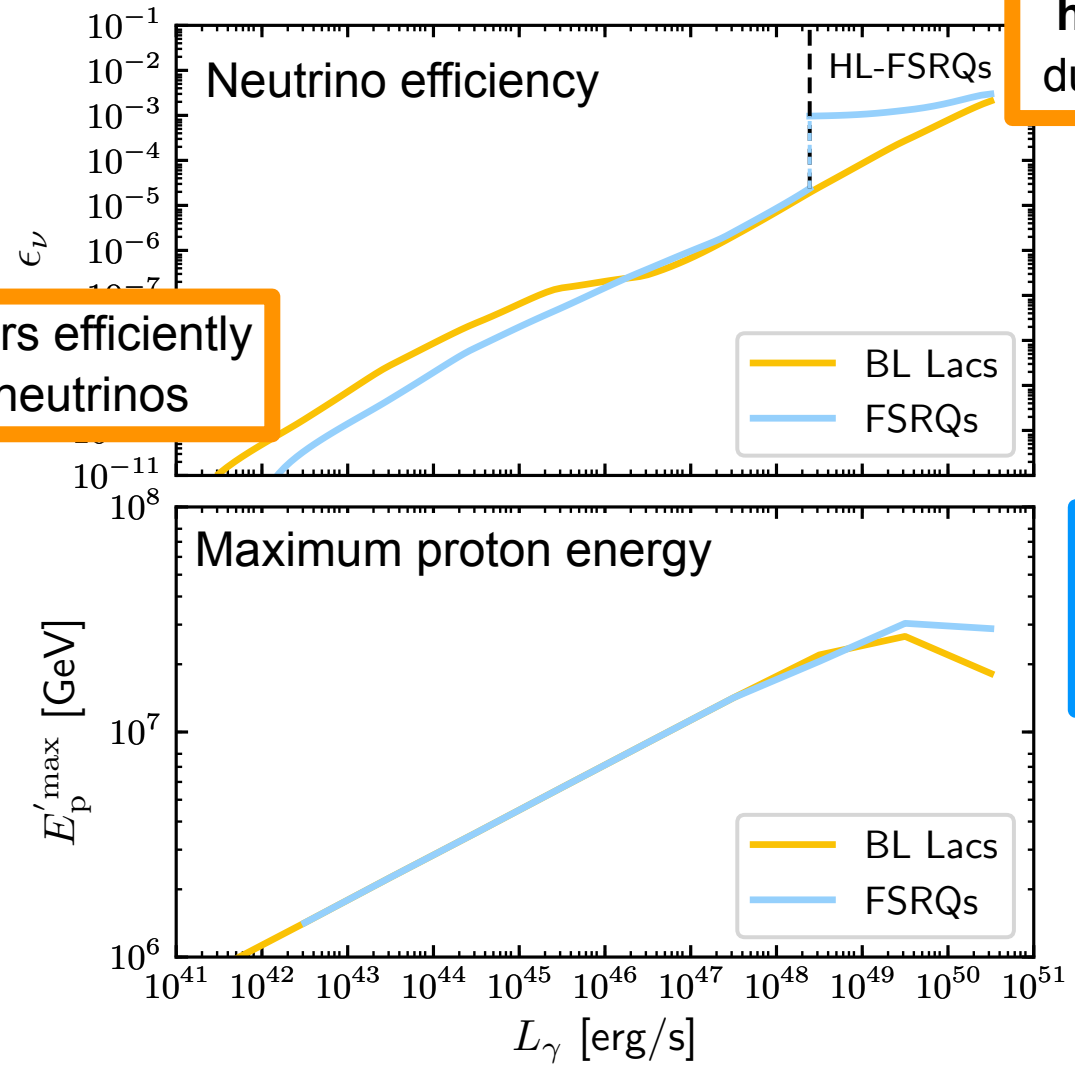


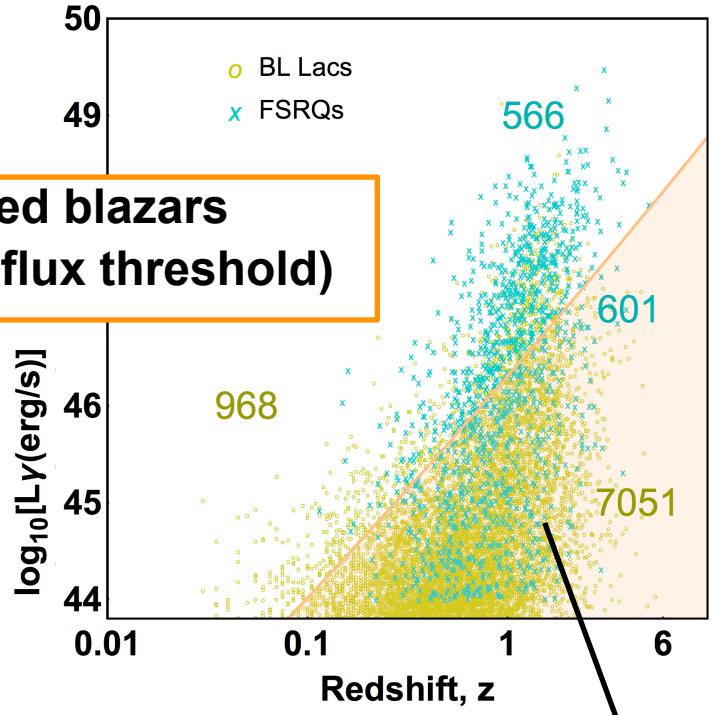
Sources have low maximum CR energy ~ 1-50 PeV because of inefficient acceleration

Connection to UHECRs compromised in this model

Source distribution

Based on Ajello et al. 2012 (1110.3787) and 2014 (1310.0006)

~1500 resolved blazars
(above the Fermi flux threshold)



~7600 sources that are unresolved but expected

[Palladino, XR, Gao & Winter, arXiv:1806.04769]

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50% of FSRQs resolved

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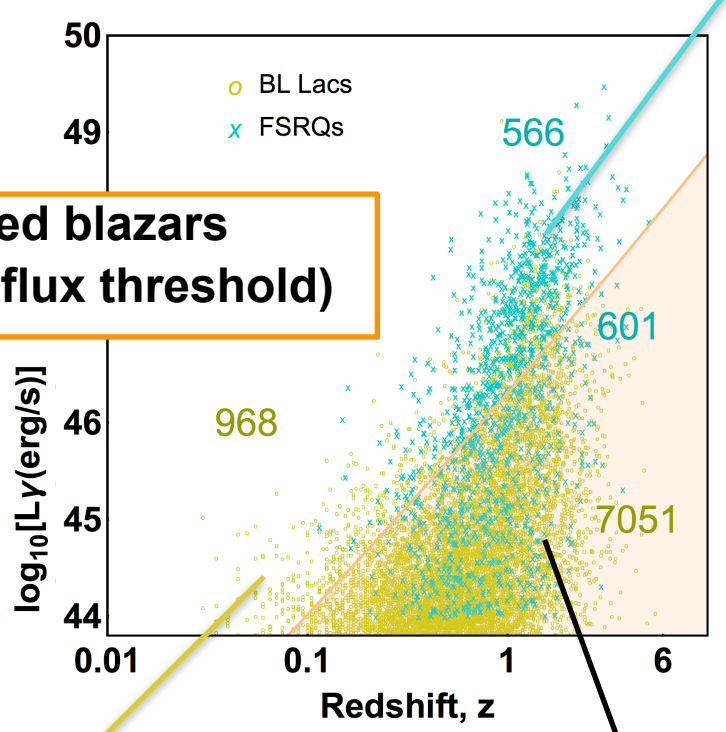

only 15% of BL Lacs resolved

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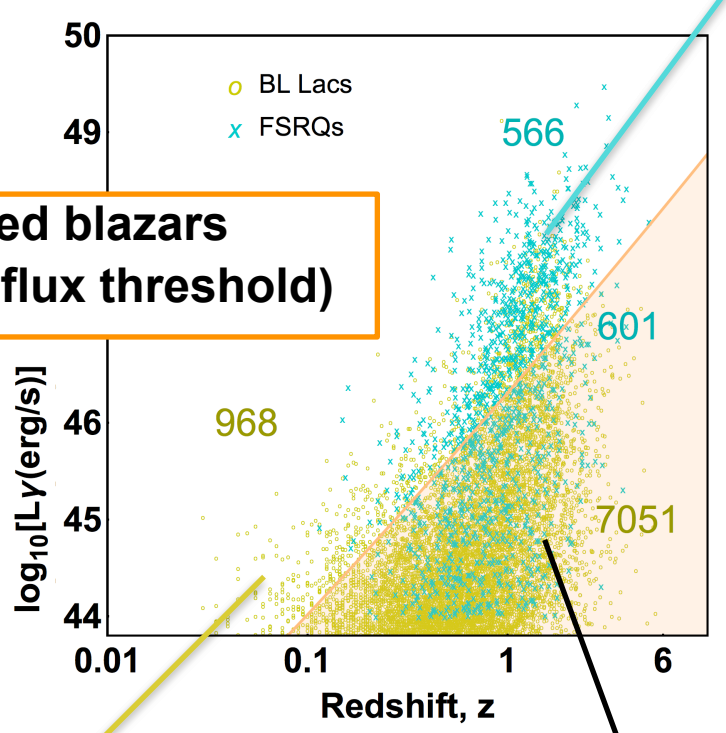

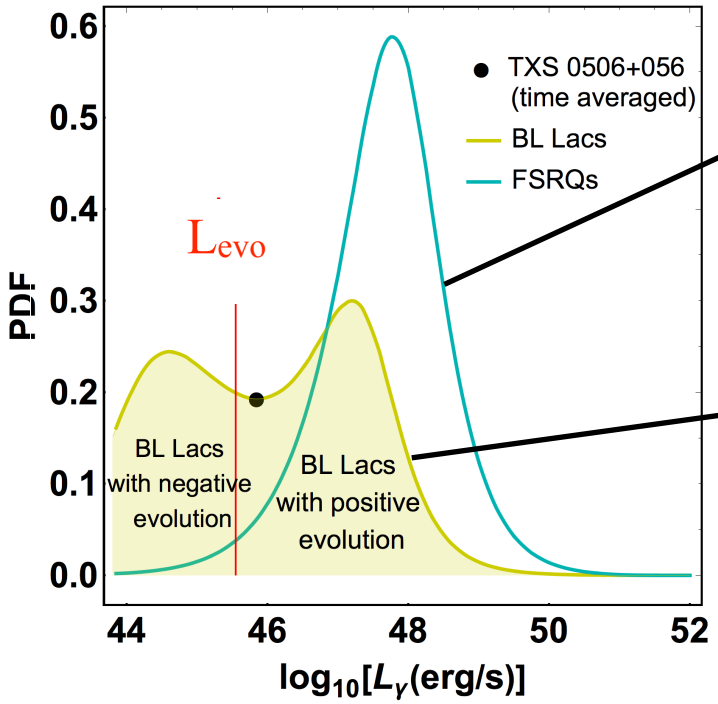

FSRQs peaked around 10^{48} erg/s

2 populations of BL Lacs

only 15% of BL Lacs resolved

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Diffuse neutrino spectrum

$$L_\nu = \eta_\nu \times \xi_p \times L_\gamma$$

Is it possible that the blazar population explains the IceCube ***flux above 300 TeV***, while obeying the ***stacking limit?***

(ApJ 2017, lack of correlations with resolved gamma sources)

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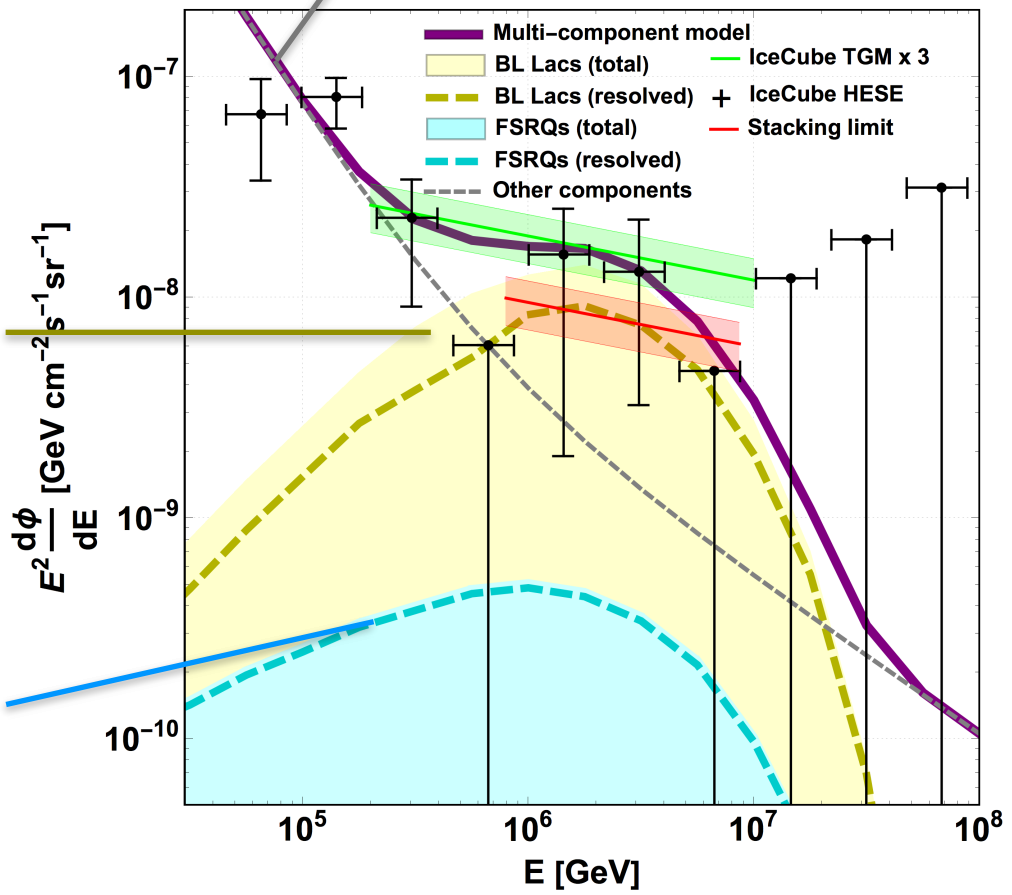
E~100 TeV: galactic component, residual atmospheric background
[Palladino & Winter 1801.07277]

BL Lacs (half of which unresolved) can power the PeV flux

FSRQ contribution highly **suppressed** not to violate stacking bounds



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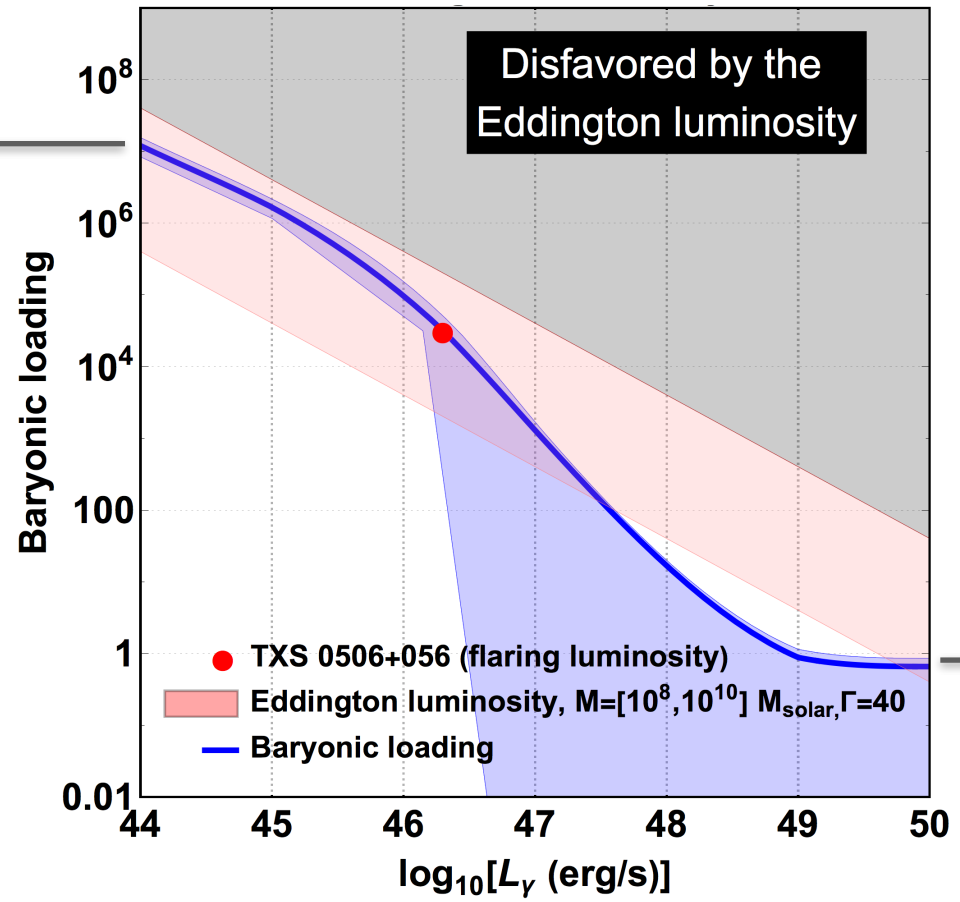
Baryonic loading with luminosity

High baryonic loading of low-luminosity sources (mostly **BL Lacs**!)

$$L_\nu / L_\gamma = 10.5\%$$



High-luminosity sources (mostly **FSRQs**!) must be predominantly leptonic

$$L_\nu / L_\gamma < 0.5\%$$

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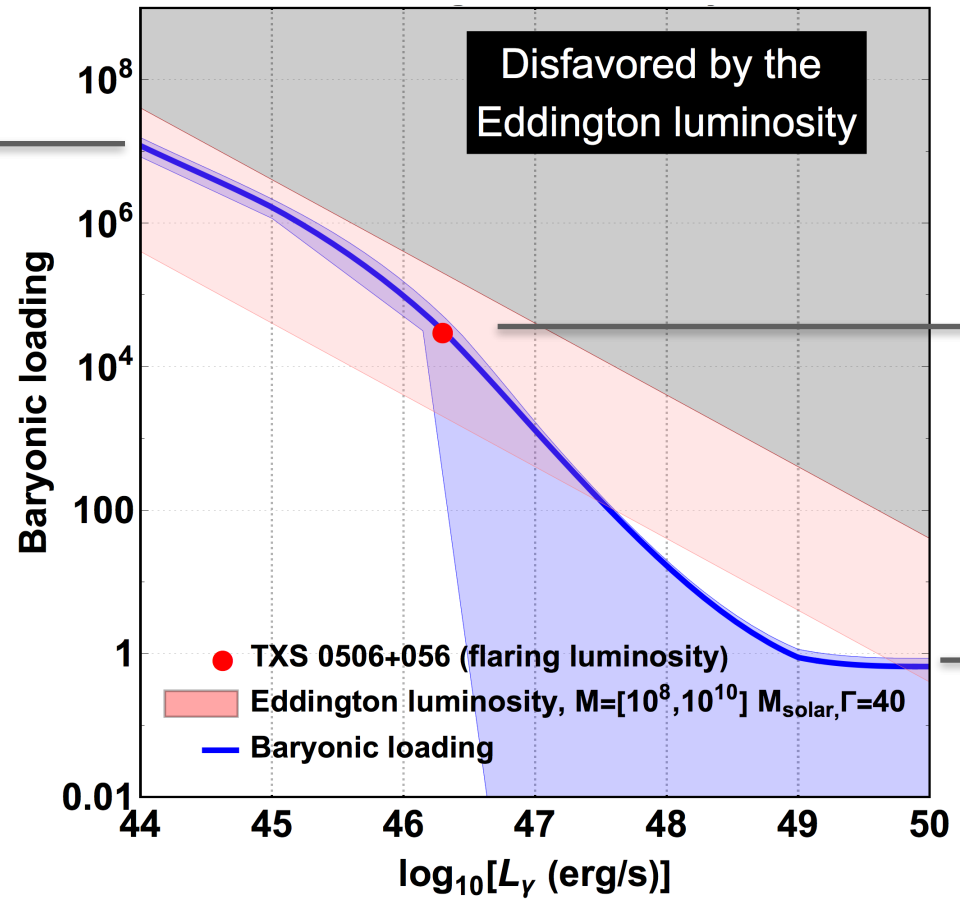

TXS 0506+056 flare:
intermediate baryonic loading
$\xi_p = 3 \times 10^4$
[Gao et al 2018]

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(mostly **FSRQs**!)
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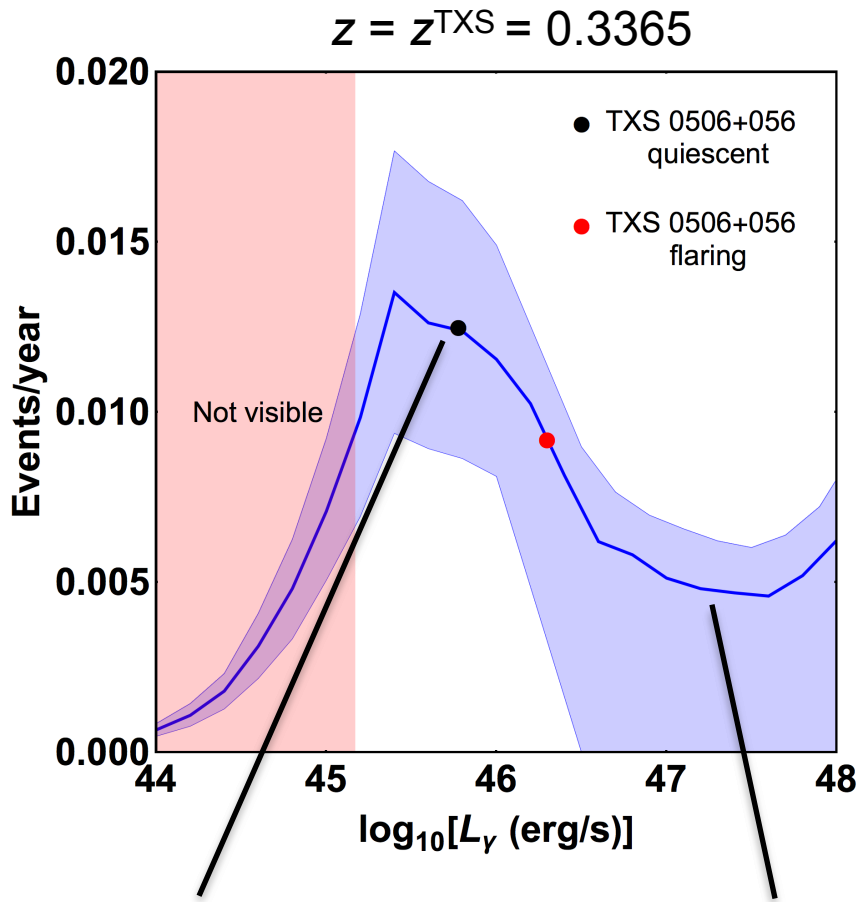
The case of TXS 0506+056



TXS is in the luminosity range of strong neutrino emitters

For high luminosities the neutrino flux is **suppressed** by the low baryonic loading

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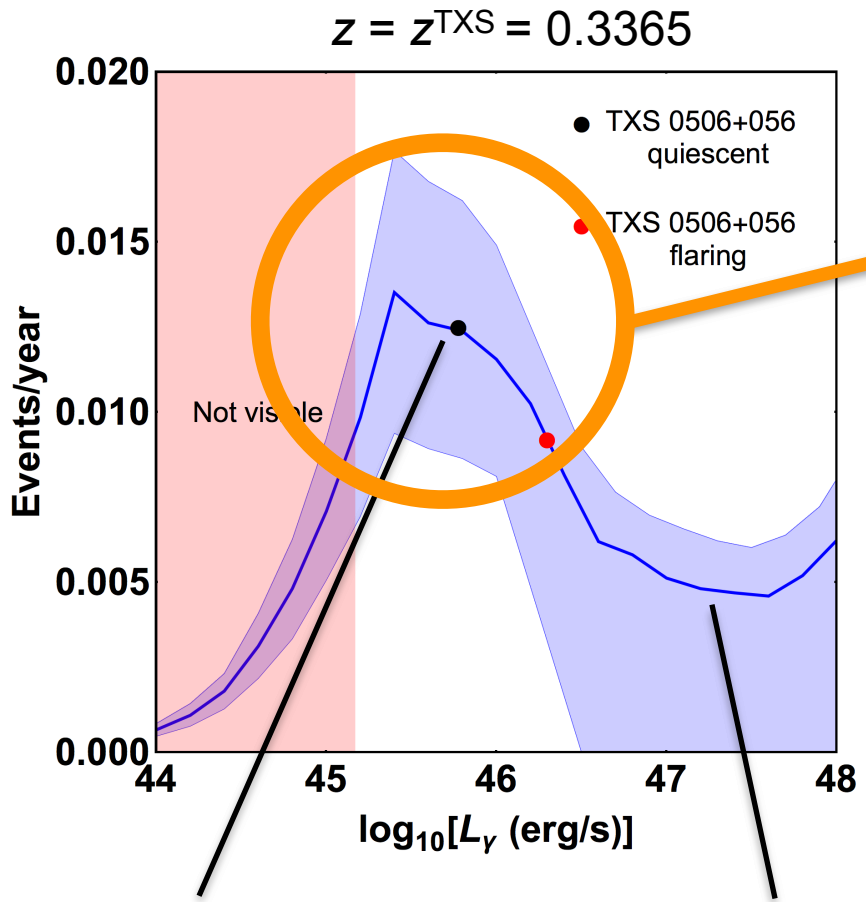

We expect future detections to come from sources with

$$10^{45} < L_\gamma(\mathrm{erg/s}) < 3 \times 10^{46}$$

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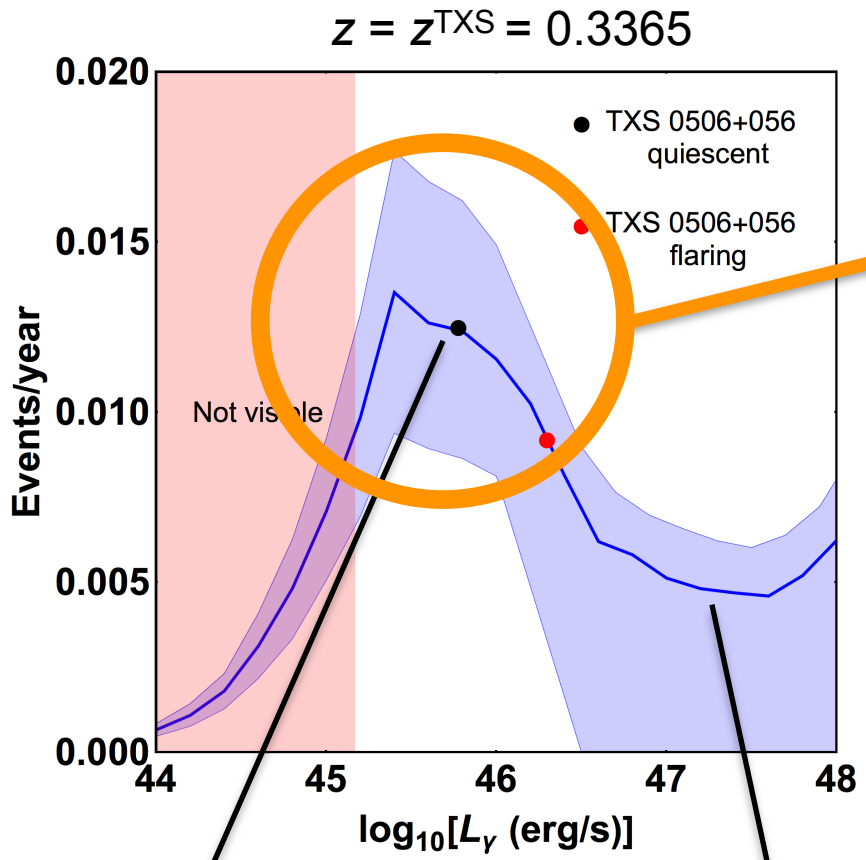

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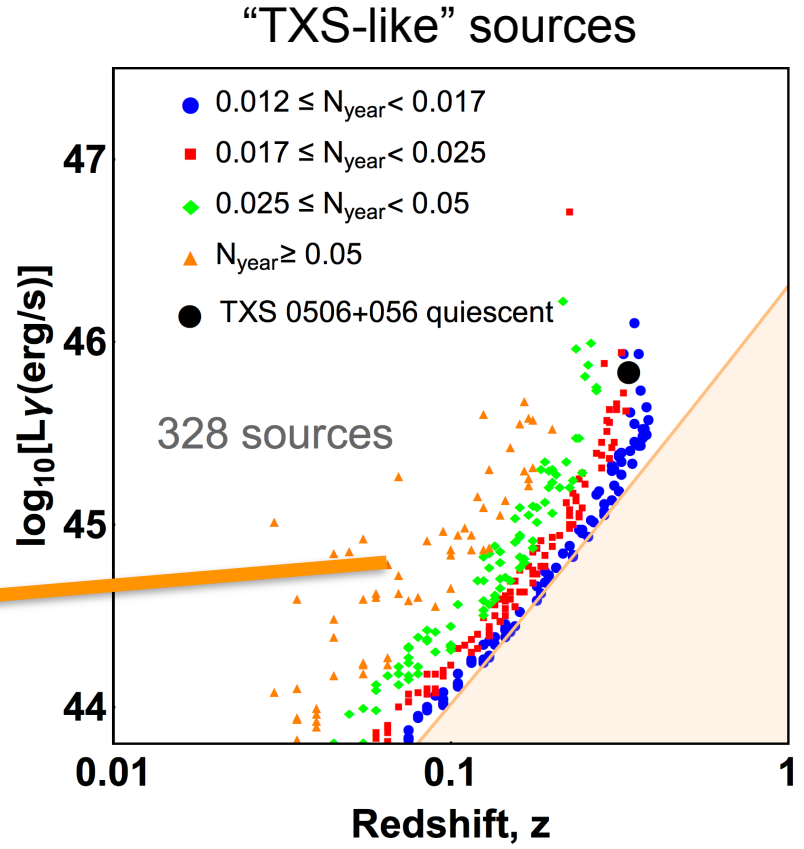
328 catalogued blazars capable of emitting more neutrinos than TXS

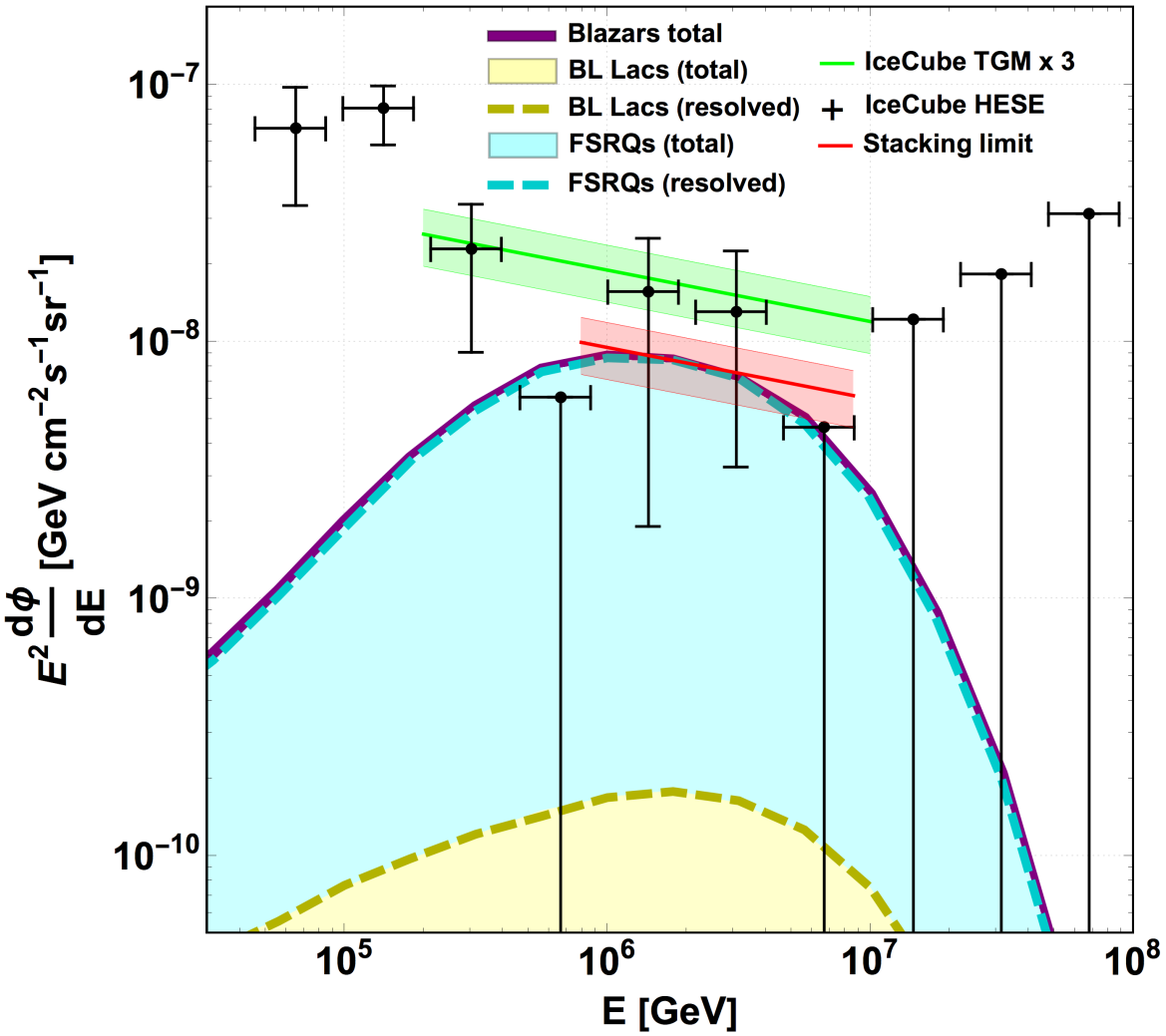


Expected $0.96 \frac{\text{correlations}}{\text{year}}$

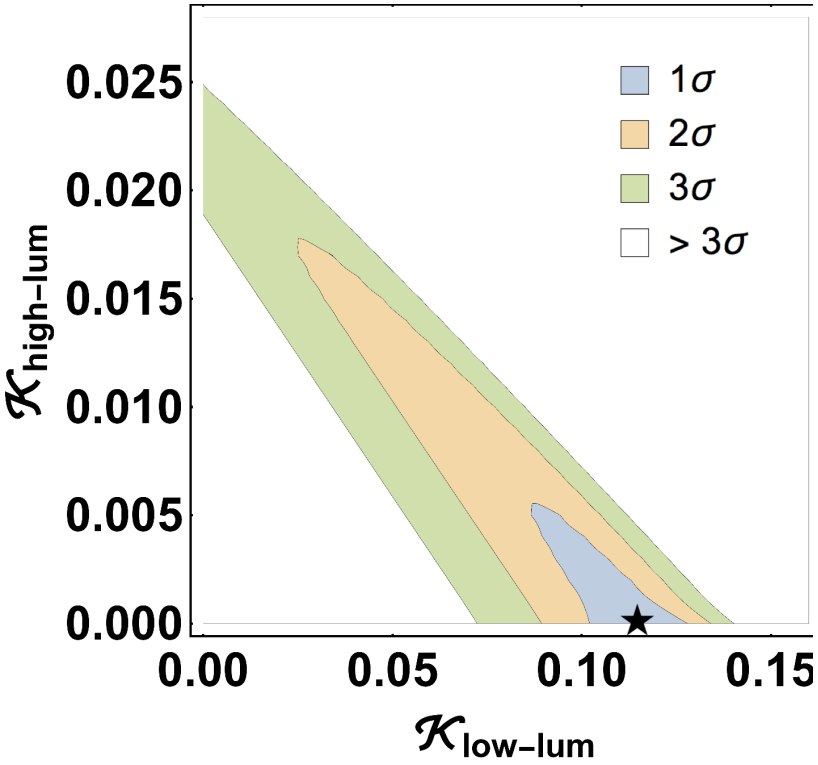
Conclusion

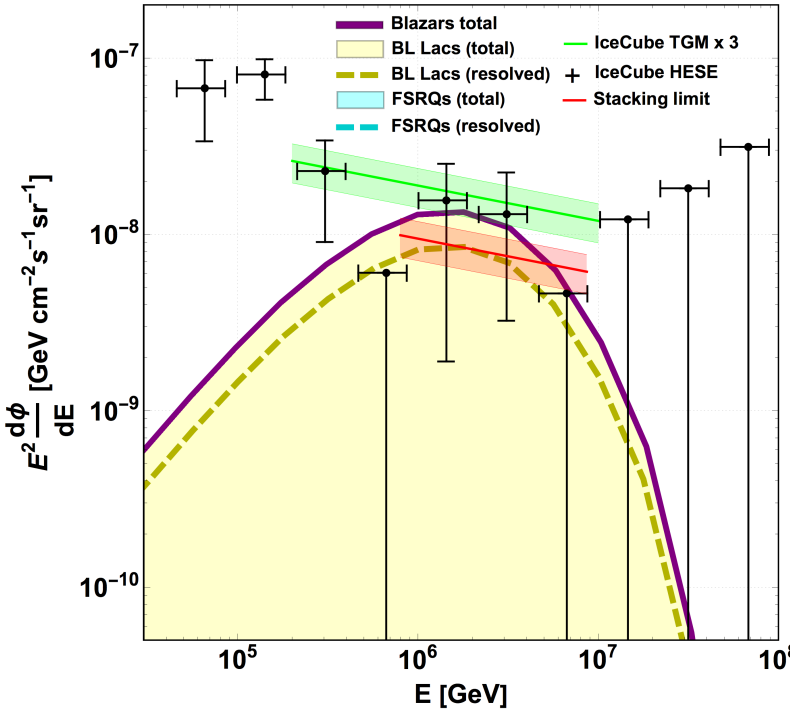
- We have shown that unresolved blazars can power the diffuse IceCube PeV flux without violating the limits imposed by lack of correlations with known sources
- Taking into account current population studies, this means high-luminosity blazars, especially FSRQs, should be mostly leptonic
- On the other hand, the estimated baryonic loading of BL Lacs does not exceed their typical Eddington luminosity
- We expect future coincidences to be associated to nearby sources with $L_\gamma \sim 10^{45}\ \mathrm{erg/s}$
- IceCube Gen2 can rule out our model in about 3.5 years of data if no multiplet neutrinos are observed (two neutrinos from the same direction)

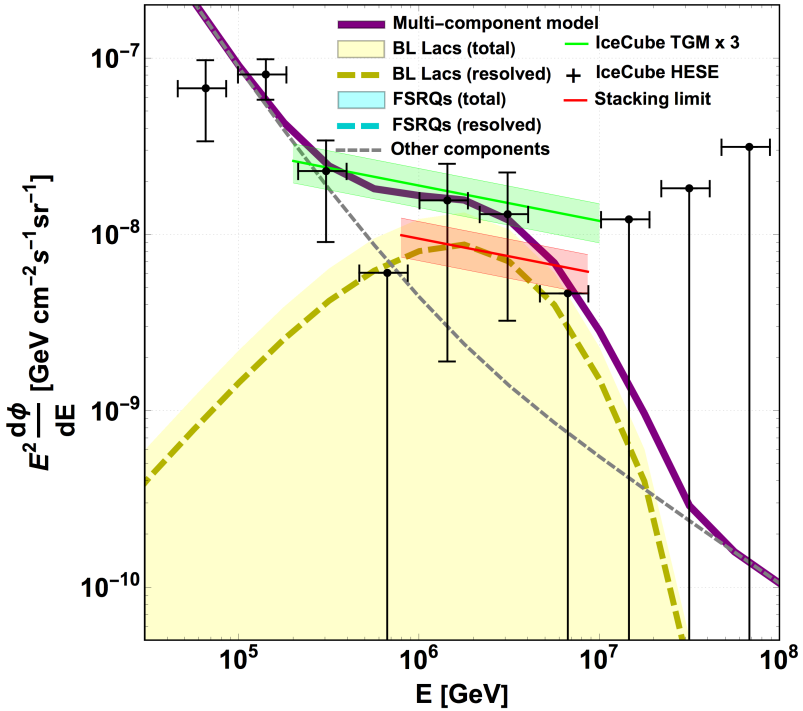
Backup


Blazars total
BL Lacs (total)
BL Lacs (resolved)
FSRQs (total)
FSRQs (resolved)
IceCube TGM x 3
IceCube HESE
Stacking limit
$E^2 \frac{d\phi}{dE}$ [GeV cm^{-2}s^{-1}sr^{-1}]
E [GeV]
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^5
10^6
10^7
10^8

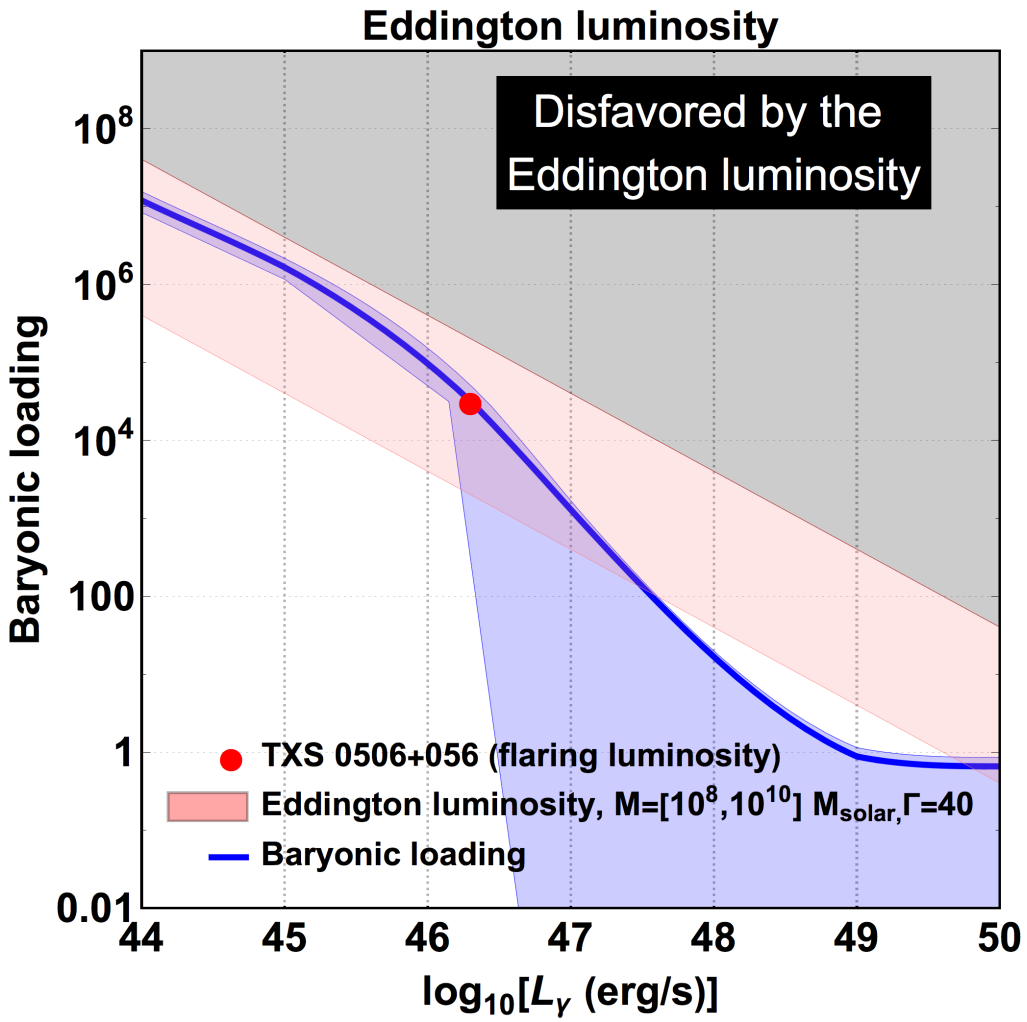
Backup

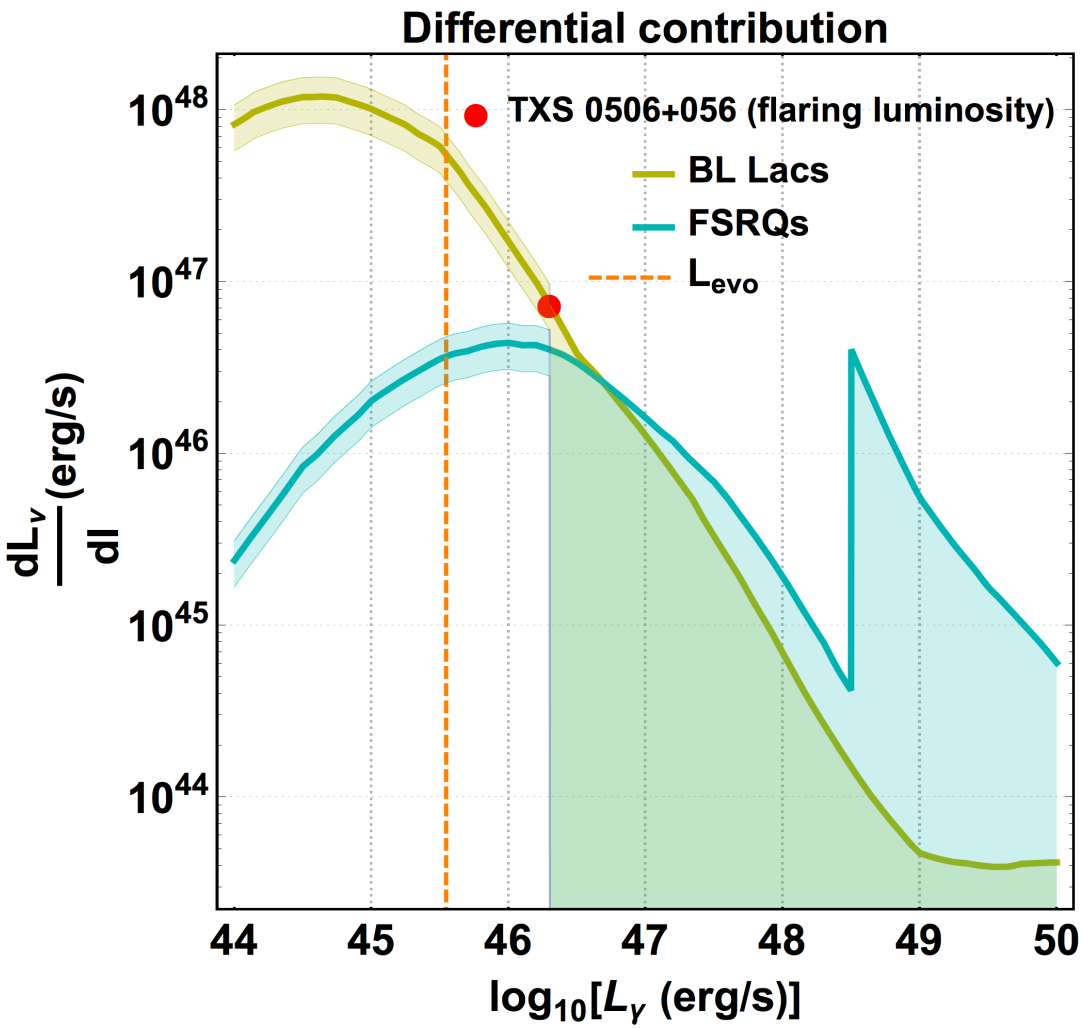

1σ
2σ
3σ
> 3σ
0.025
0.020
0.015
0.010
0.005
0.000
0.00
0.05
0.10
0.15
$\mathcal{K}_{\text{high-lum}}$
$\mathcal{K}_{\text{low-lum}}$


Blazars total
BL Lacs (total)
BL Lacs (resolved)
FSRQs (total)
FSRQs (resolved)
IceCube TGM x 3
IceCube HESE
Stacking limit
$E^2 \frac{d\phi}{dE}$ [GeV cm^{-2} s^{-1} sr^{-1}]
E [GeV]

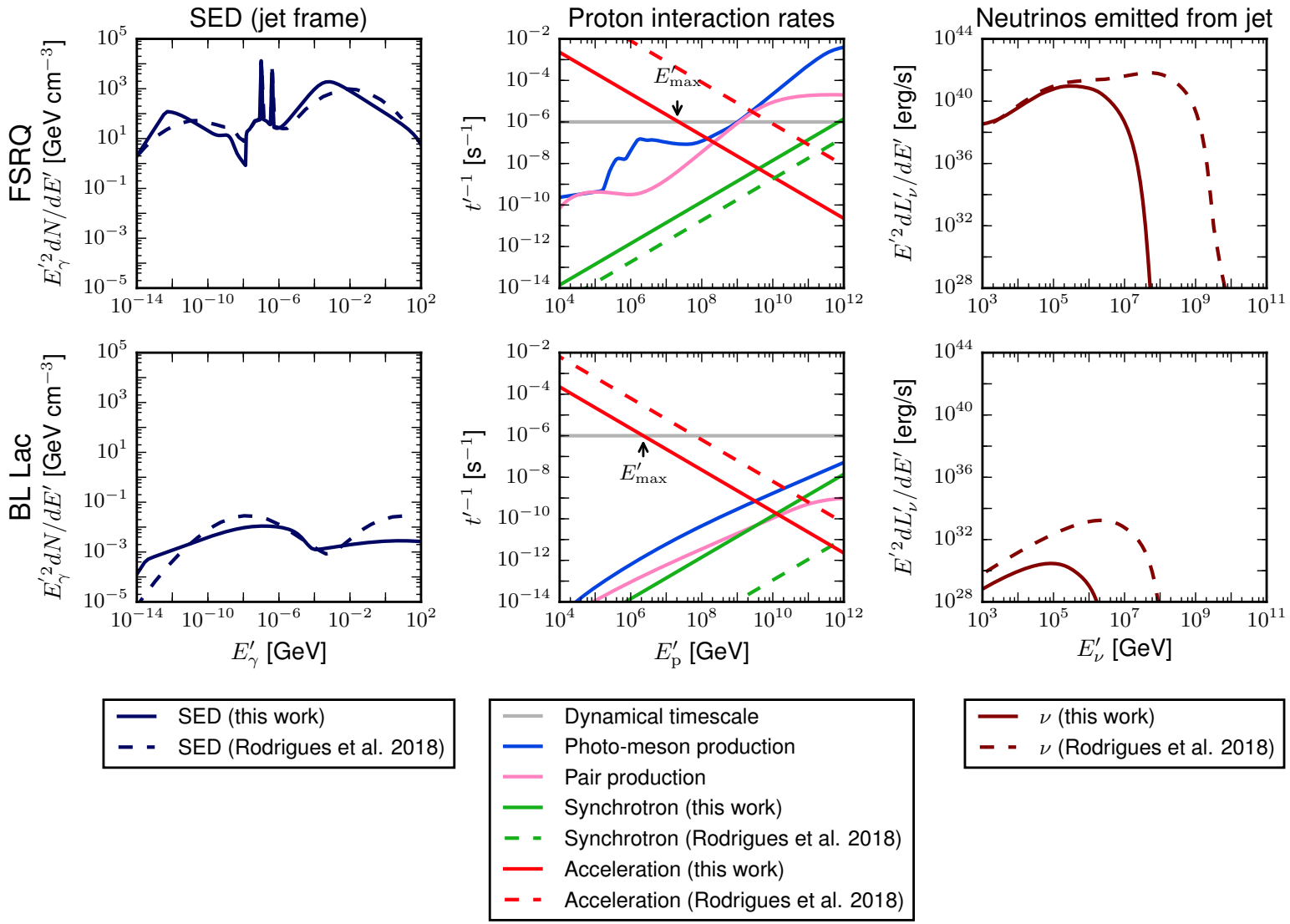

Multi-component model
BL Lacs (total)
BL Lacs (resolved)
FSRQs (total)
FSRQs (resolved)
Other components
IceCube TGM x 3
IceCube HESE
Stacking limit
$E^2 \frac{d\phi}{dE}$ [GeV cm^{-2} s^{-1} sr^{-1}]
E [GeV]

Backup

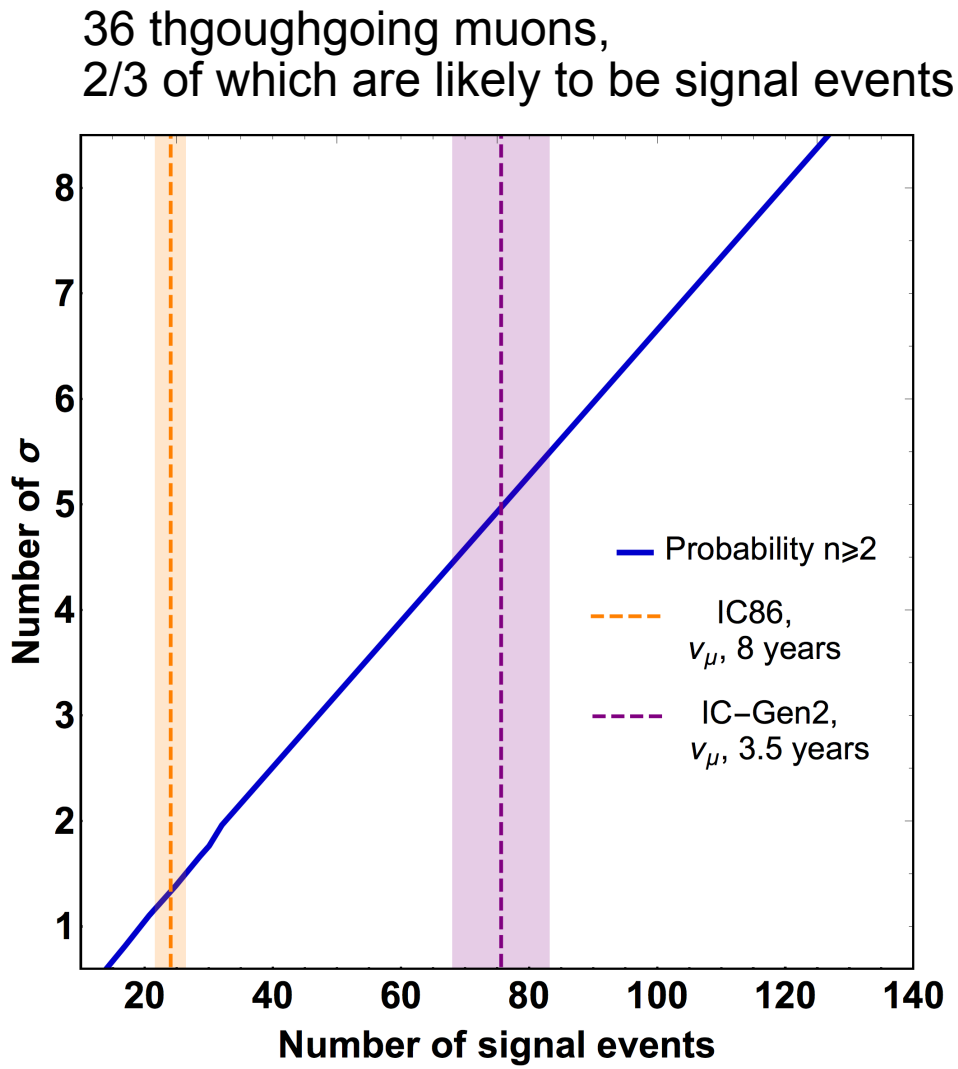

Eddington luminosity
Disfavored by the Eddington luminosity
Baryonic loading
10^8
10^6
10^4
100
1
0.01
TXS 0506+056 (flaring luminosity)
Eddington luminosity, M=[10^8,10^{10}] M_{solar},Γ=40
Baryonic loading
44
45
46
47
48
49
50
$\log_{10}[L_\gamma$ (erg/s)]


Differential contribution
10^{48}
10^{47}
10^{46}
10^{45}
10^{44}
$\frac{dL_\nu}{dl}$(erg/s)
TXS 0506+056 (flaring luminosity)
BL Lacs
FSRQs
L_{evo}
44
45
46
47
48
49
50
$\log_{10}[L_\gamma$ (erg/s)]

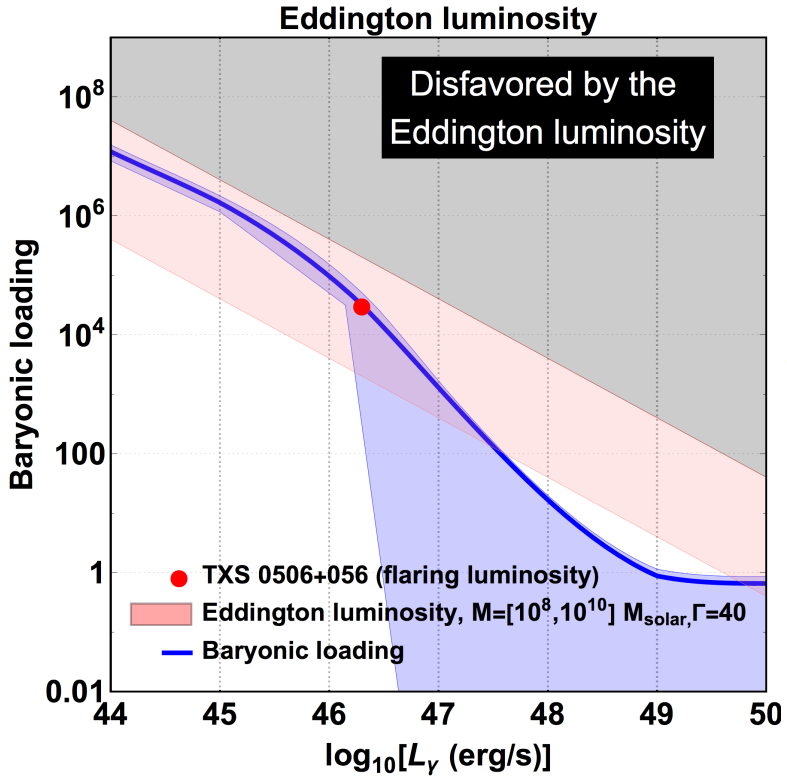
Backup


SED (jet frame)
Proton interaction rates
Neutrinos emitted from jet
FSRQ
BL Lac
$E'^2_\gamma dN/dE'$ [GeV cm^{-3}]
t'^{-1} [s^{-1}]
$E'^2 dL'_\nu/dE'$ [erg/s]
$E'_{\max}$
E'_γ [GeV]
E'_p [GeV]
E'_ν [GeV]
SED (this work)
SED (Rodrigues et al. 2018)
Dynamical timescale
Photo-meson production
Pair production
Synchrotron (this work)
Synchrotron (Rodrigues et al. 2018)
Acceleration (this work)
Acceleration (Rodrigues et al. 2018)
ν (this work)
ν (Rodrigues et al. 2018)

Backup


36 thgoughgoing muons,
2/3 of which are likely to be signal events
Number of σ
1
2
3
4
5
6
7
8
20
40
60
80
100
120
140
Number of signal events
Probability n≥2
IC86,
ν_μ, 8 years
IC−Gen2,
ν_μ, 3.5 years

Backup


Eddington luminosity
Disfavored by the Eddington luminosity
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Eddington luminosity, M=[10^8,10^10] M_solar,Γ=40
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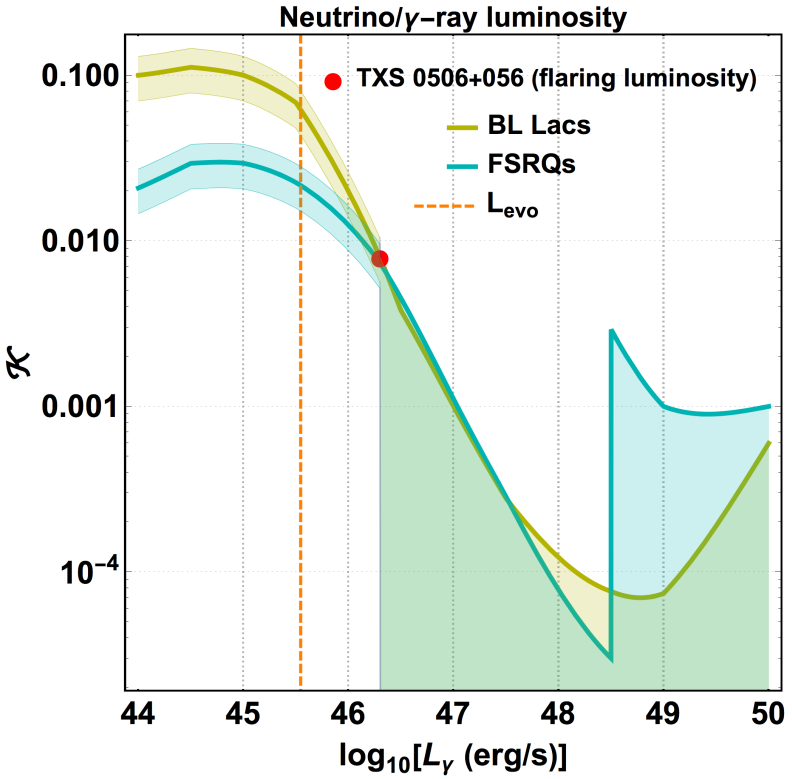
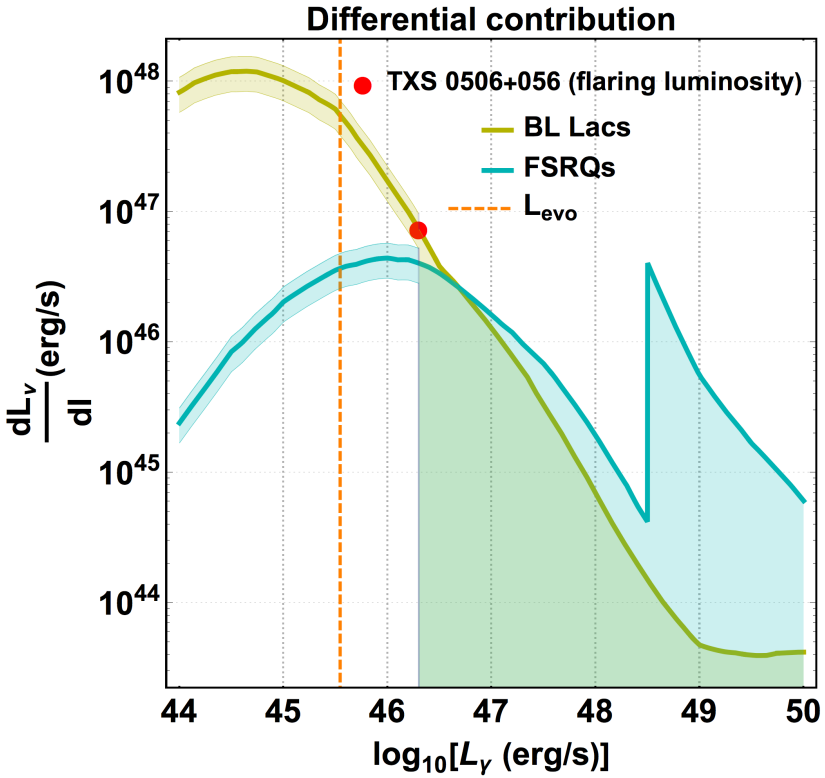
log10[L_γ (erg/s)]


Neutrino/γ−ray luminosity
TXS 0506+056 (flaring luminosity)
BL Lacs
FSRQs
L_evo
κ
log10[L_γ (erg/s)]


Differential contribution
TXS 0506+056 (flaring luminosity)
BL Lacs
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L_evo
dL_ν/dl (erg/s)
log10[L_γ (erg/s)]