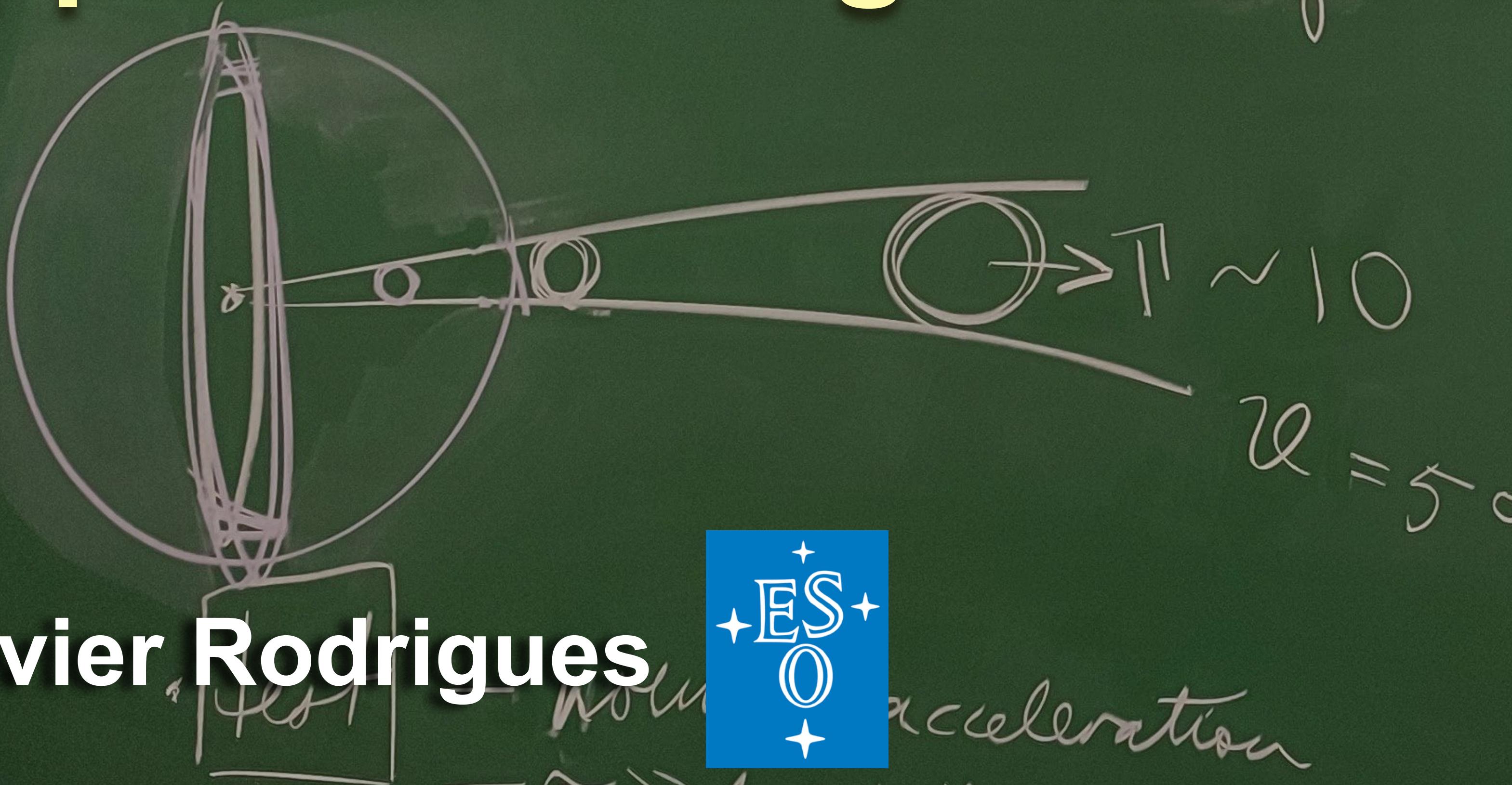


Cosmic ray interaction models applied to a large blazar sample

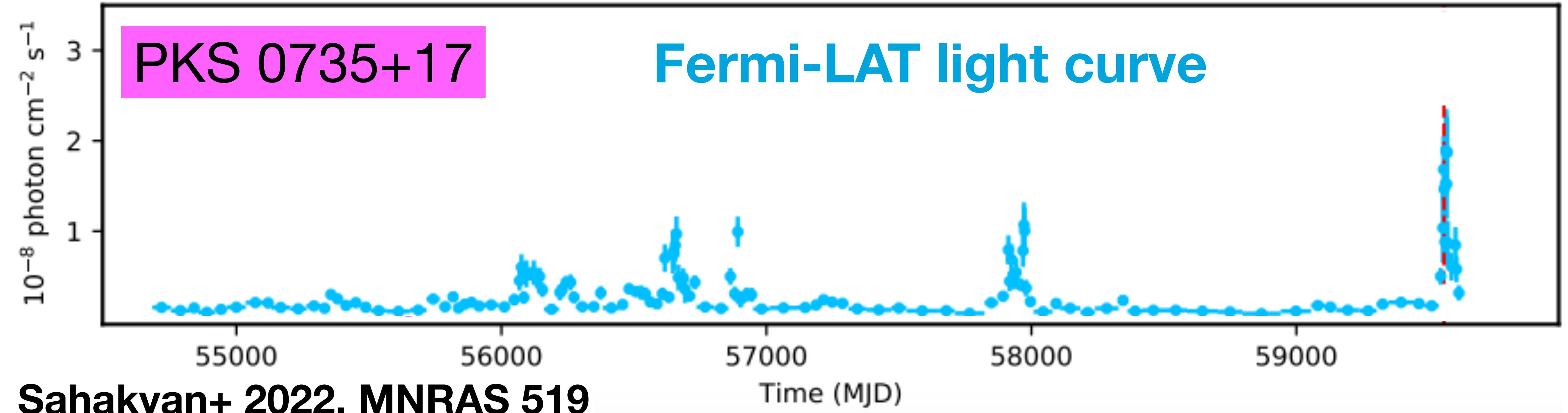


Xavier Rodrigues



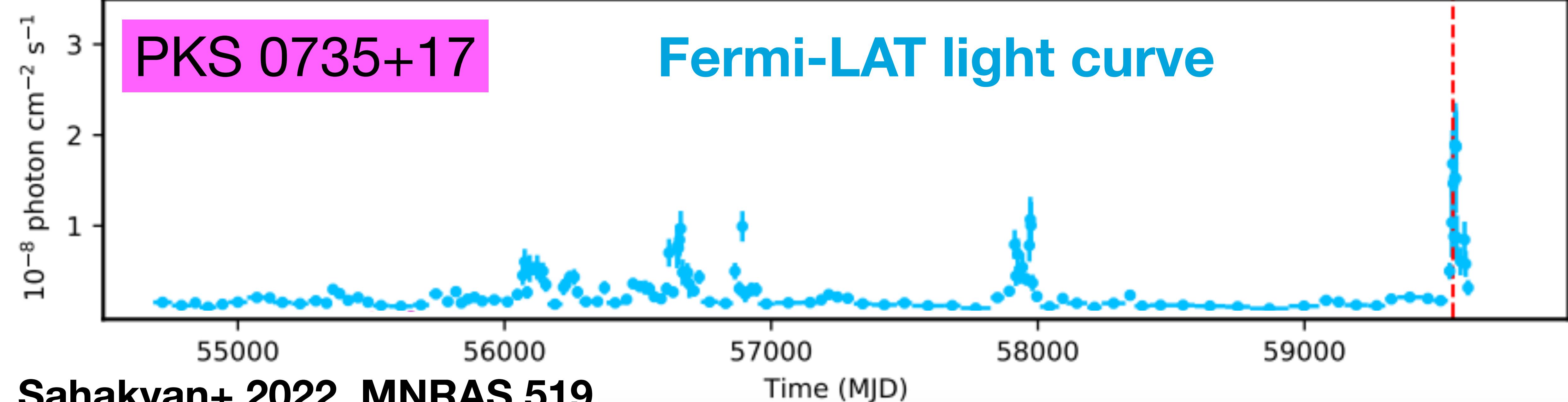
TeV Particle Astrophysics (TeVPA)
Naples, September 11 2023

What is a hadronic signature?

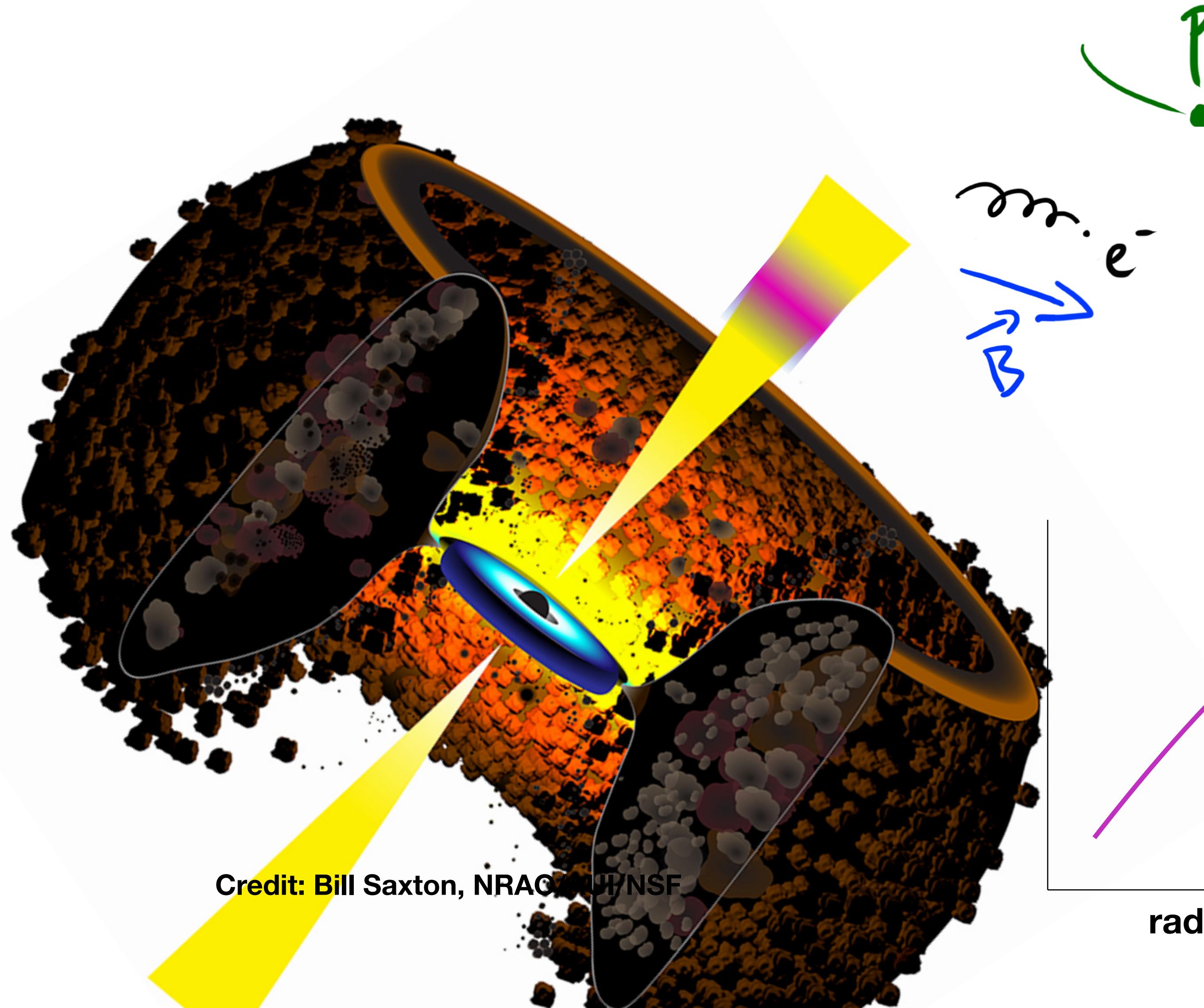


What is a hadronic signature?

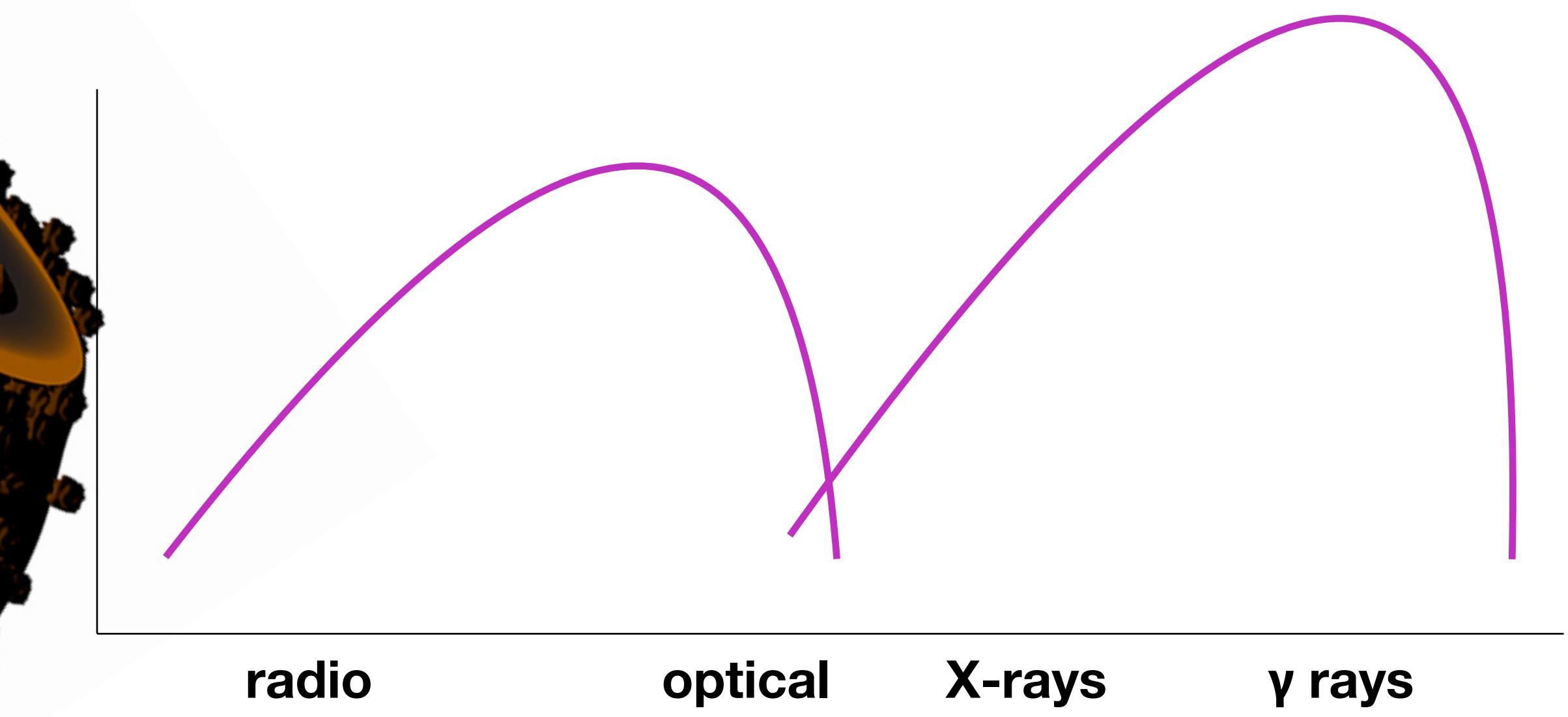
IceCube detection



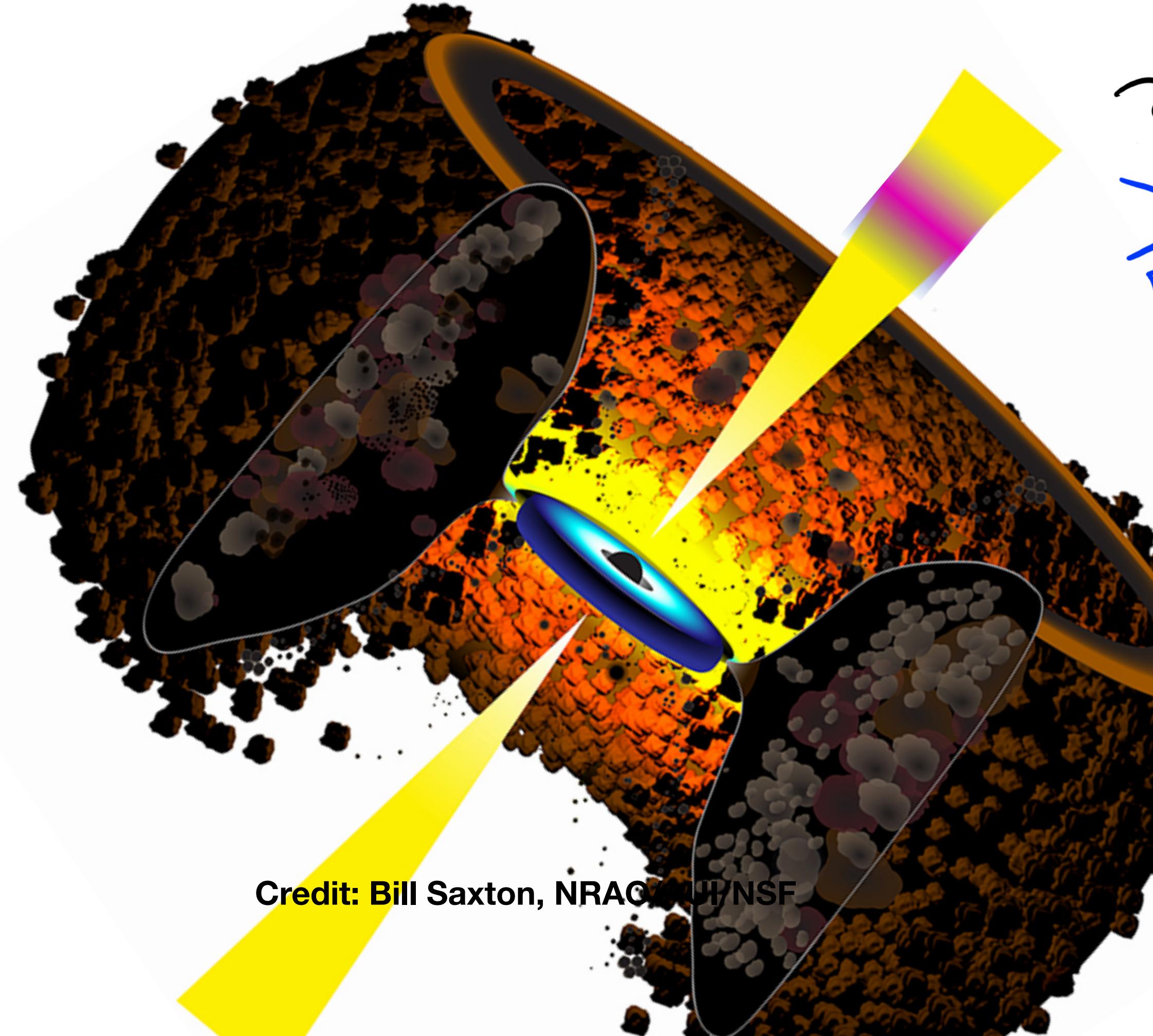
Modeling active galaxies



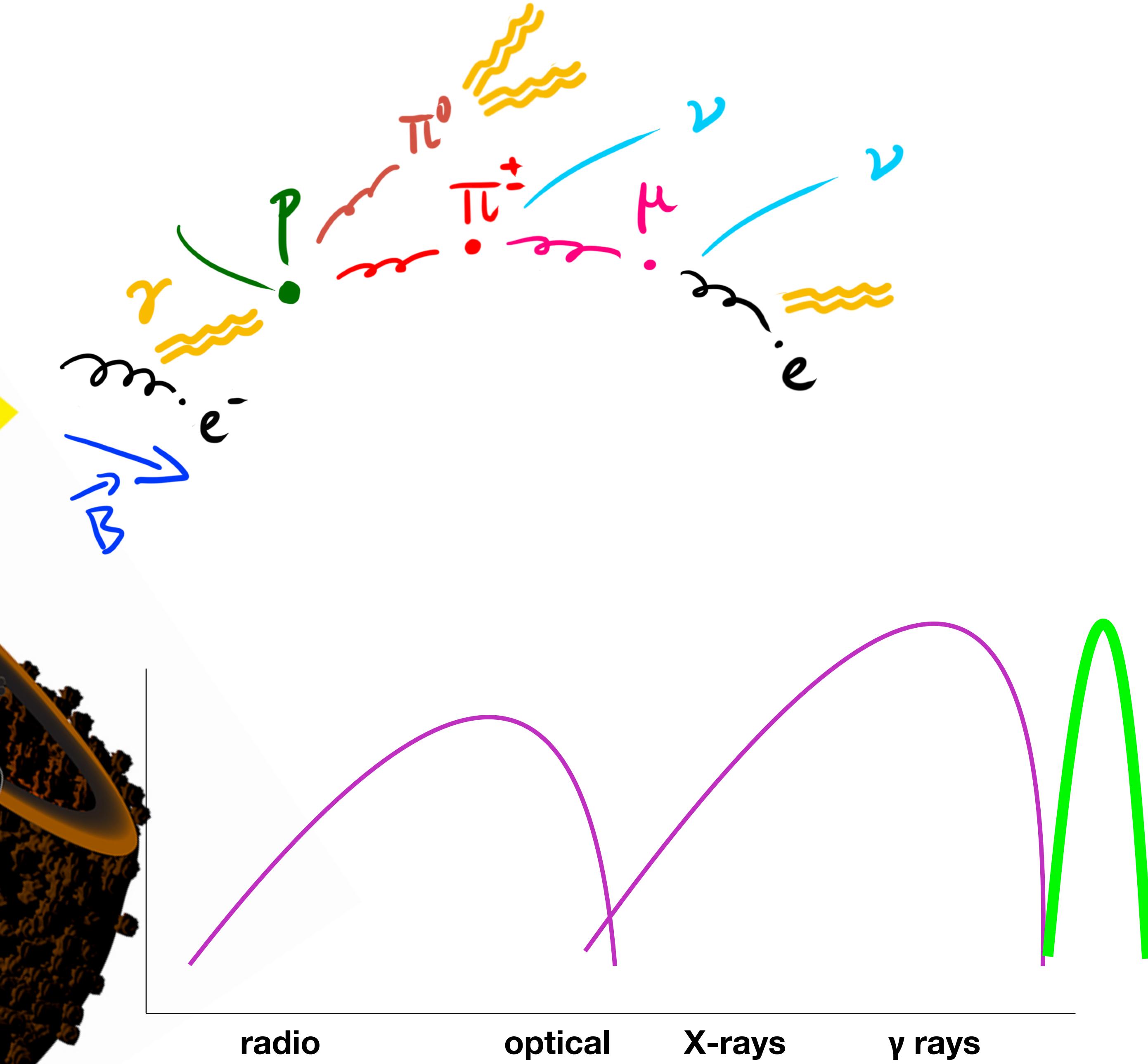
Credit: Bill Saxton, NRAO/AUI/NSF



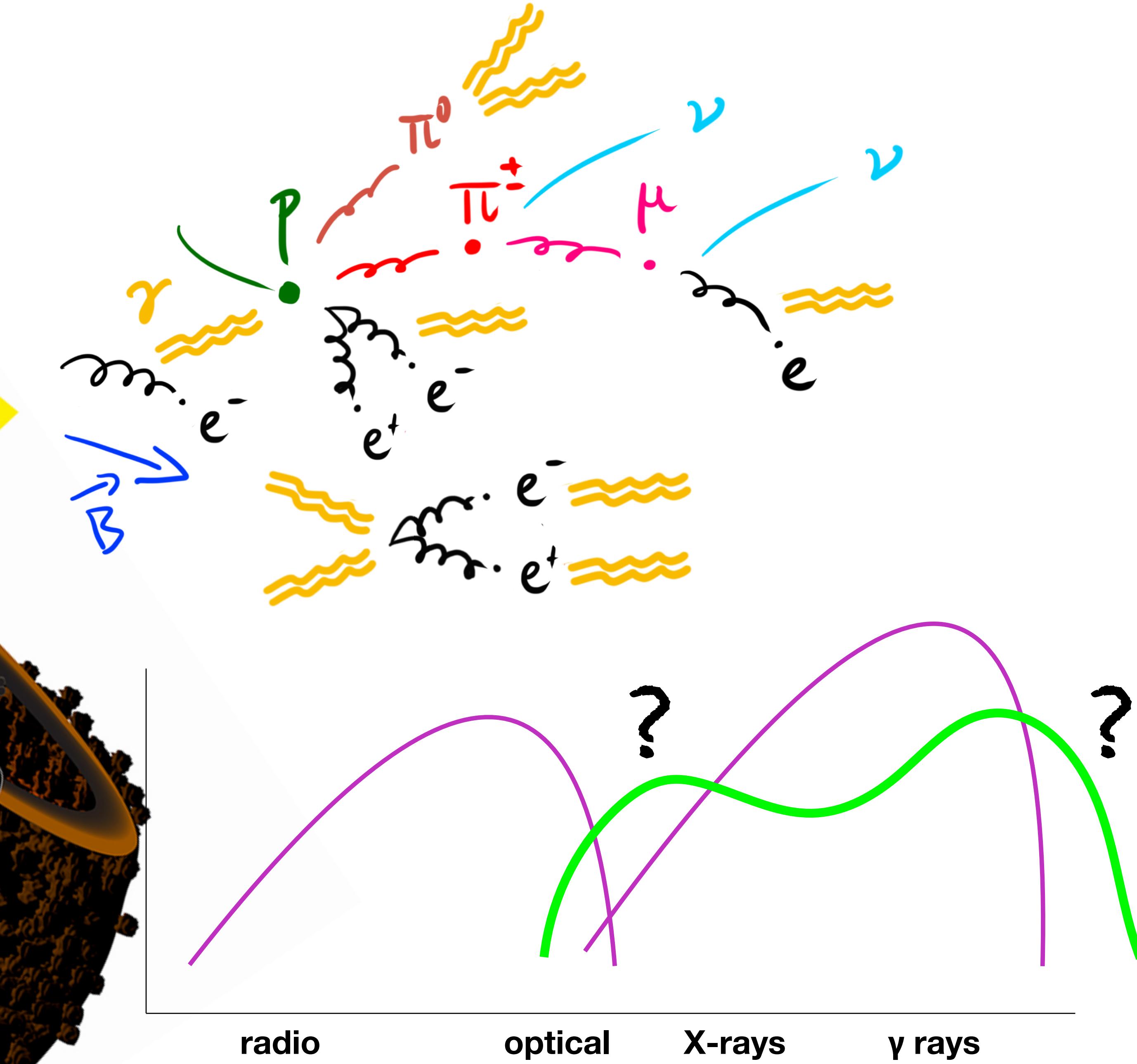
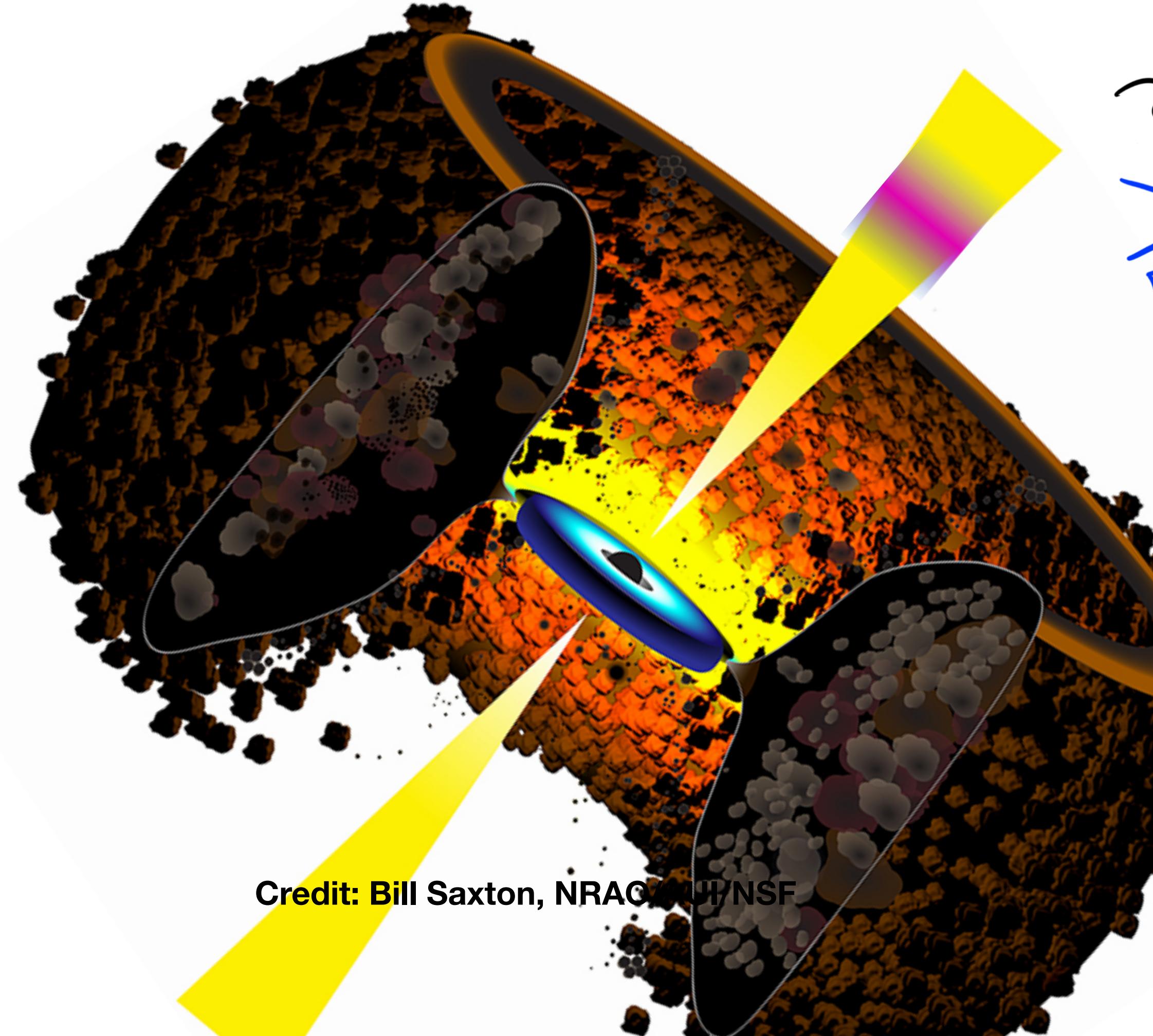
Modeling active galaxies



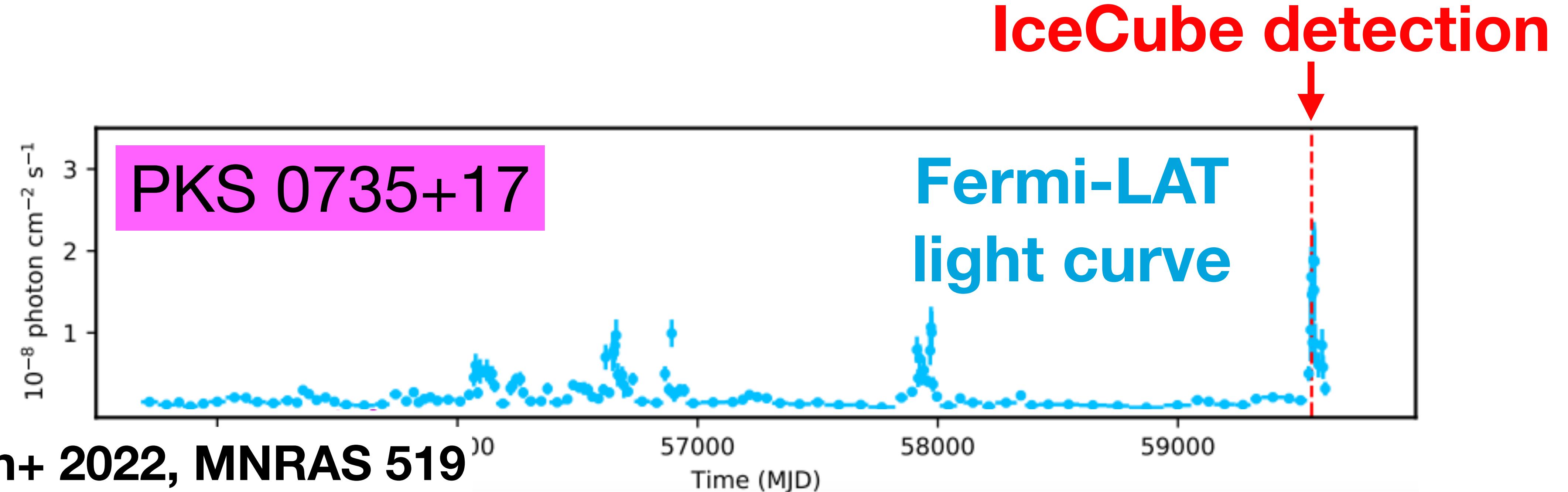
Credit: Bill Saxton, NRAO/AUI/NSF



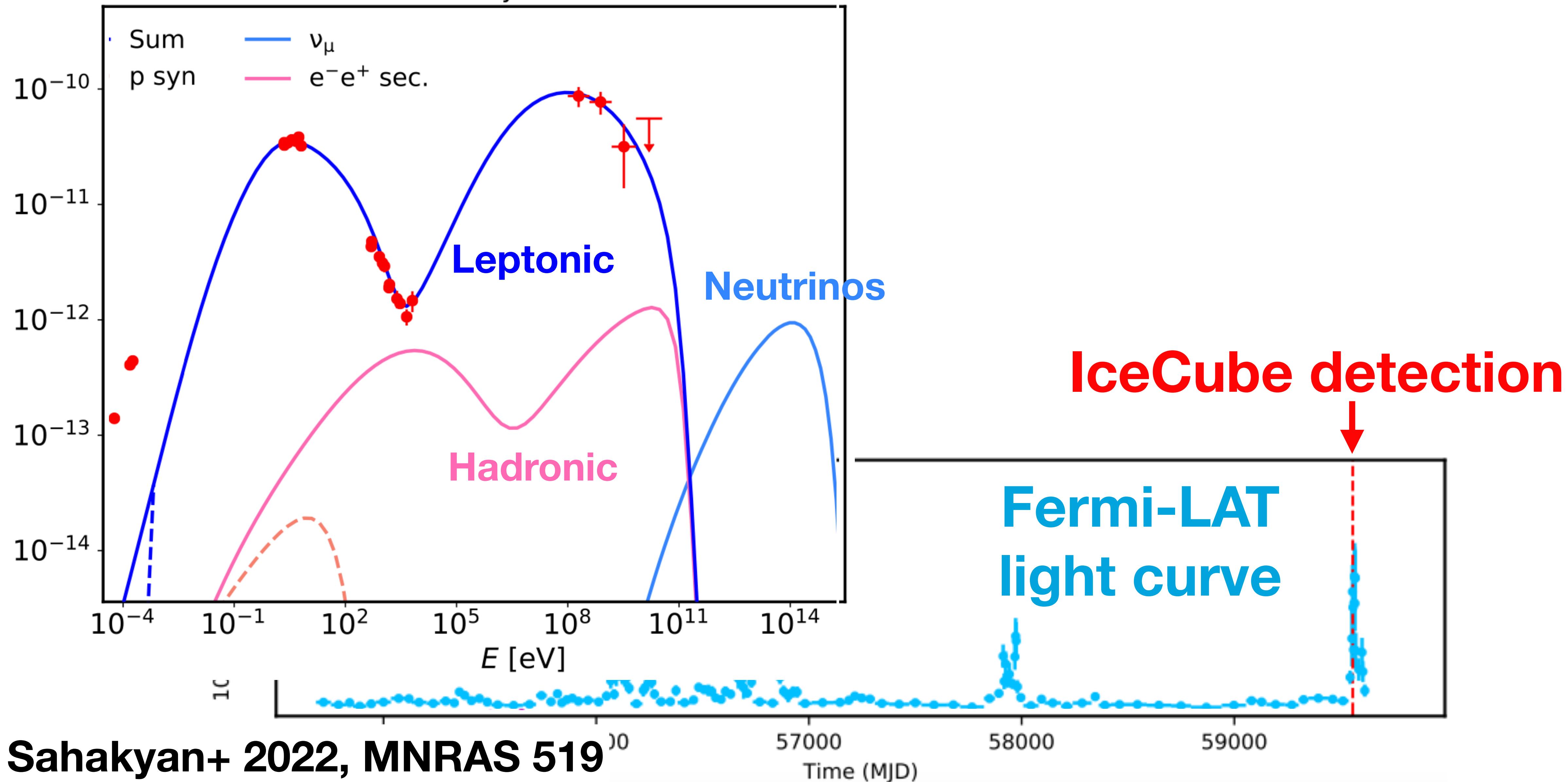
Modeling active galaxies



What is a hadronic signature?



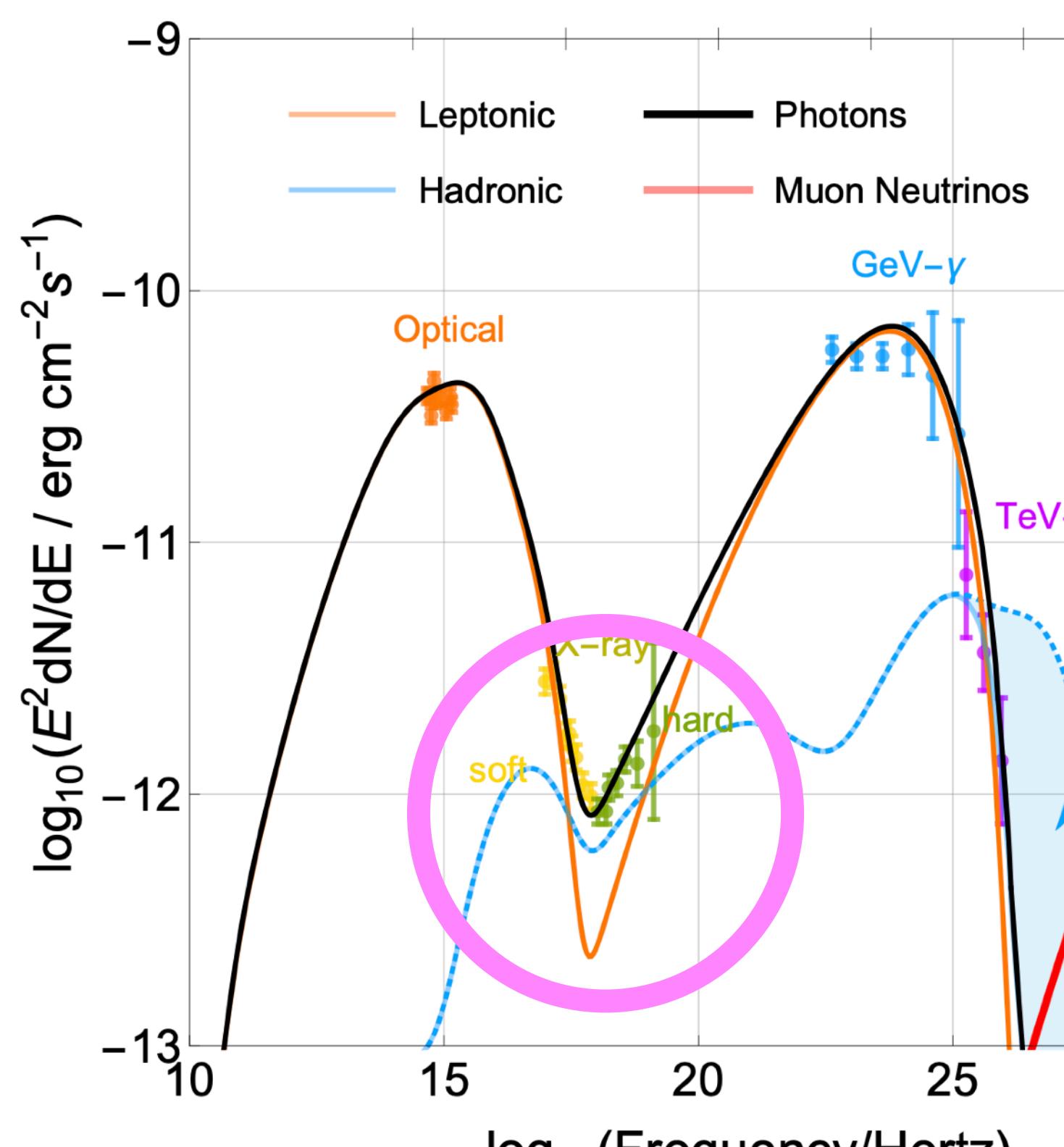
What is a hadronic signature?



What is a hadronic signature?

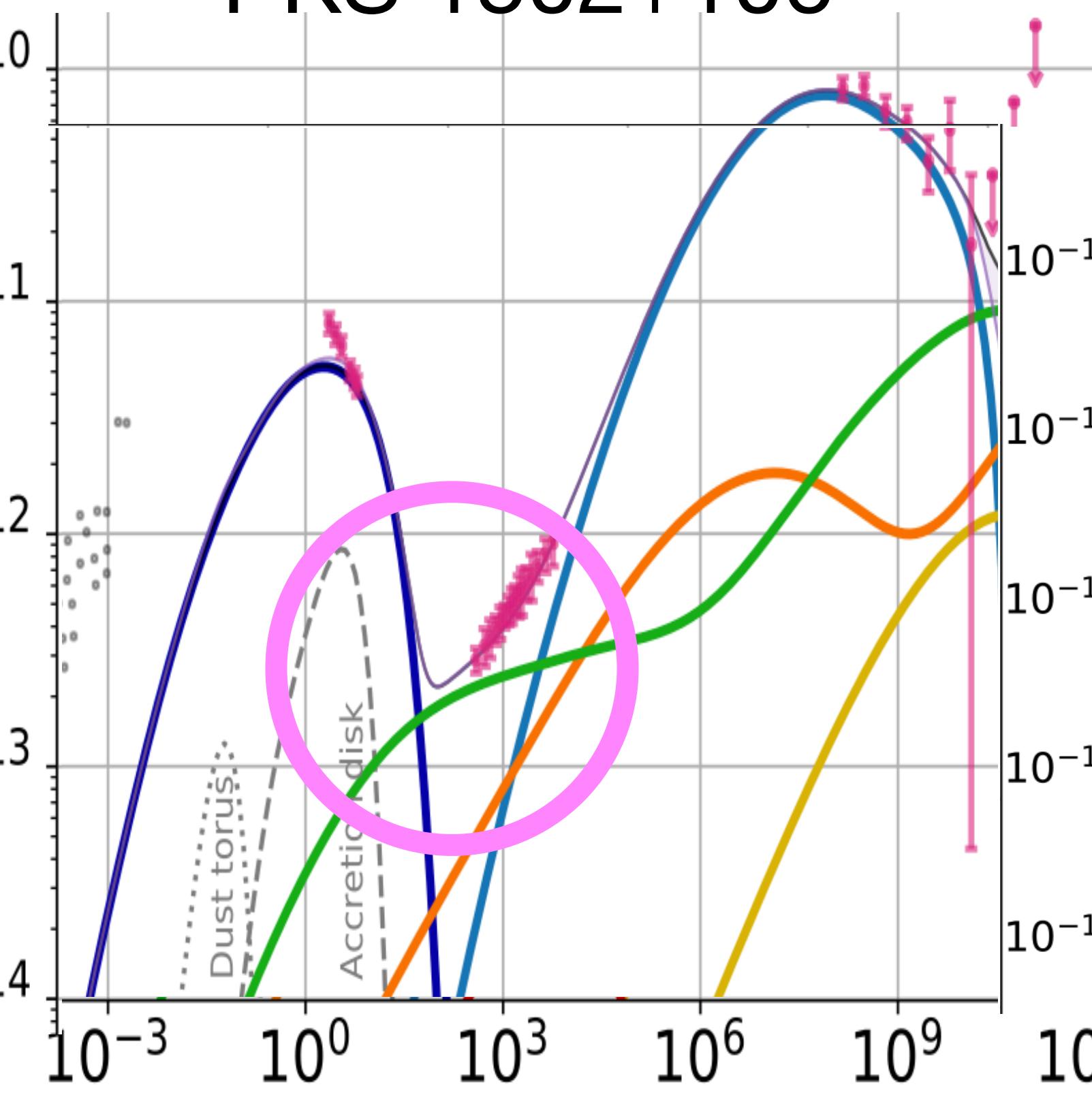
See also talk by G. Clairfontaine
tomorrow, neutrino session

TXS 0506+056



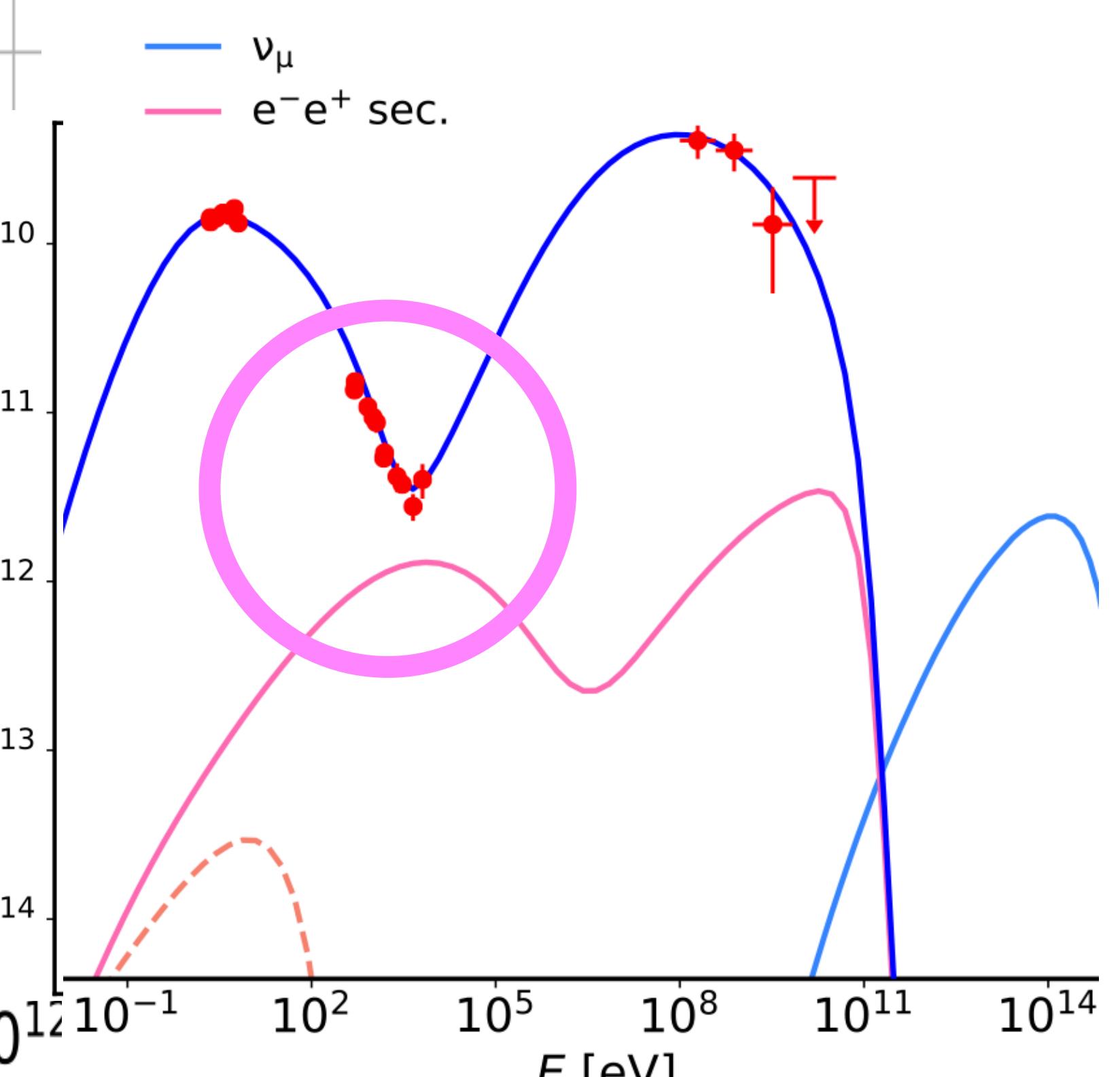
Gao+ 2019

PKS 1502+106



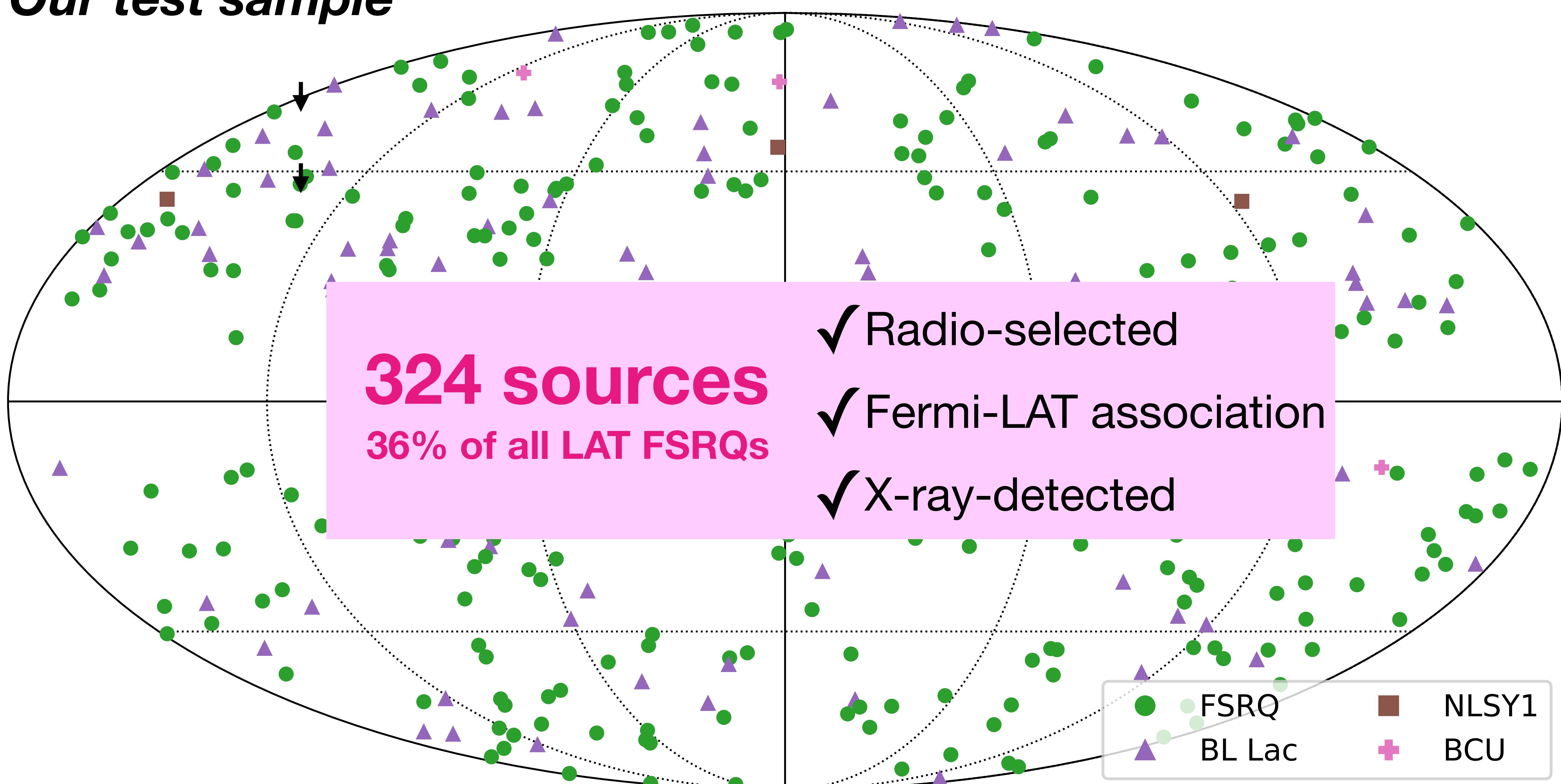
Rodrigues+ 2021

PKS 0735+17

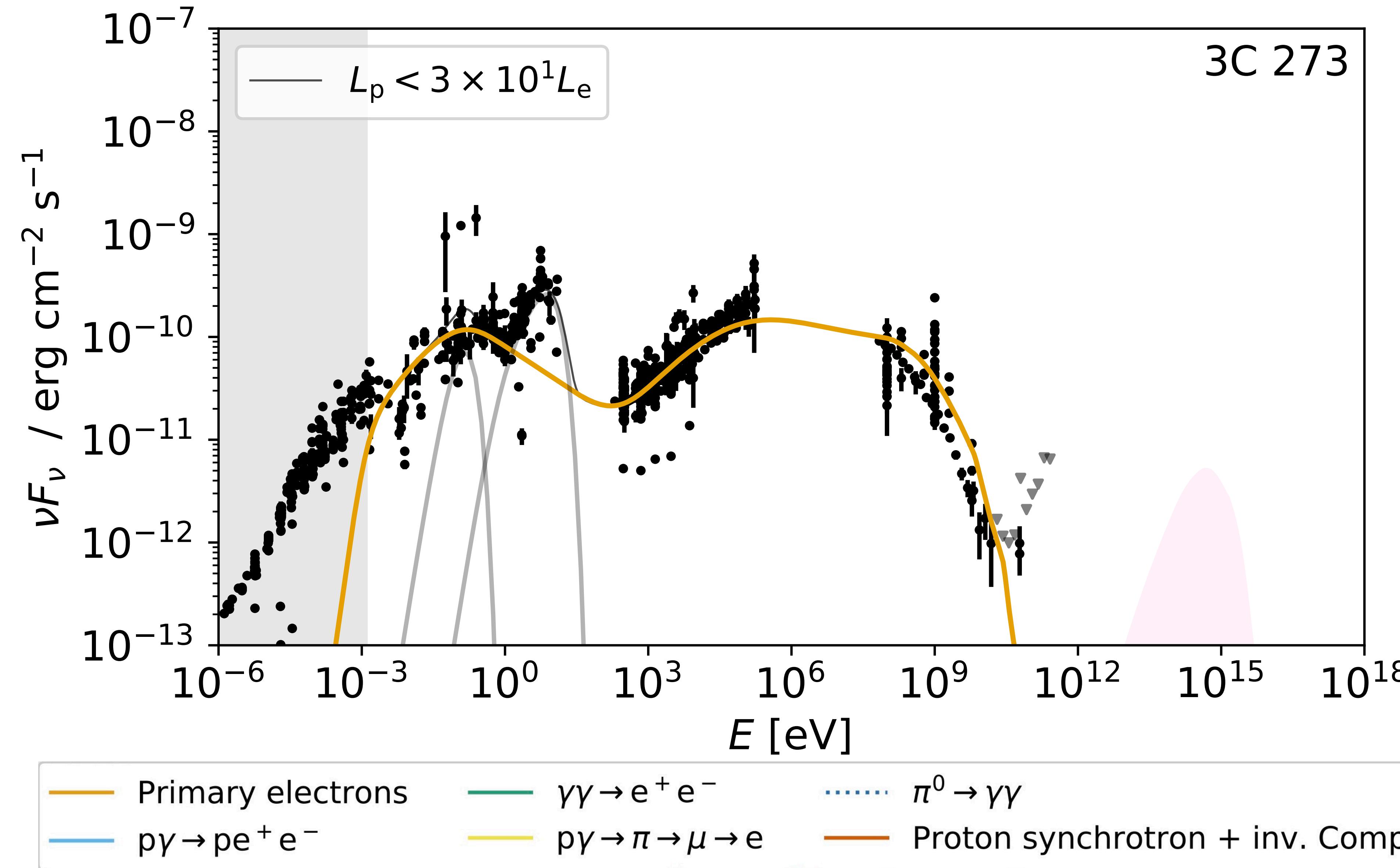


Sahakyan+ 2022

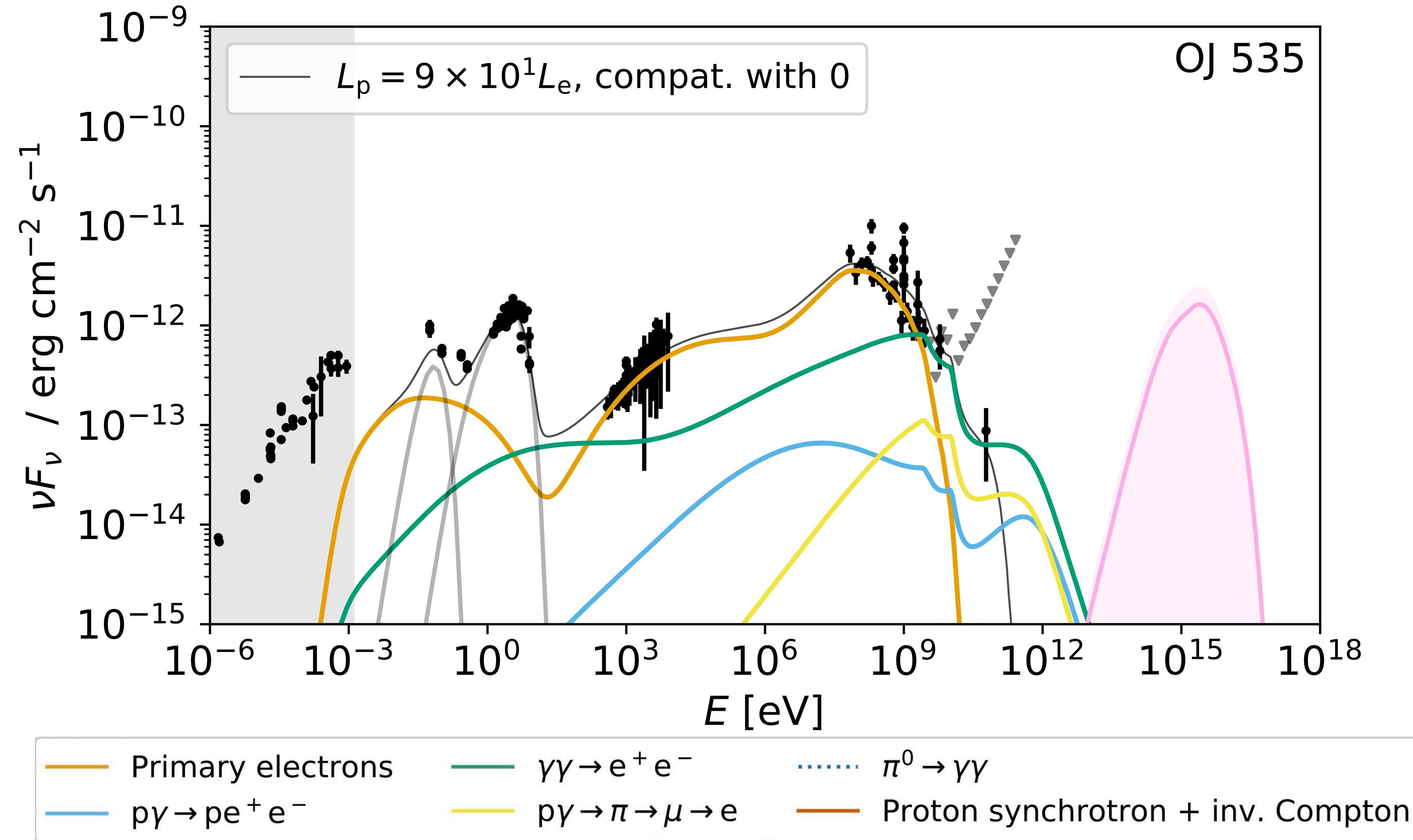
Our test sample



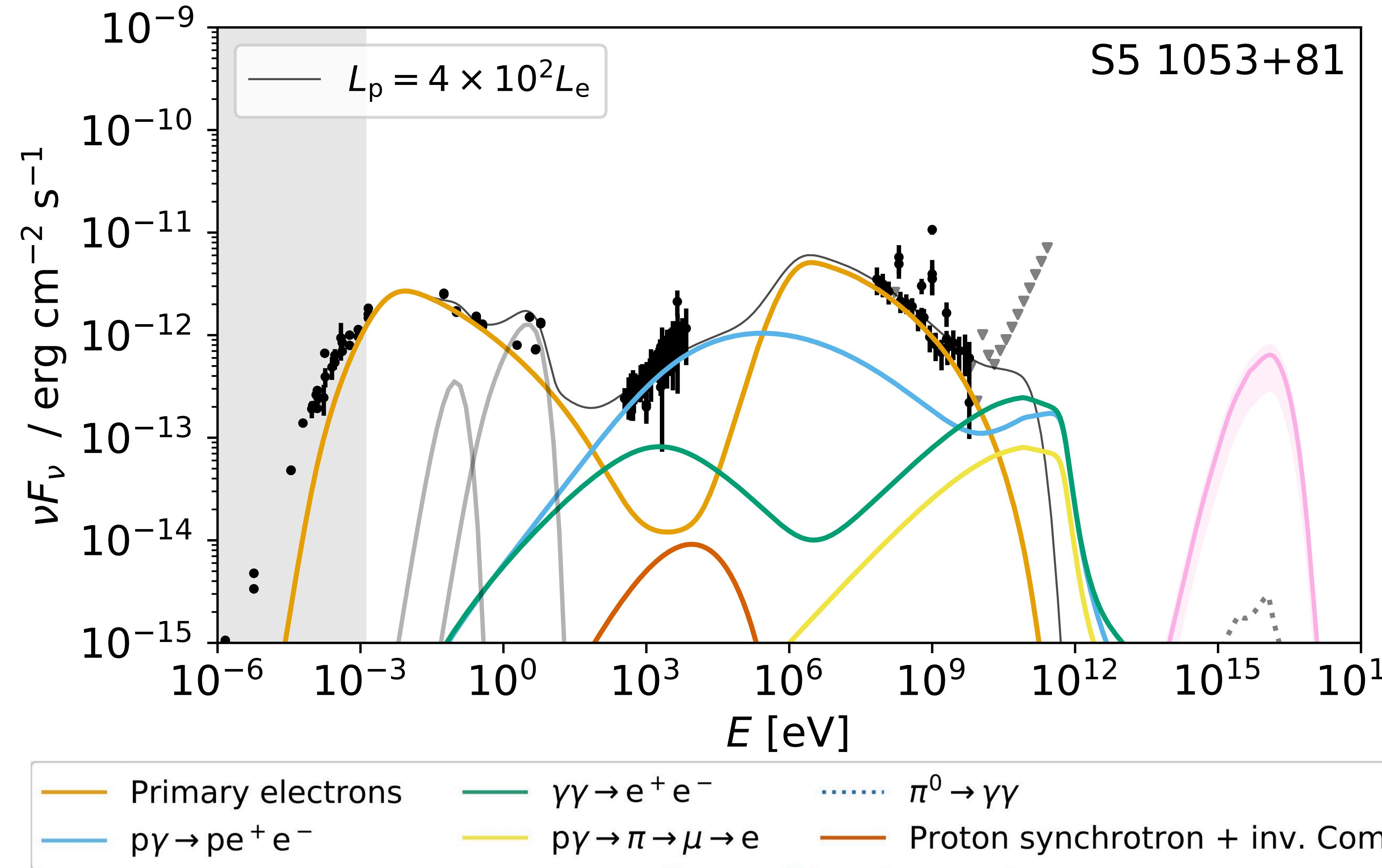
Best-fit solution is leptonic (66% of the sample):



Hadronic cascades help explain X-rays or VHE gammas (14% of the sample):

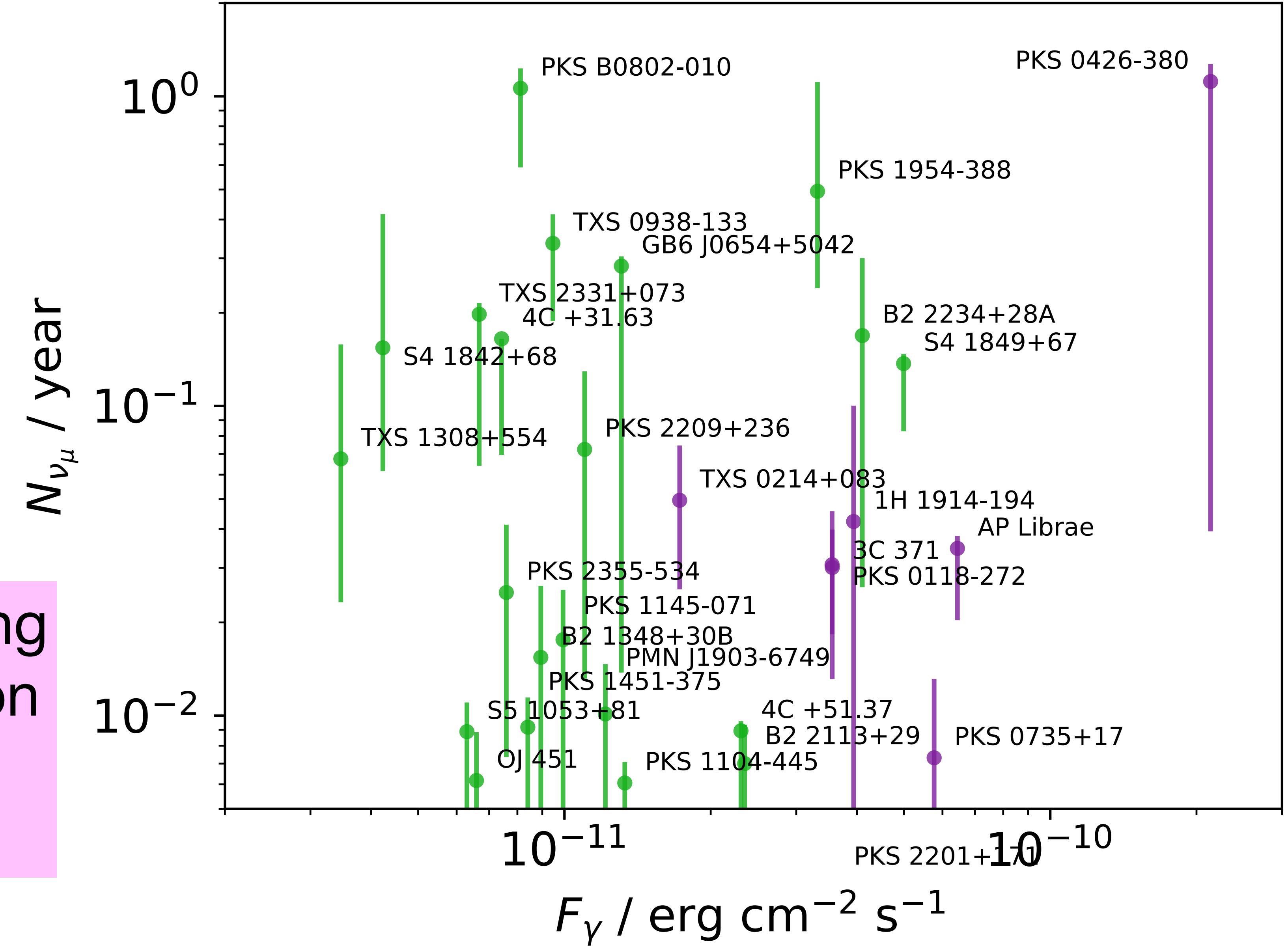


Hadronic cascades dominate X-ray emission (20% of the sample):



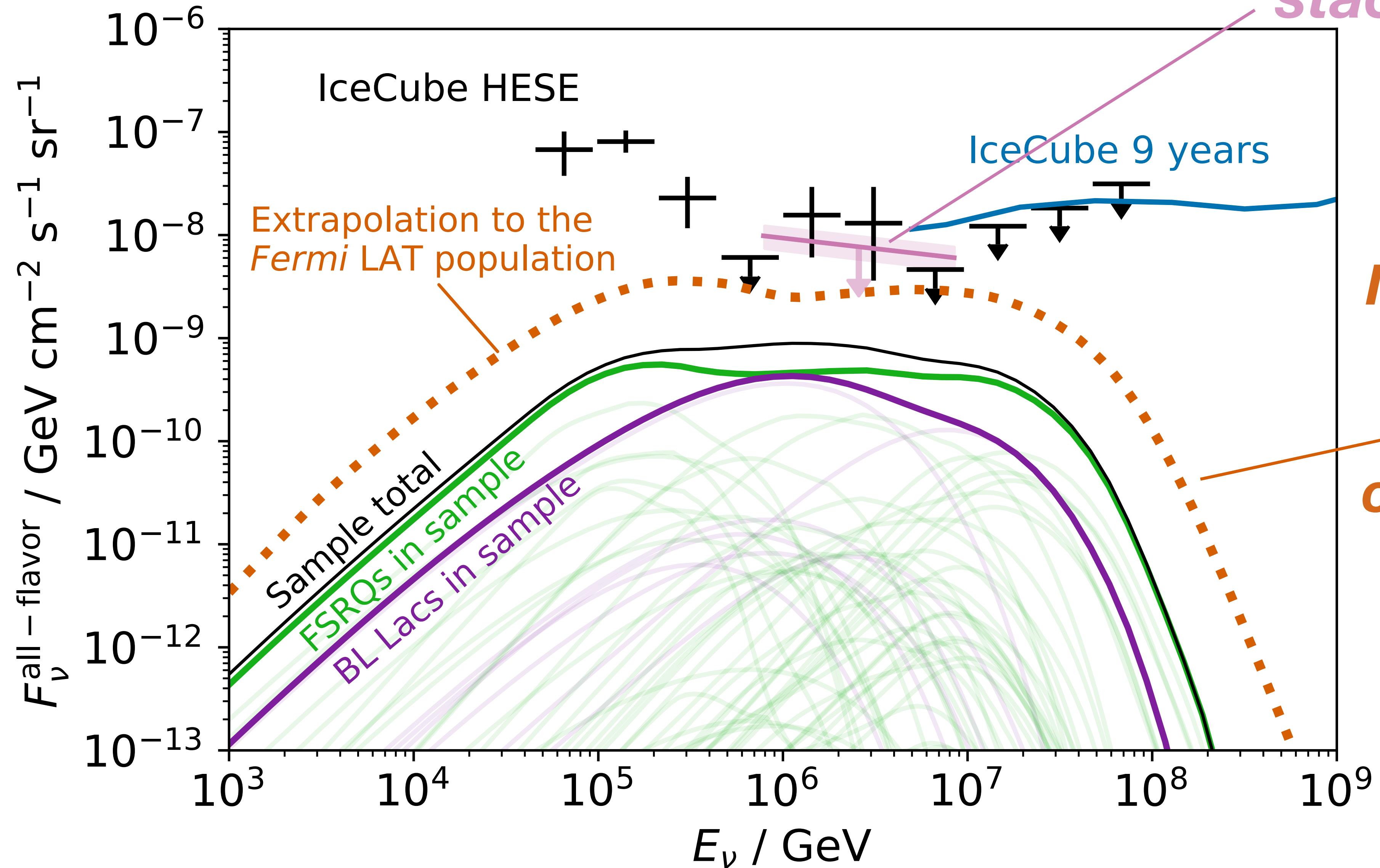
Predicted event rates

IceCube-Gen2



Gen2 will start probing
steady-state emission
from the blazar
population

Predicted diffuse flux



*IceCube
stacking limit*

*In this model, the
the Fermi blazar
population
contributes ~20%
of the IceCube
diffuse flux*



 Xavier Rodrigues Added example notebook

Name

-  ..
-  1ES_1959+650_flux_components.pdf
-  1ES_1959+650_flux_total.pdf
-  1ES_1959+650_mw_data.csv
-  1ES_1959+650_neutrinos.csv
-  1ES_1959+650_photons.csv

All fit results
available on Git:

github.com/xrod/lephad-blazars



**Astrophysical Multiwavelength
and MultiMessenger
Computation Software**

**Coming out this
year as open
source software!**



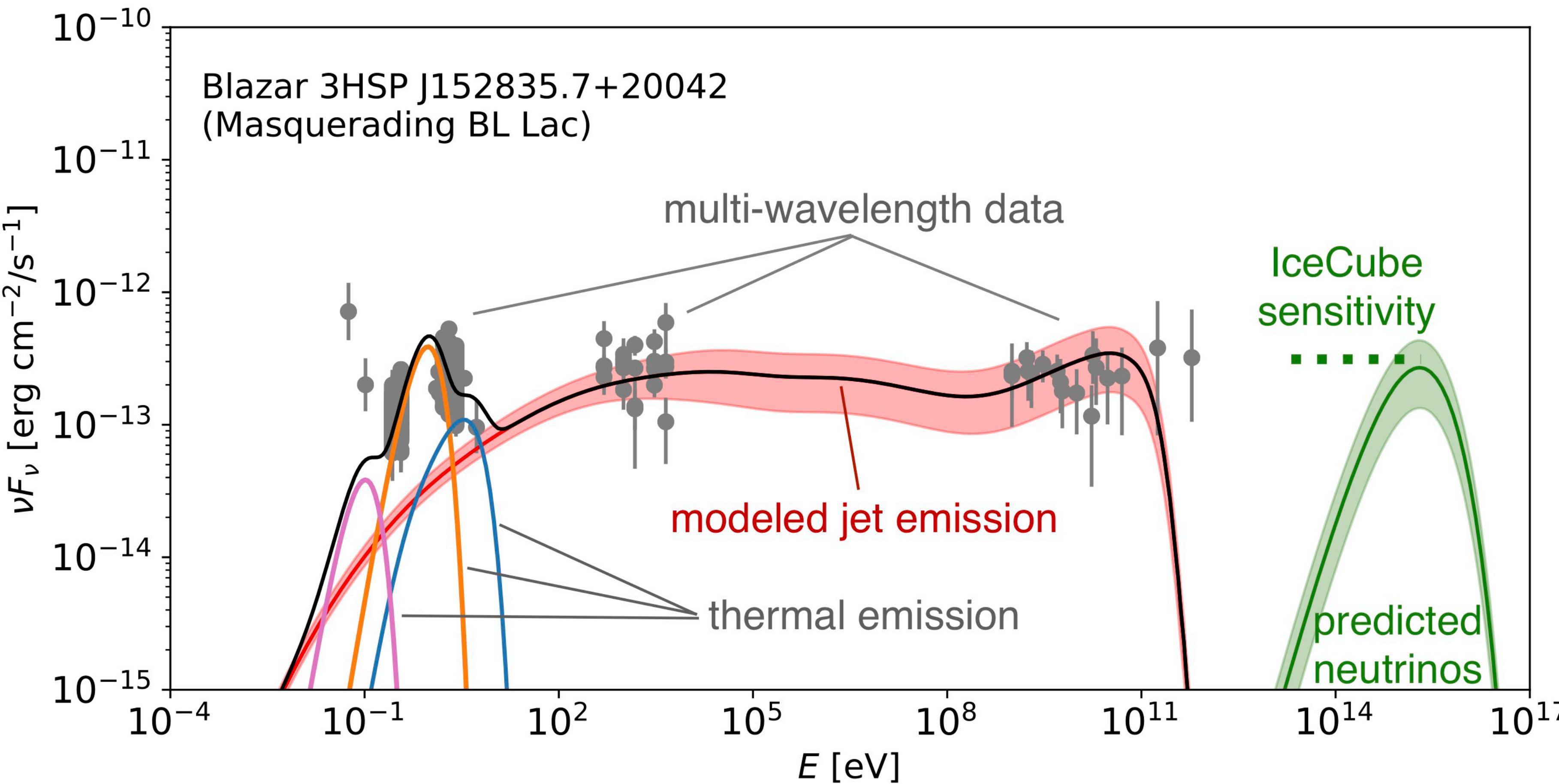
Gao+ 2017, ApJ 843

Spectra of IceCube Neutrino Candidate Sources (SIN)

Padovani+ 2021

Paiano+ 2022

Paiano+ 2023



Ongoing collaboration with

| | |
|----------------|--------------|
| P. Padovani | M. Karl |
| P. Giommi | M. Wolf |
| S. Paiano | C. Bellenghi |
| R. Falomo | E. Resconi |
| M. Petropoulou | F. Oikonomou |

Summary

We have described MW emission from 324 gamma-ray blazars, most of which FSRQs

Best-fit parameters and SED fits publicly available: github.com/xrod/lephad-blazars

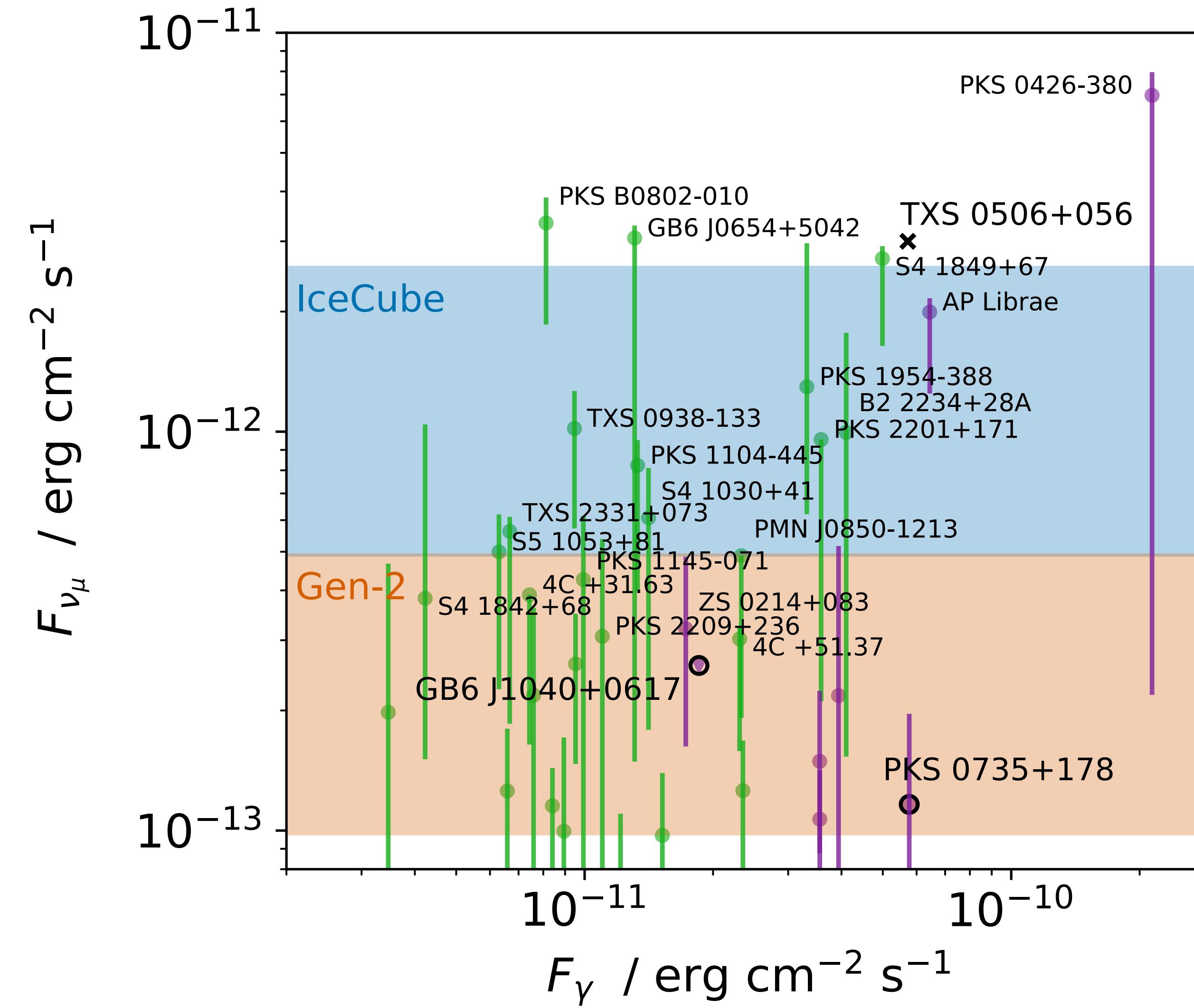
IceCube detects spurious hadronic blazar flares -> Gen2 could unveil population

Currently working on describing the role of IBLs+HBLs as neutrino emitters

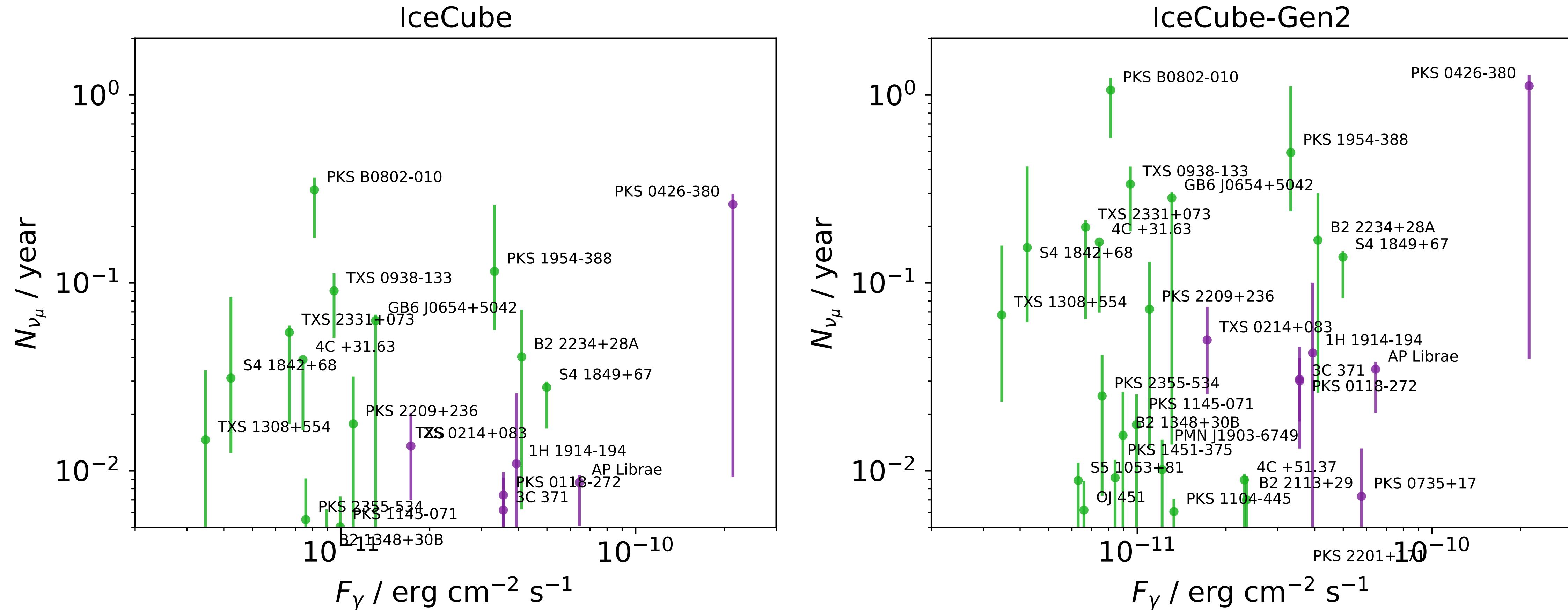
We start to connect individual source modeling to the population scale

Backup slides

Predicted muon neutrino fluxes



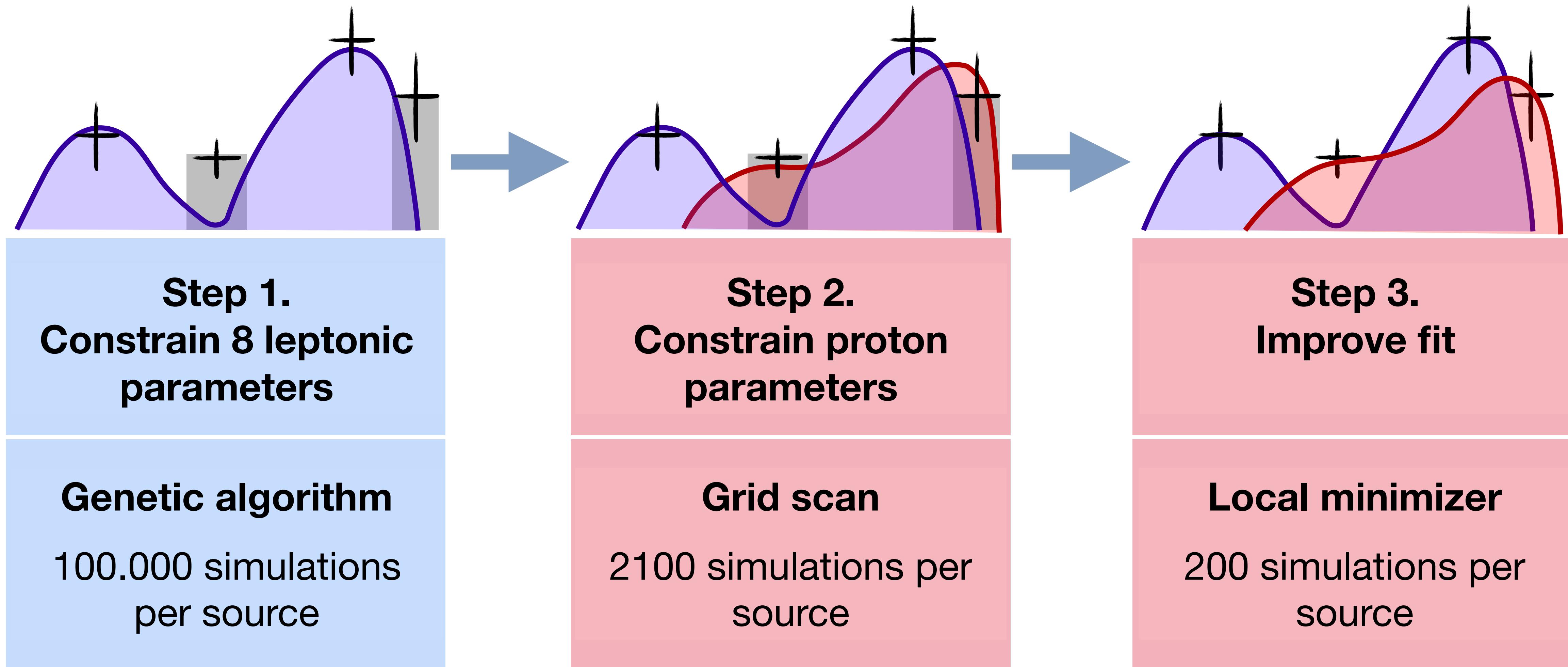
Predicted event rates



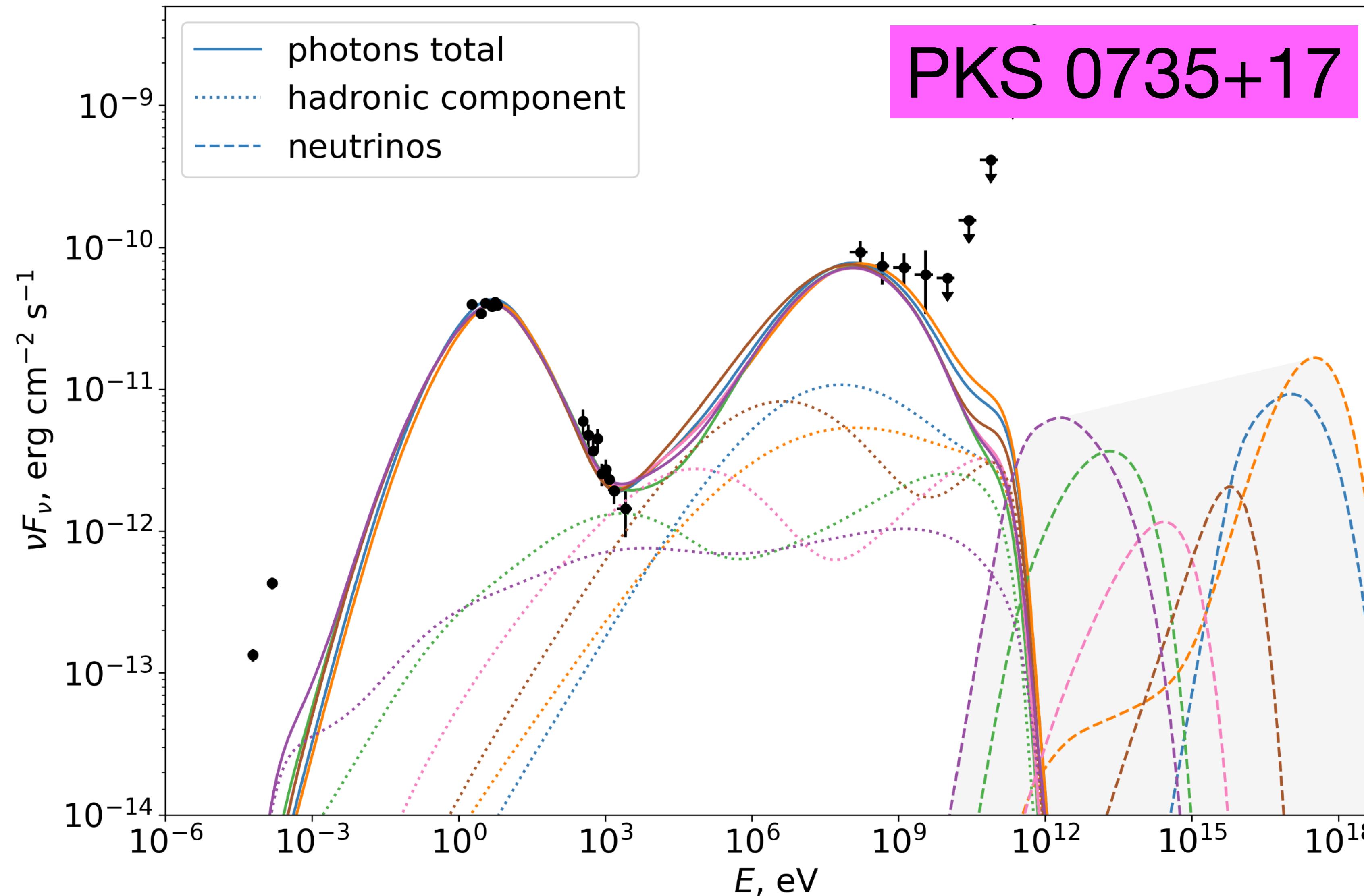
The model predicts low average detection rates from blazars

Gen2 will start probing steady-state emission from the blazar population

Fitting method for each blazar:

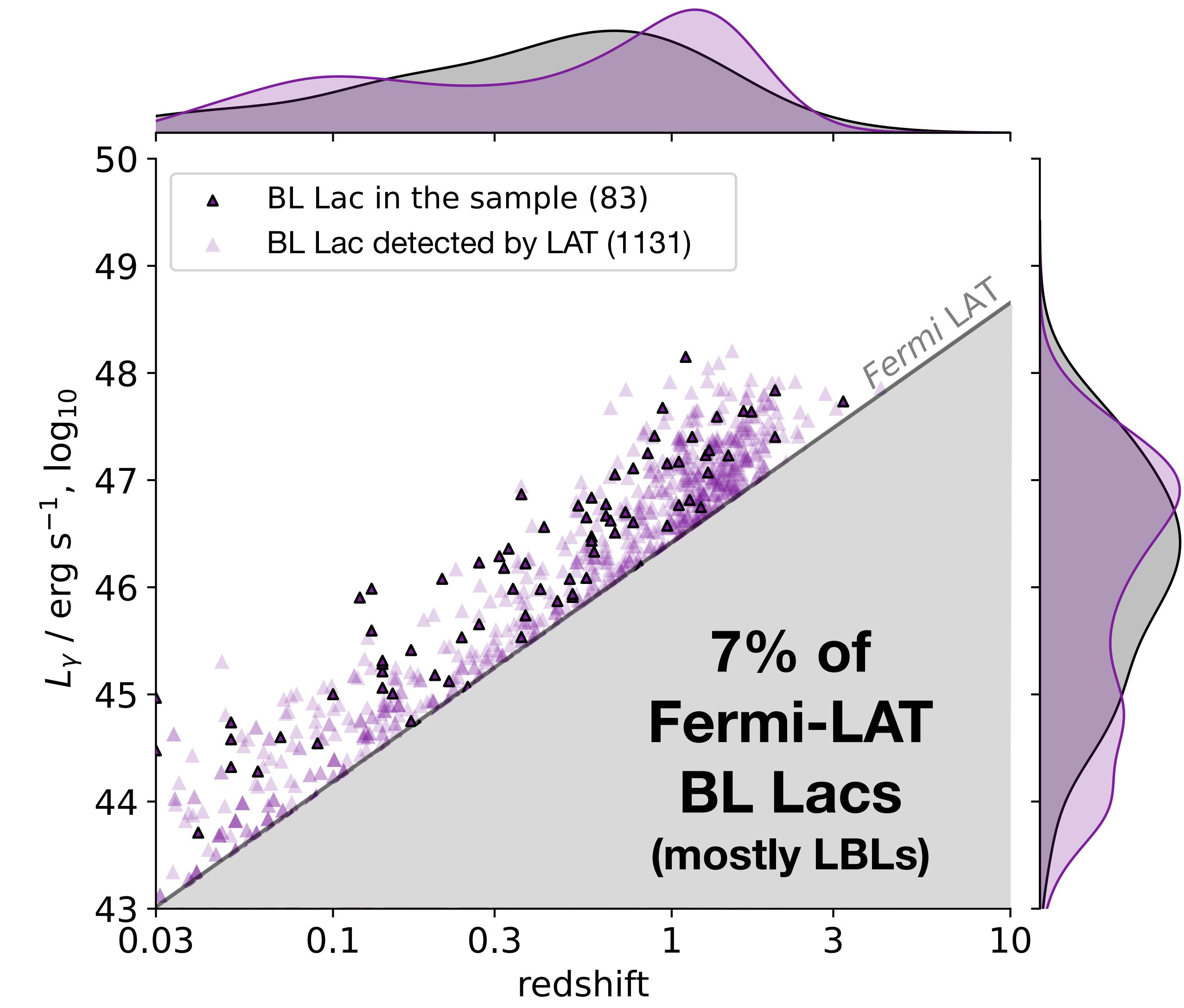
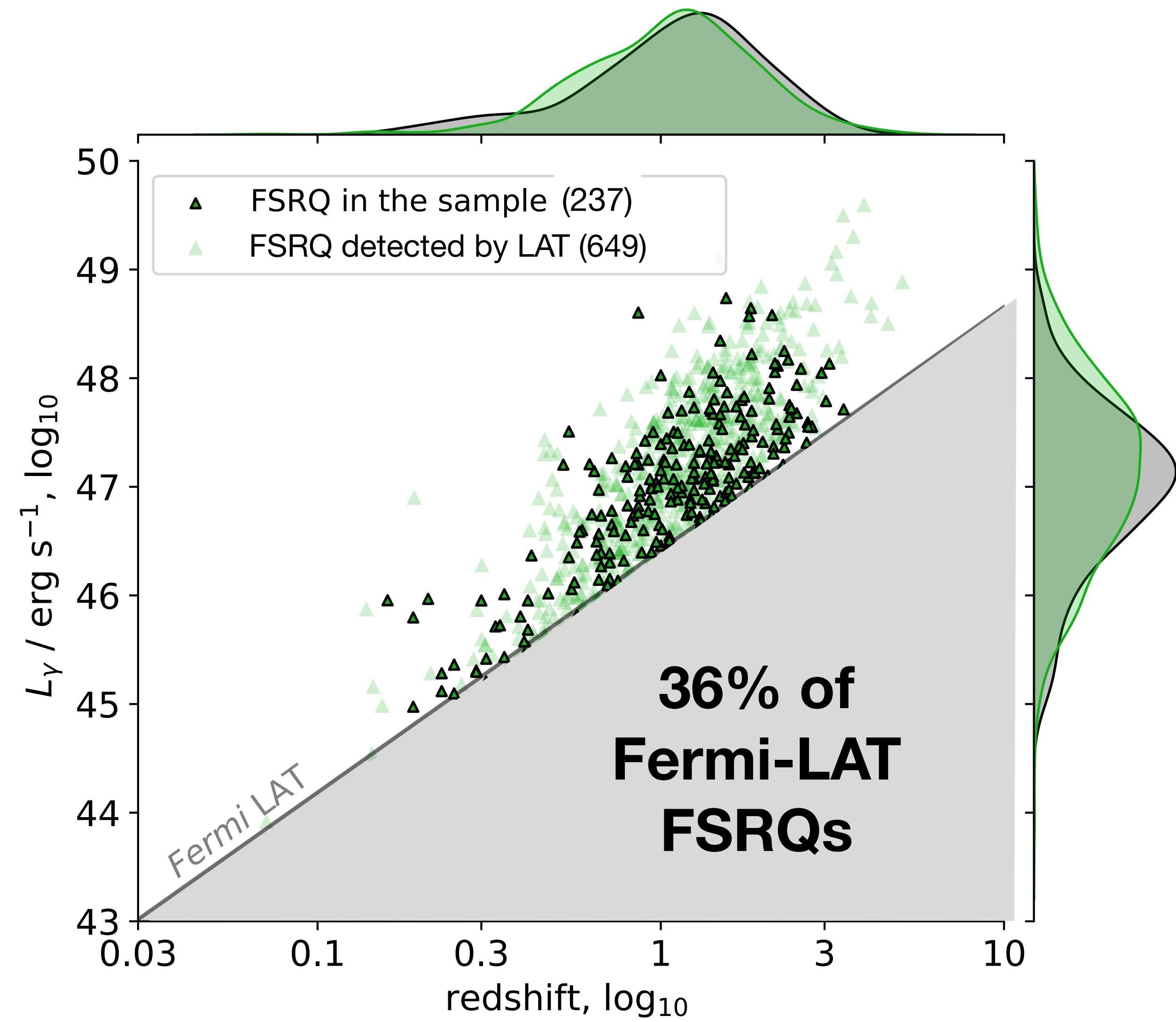


What is a hadronic signature?



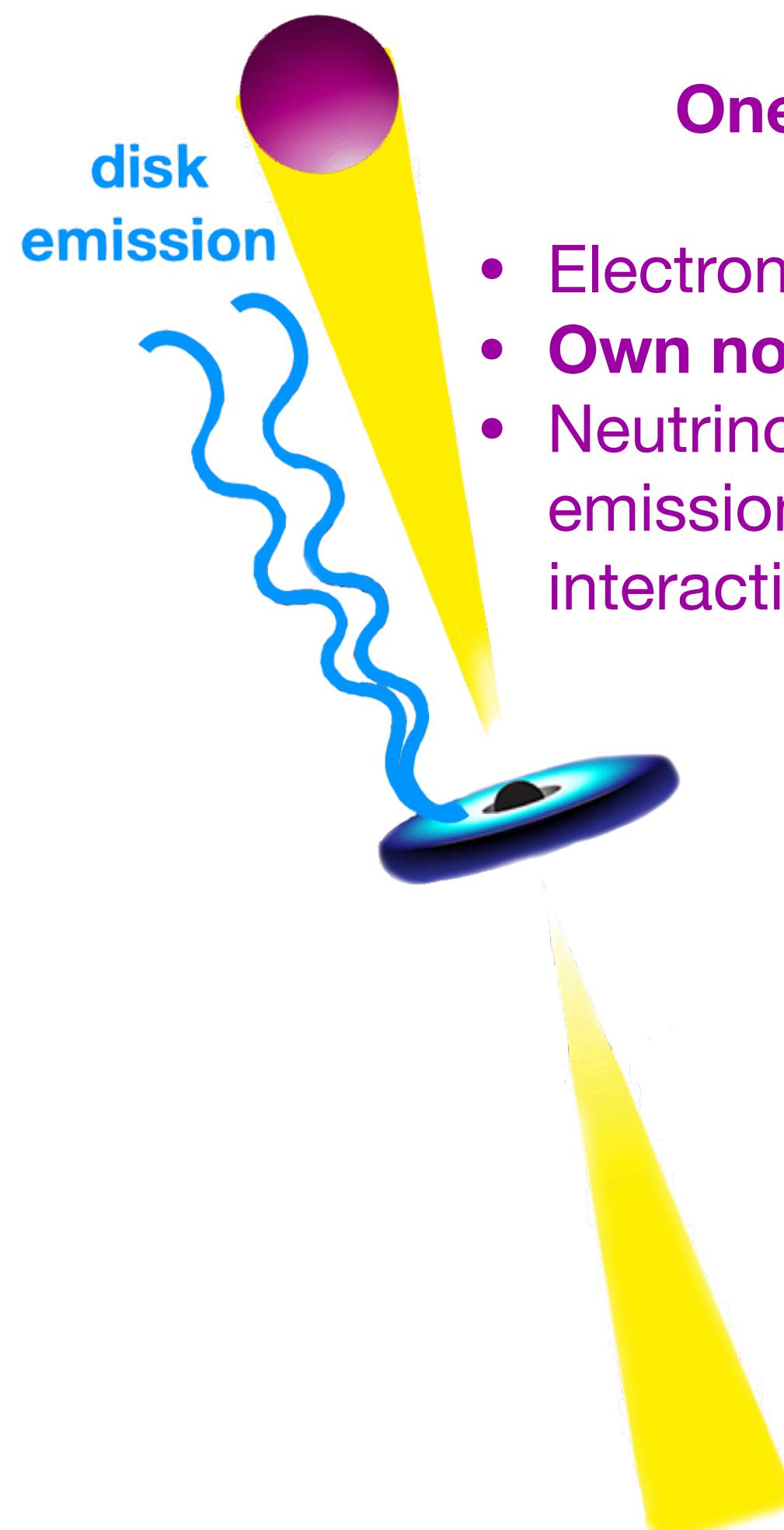
Omeliukh+ 2023 (ICRC proceedings)

Our sample



Multi-messenger models of blazar AGN

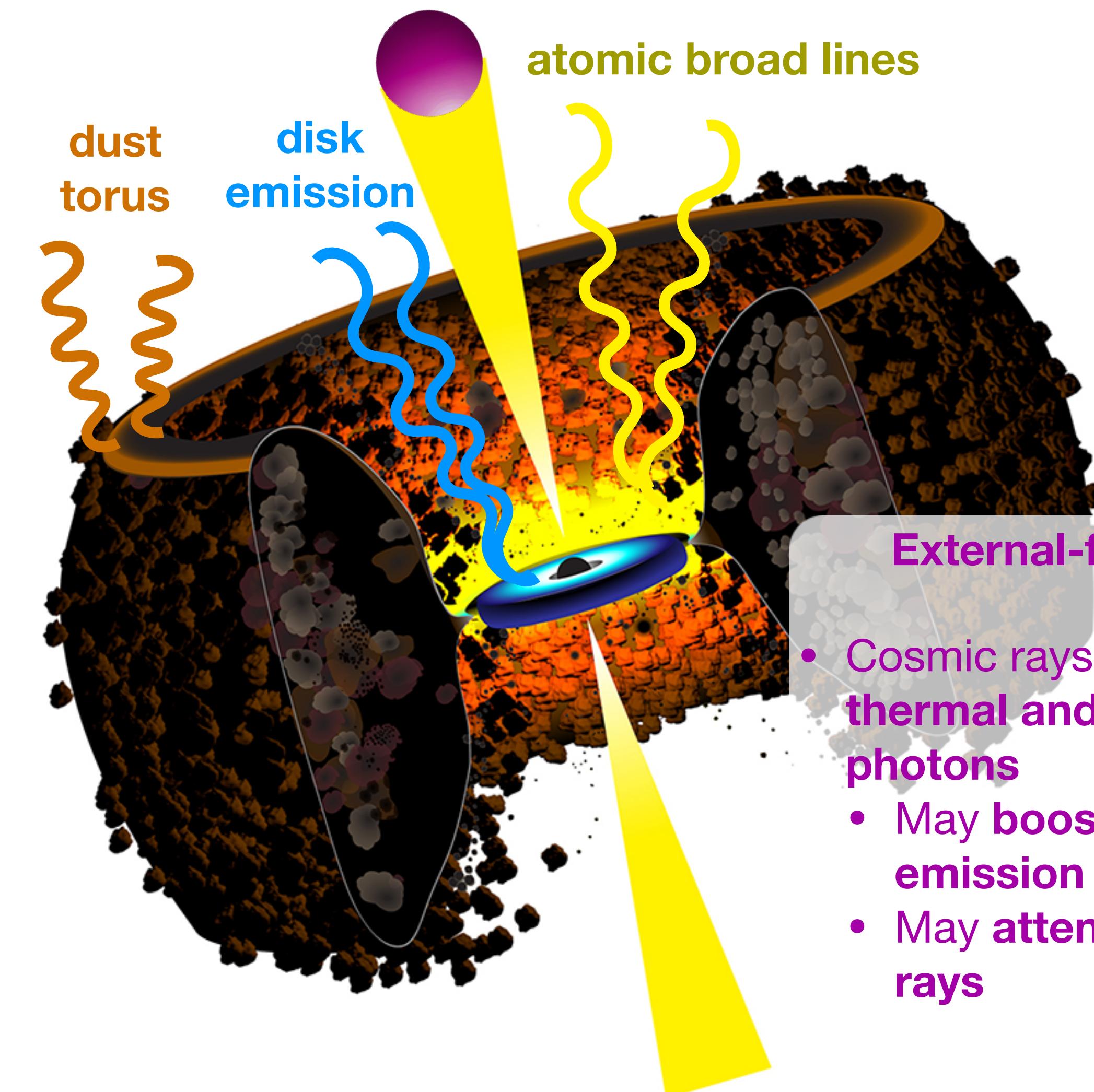
BL Lacs



One-zone model

- Electrons + cosmic rays
- **Own non-thermal radiation**
- Neutrino and gamma-ray emission from p-gamma interactions

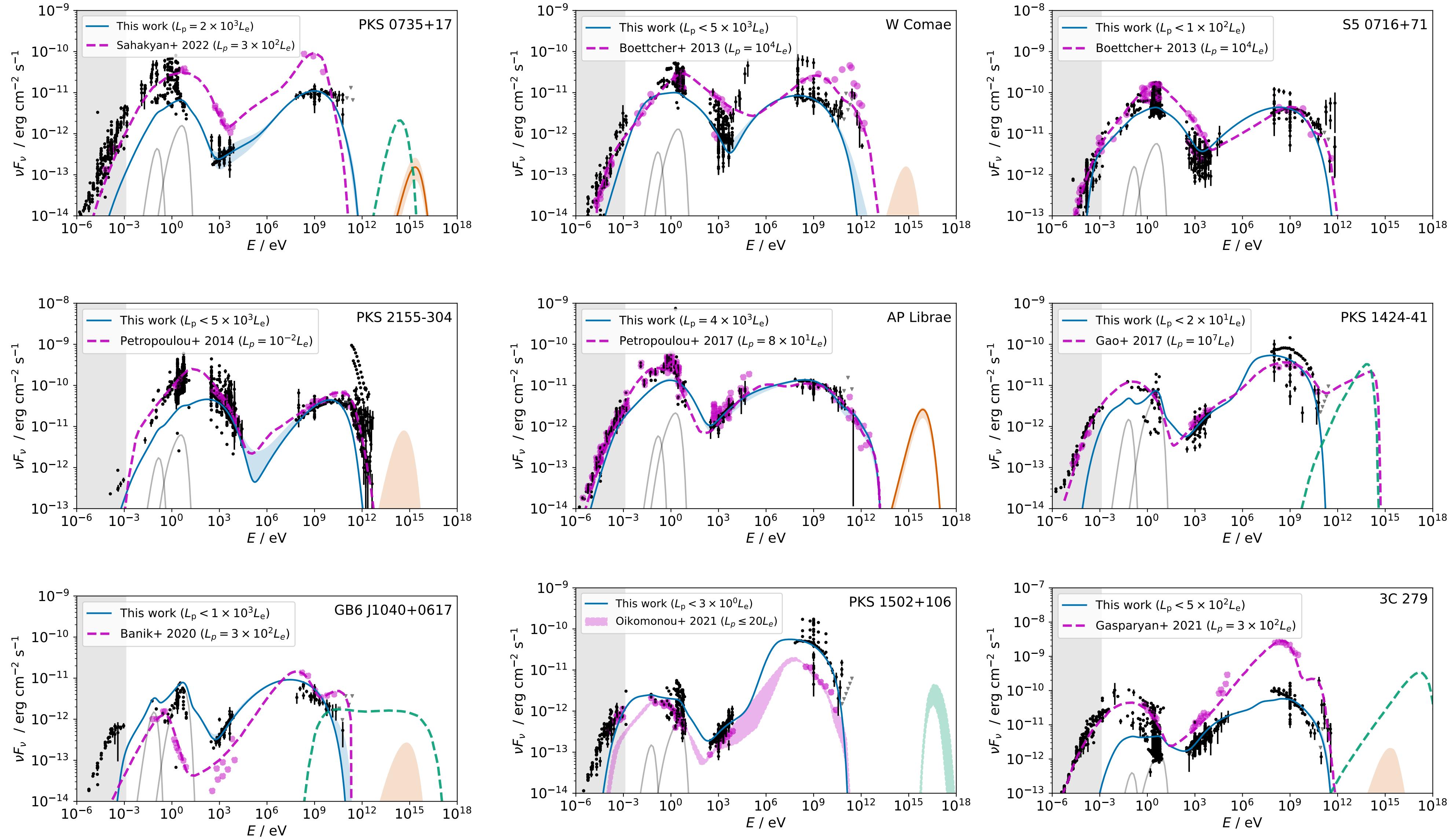
Flat-Spectrum Radio Quasars (FSRQs)

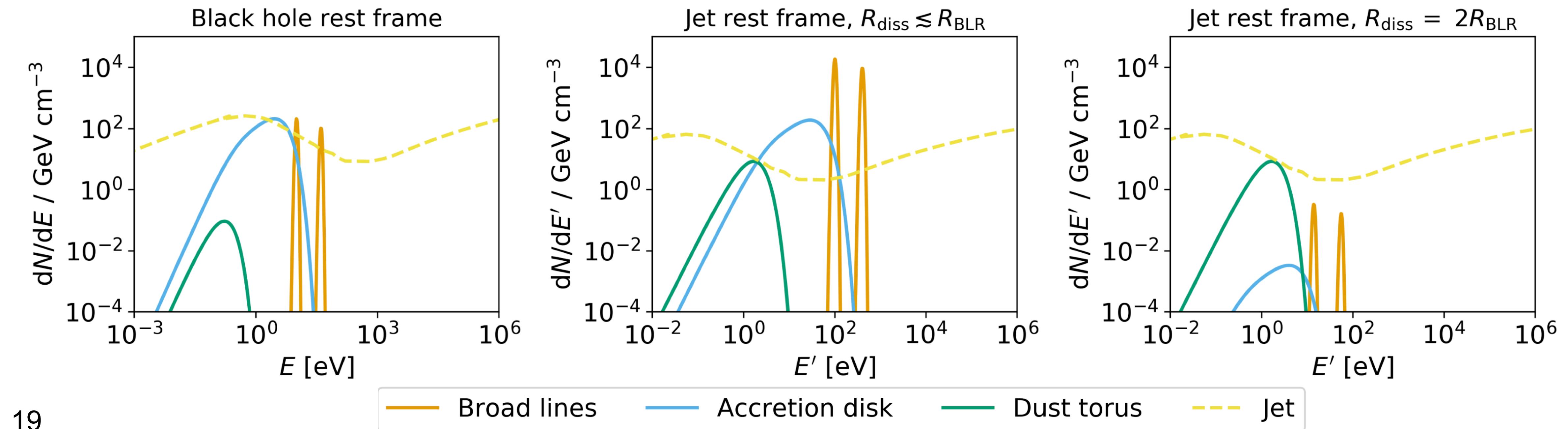
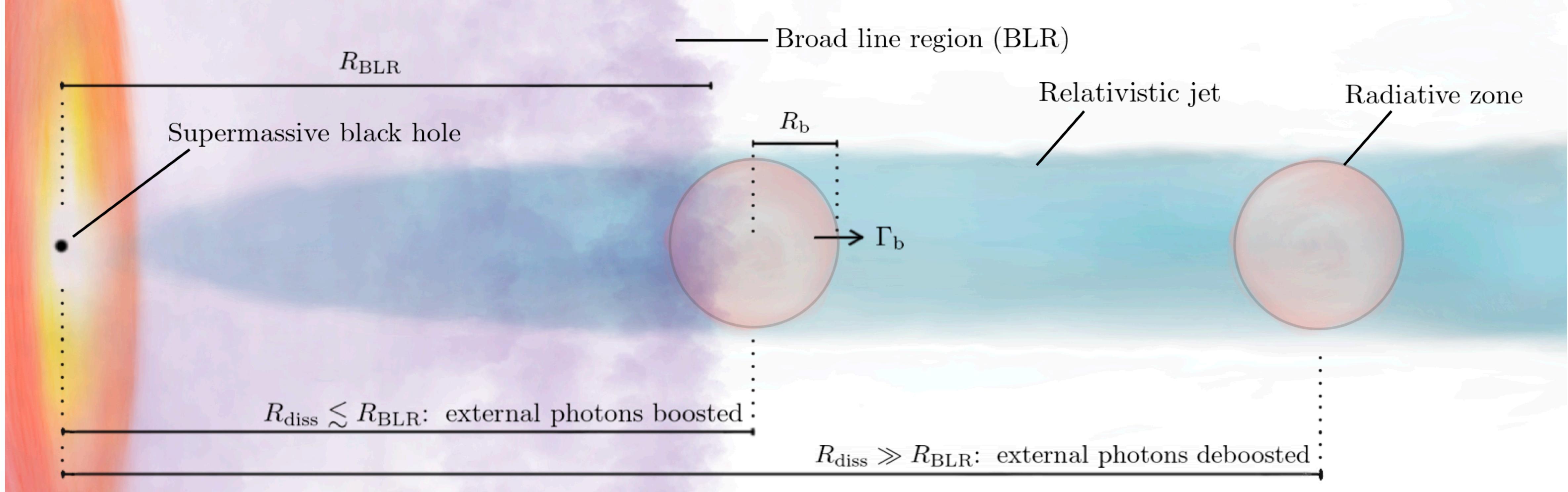


External-field model

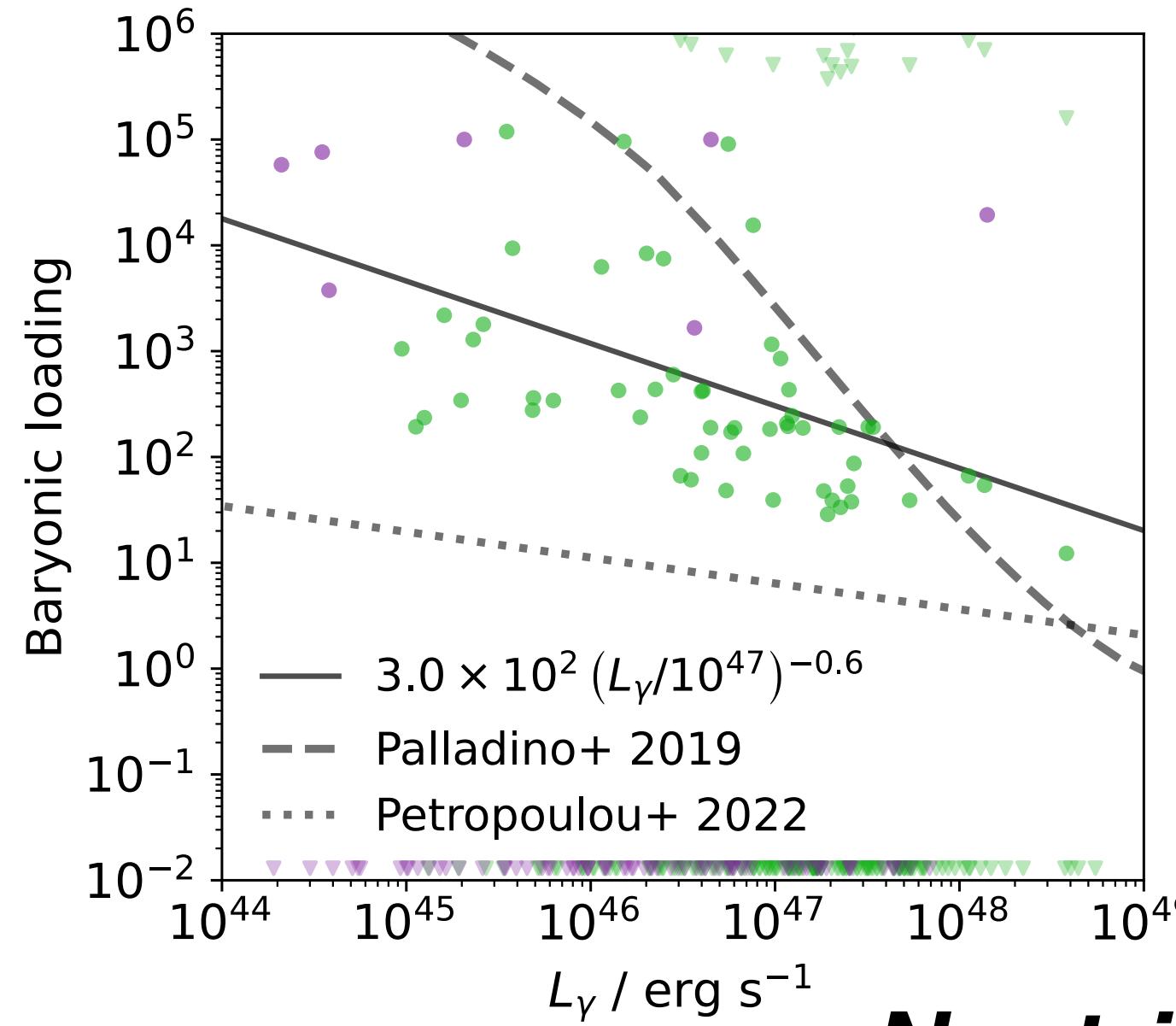
- Cosmic rays interact with **thermal and broad line photons**
 - May **boost neutrino emission**
 - May **attenuate gamma rays**

Credit: Bill Saxton, NRAO/AUI/

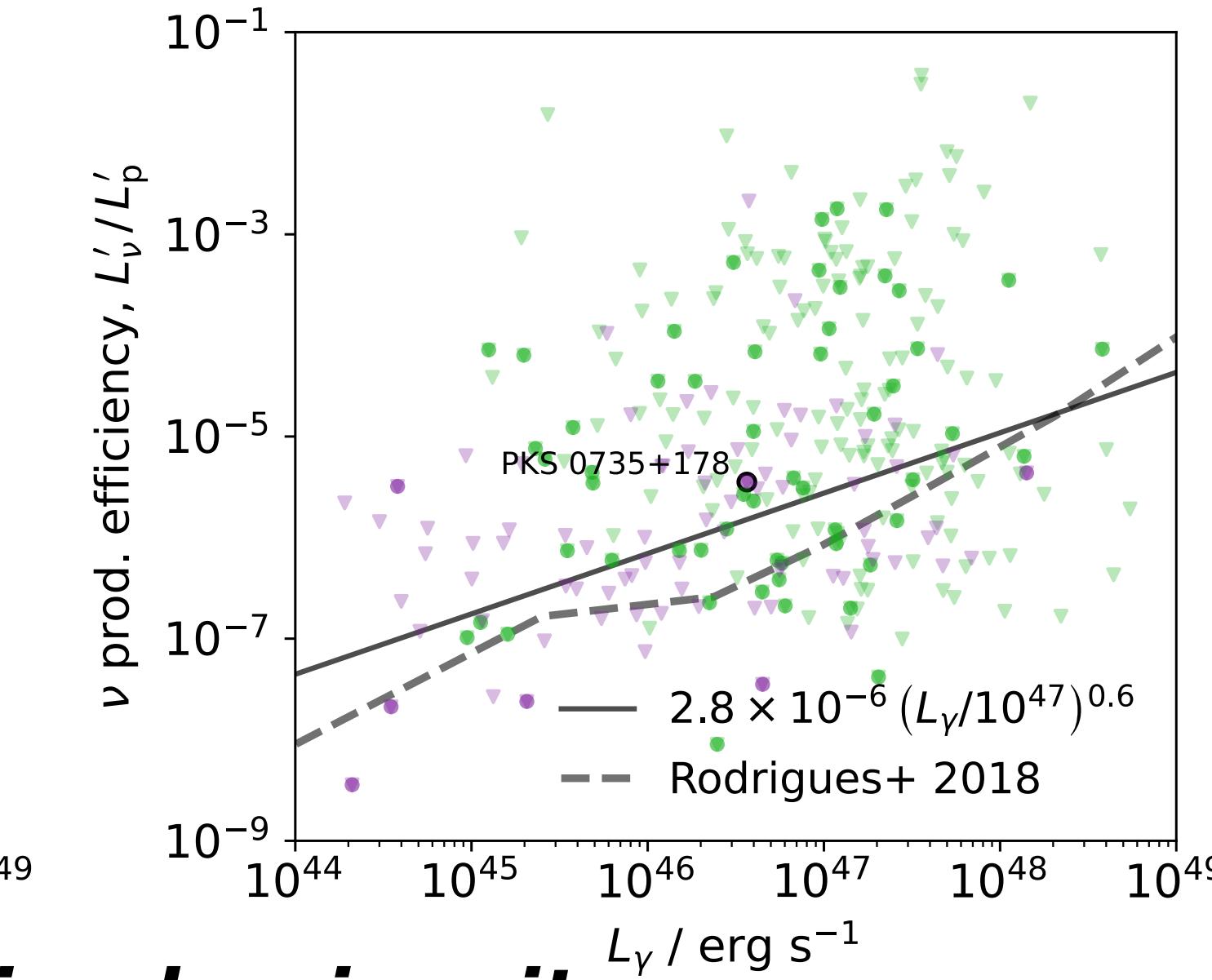




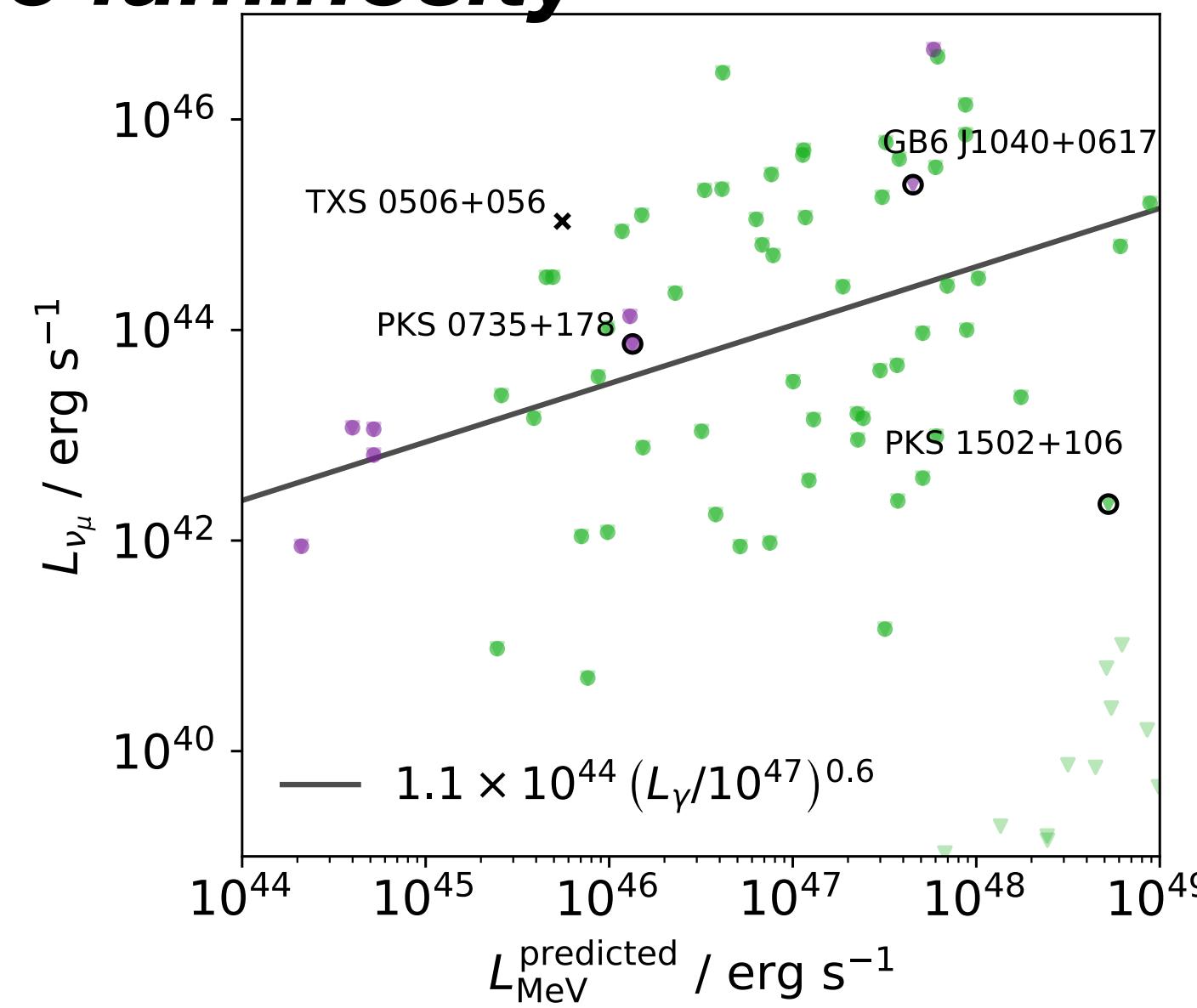
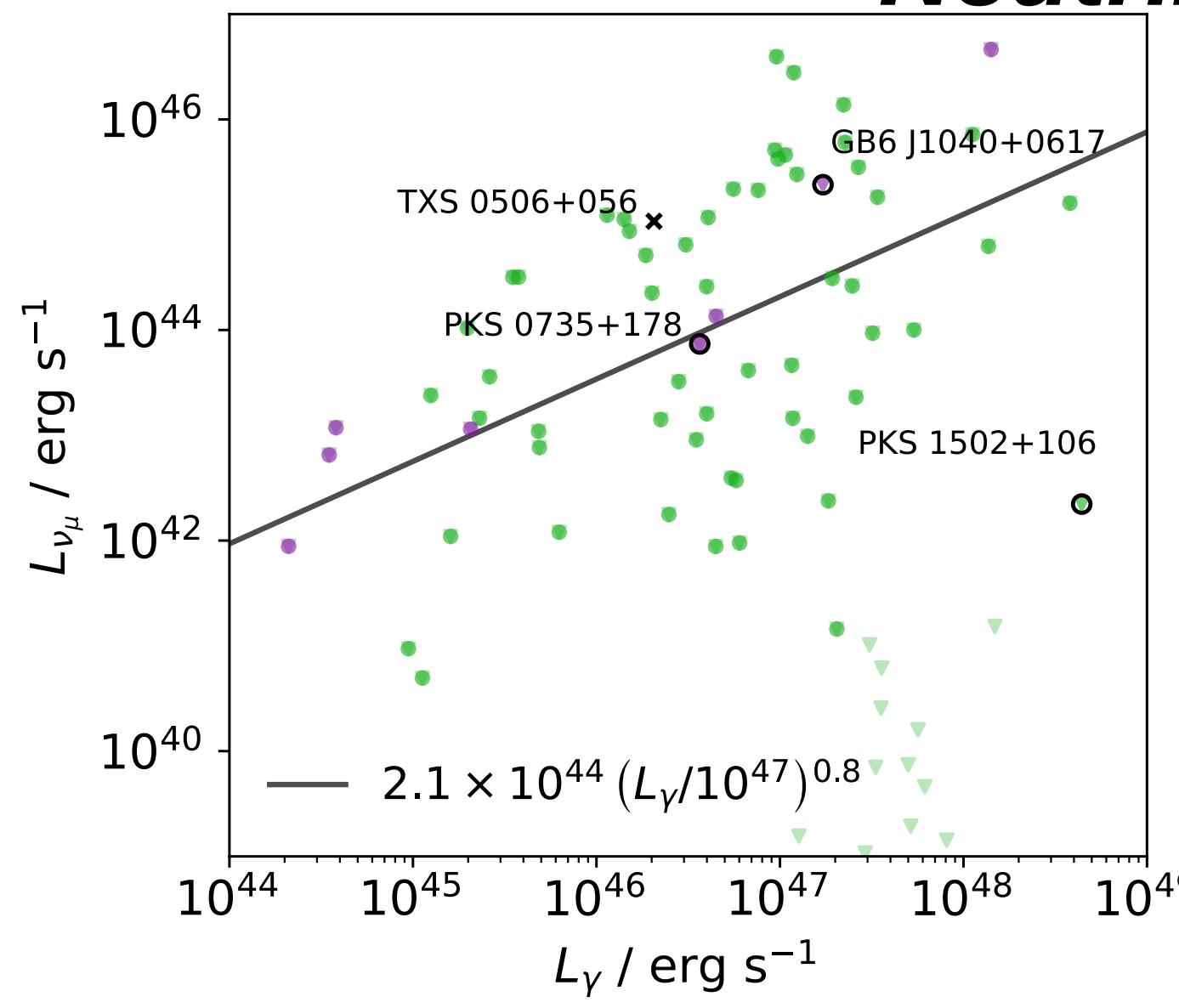
Baryonic loading



Neutrino efficiency

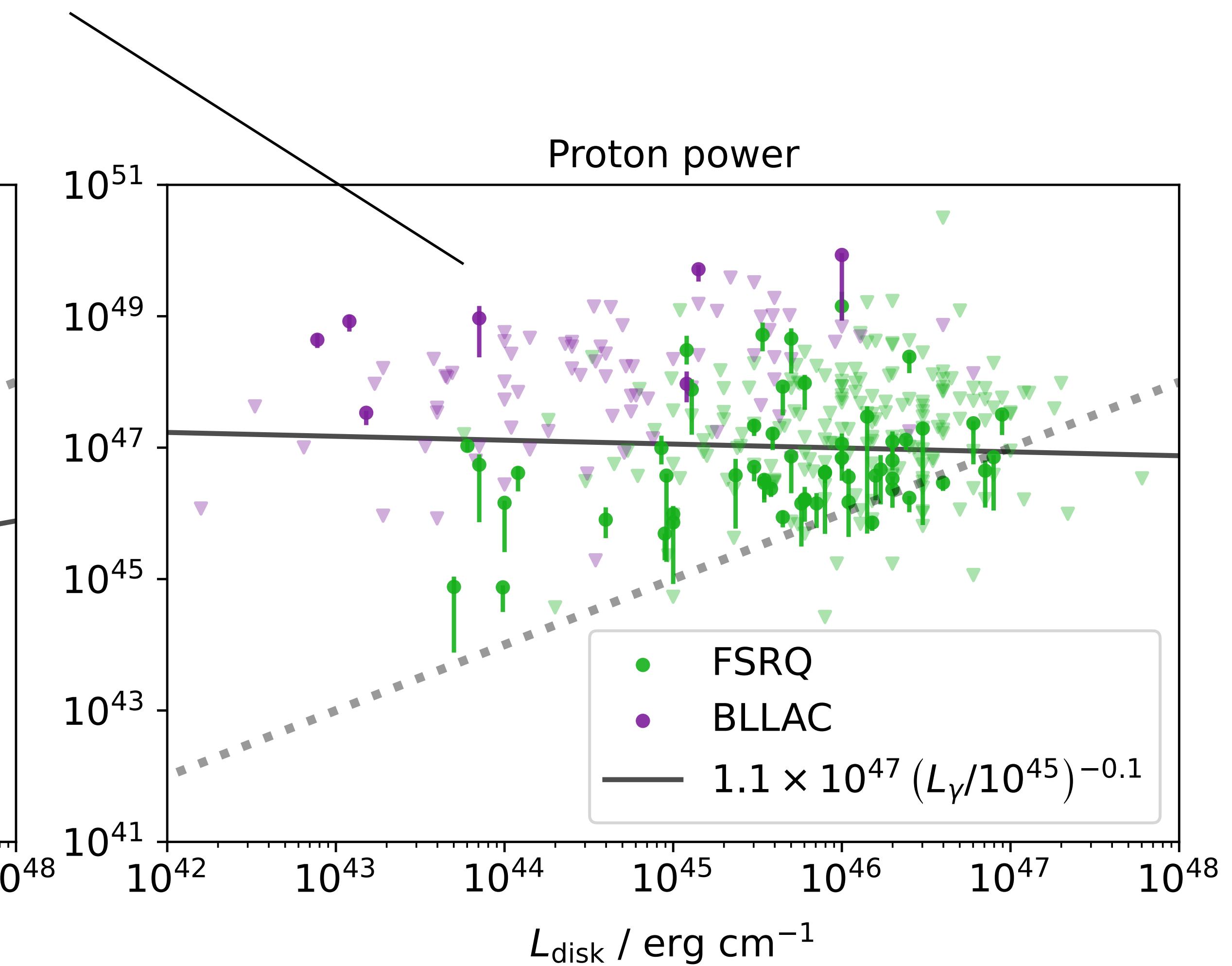
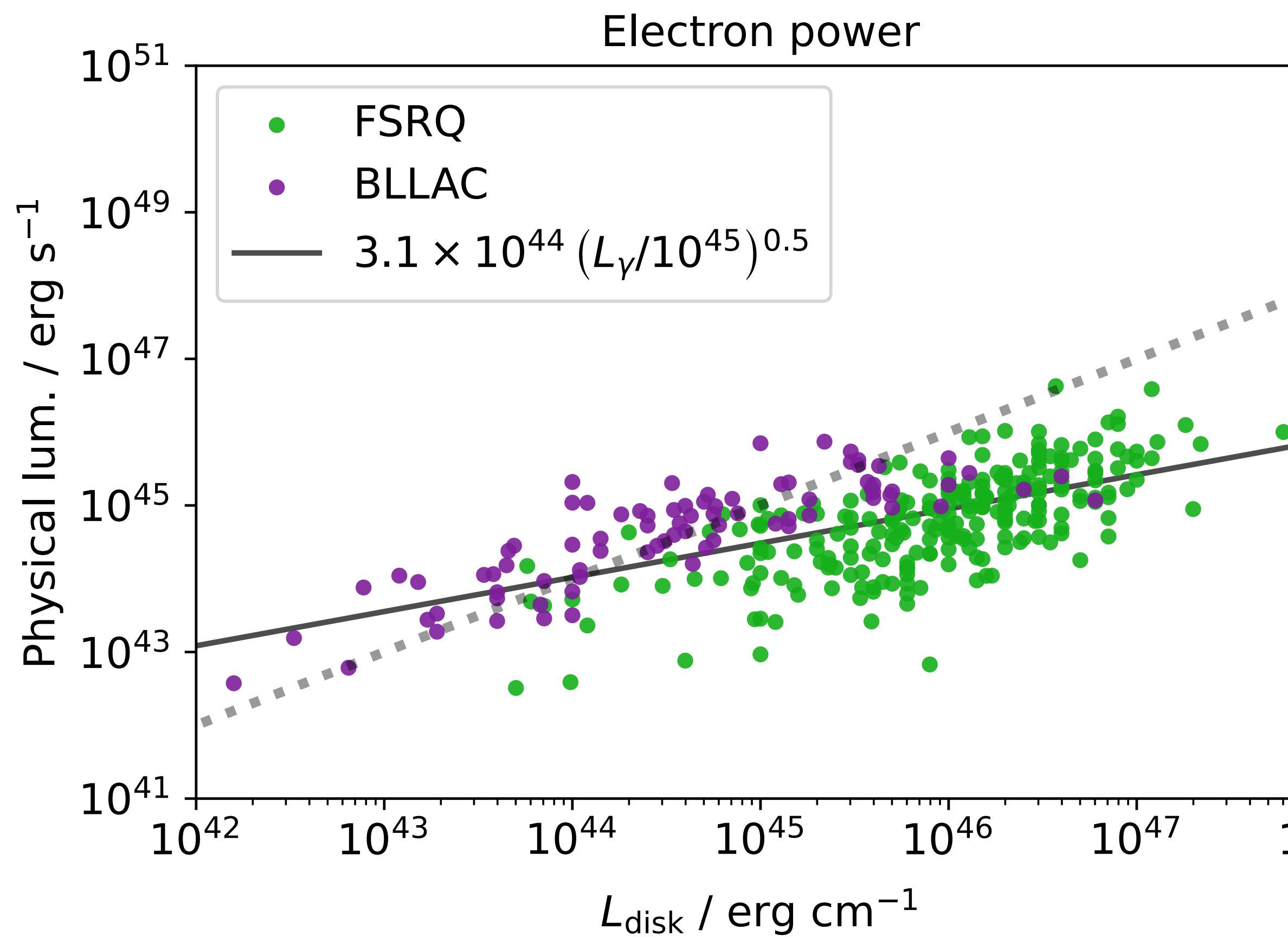


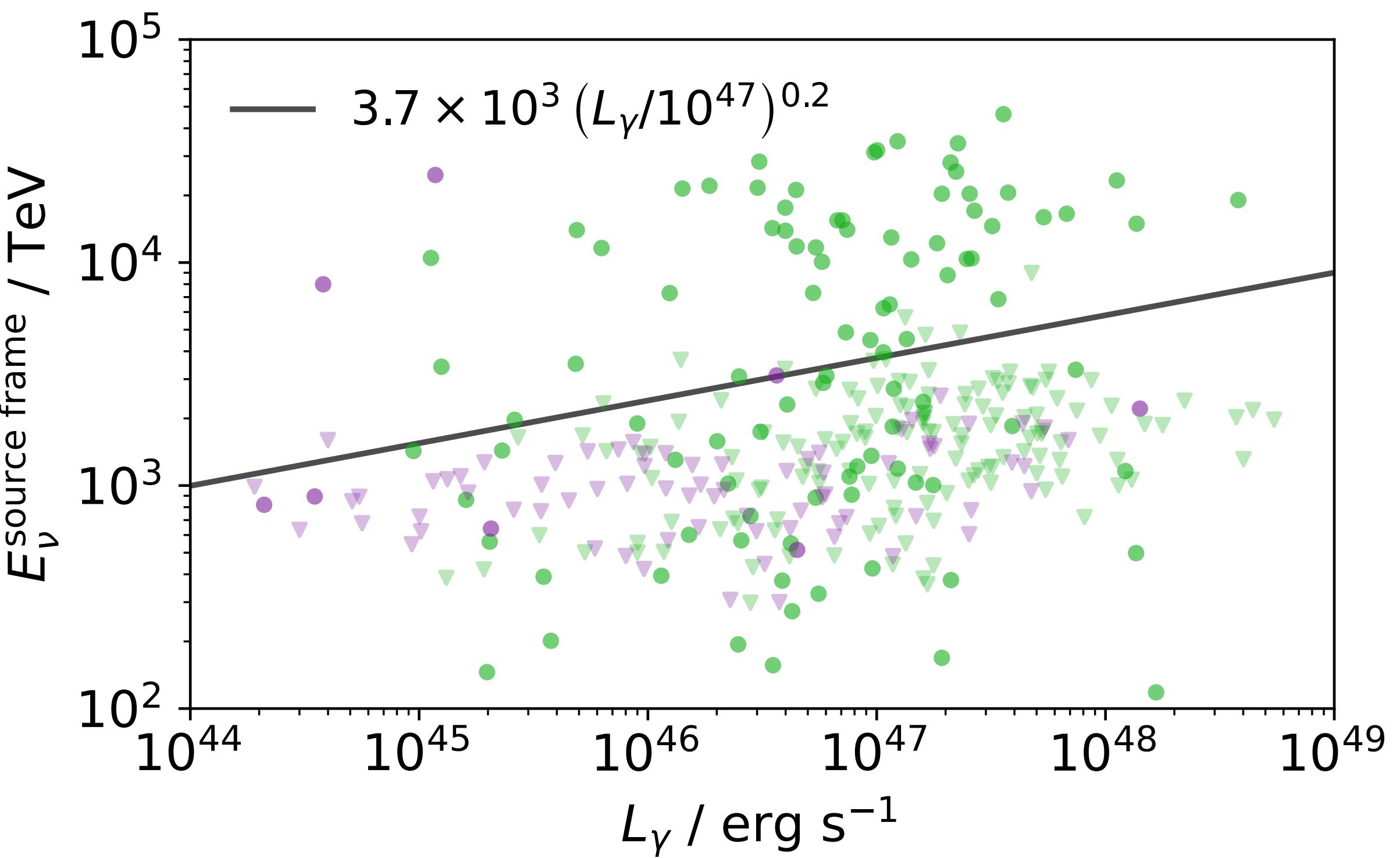
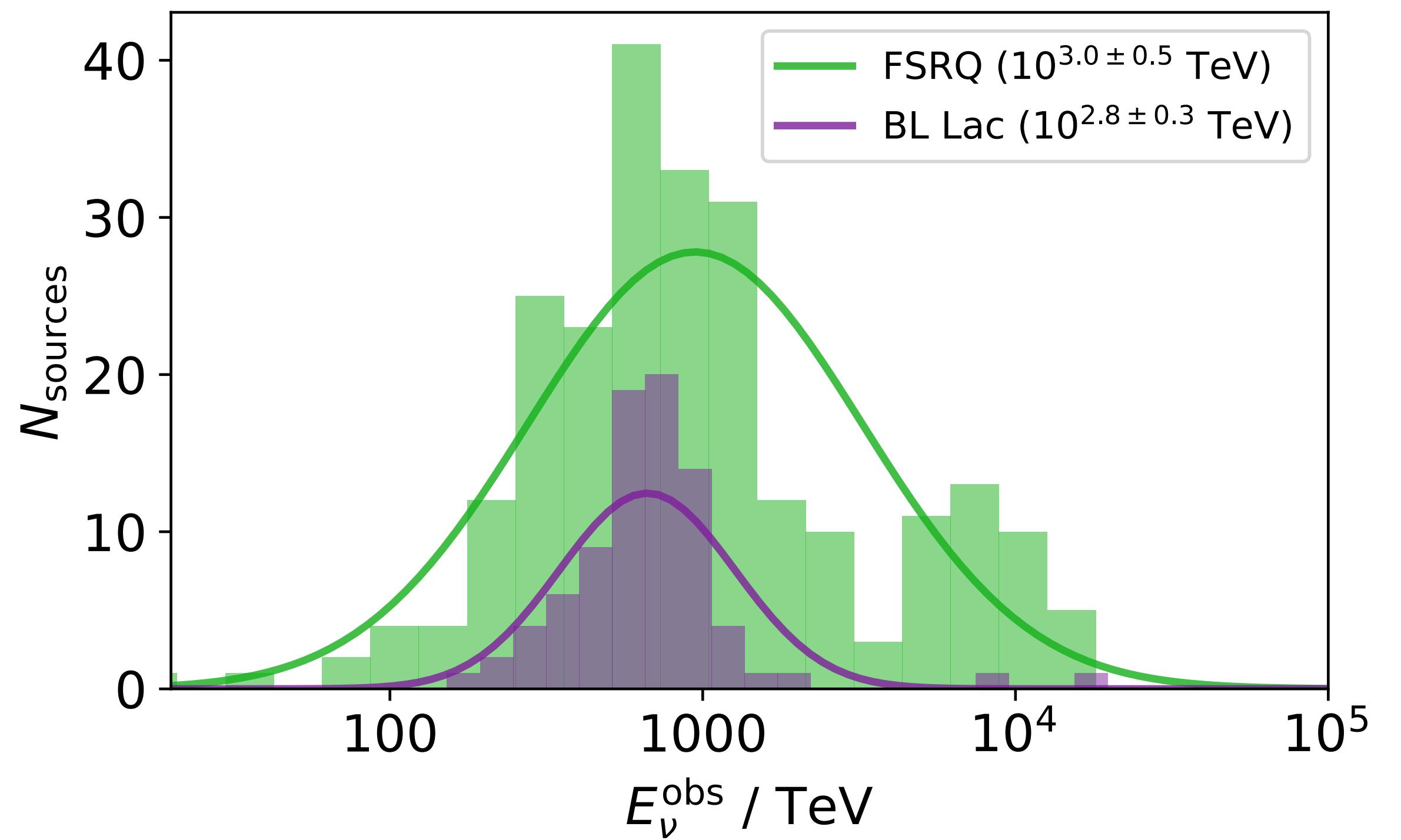
Neutrino luminosity



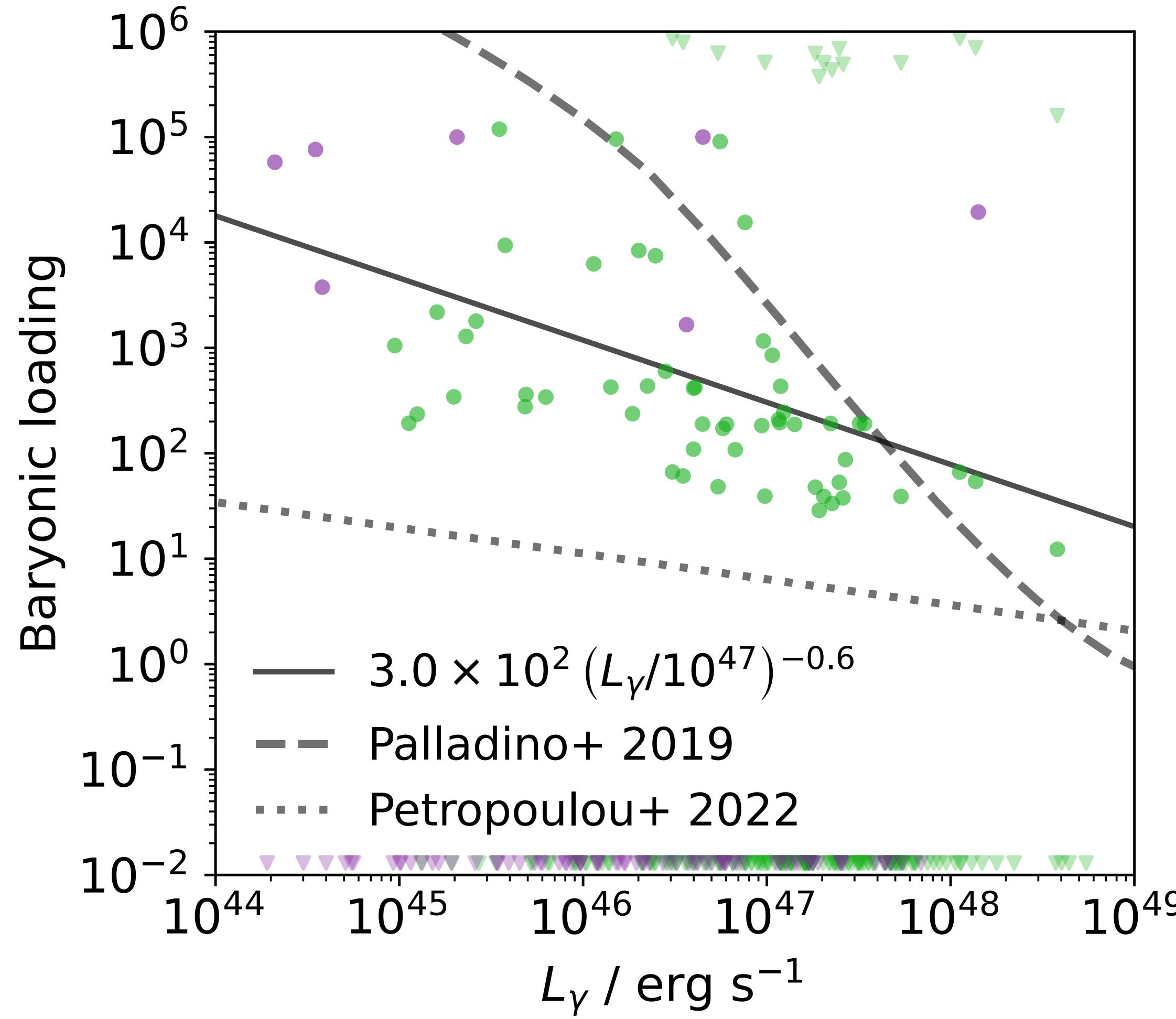
Required cosmic-ray power

Proton injection powers have large spread

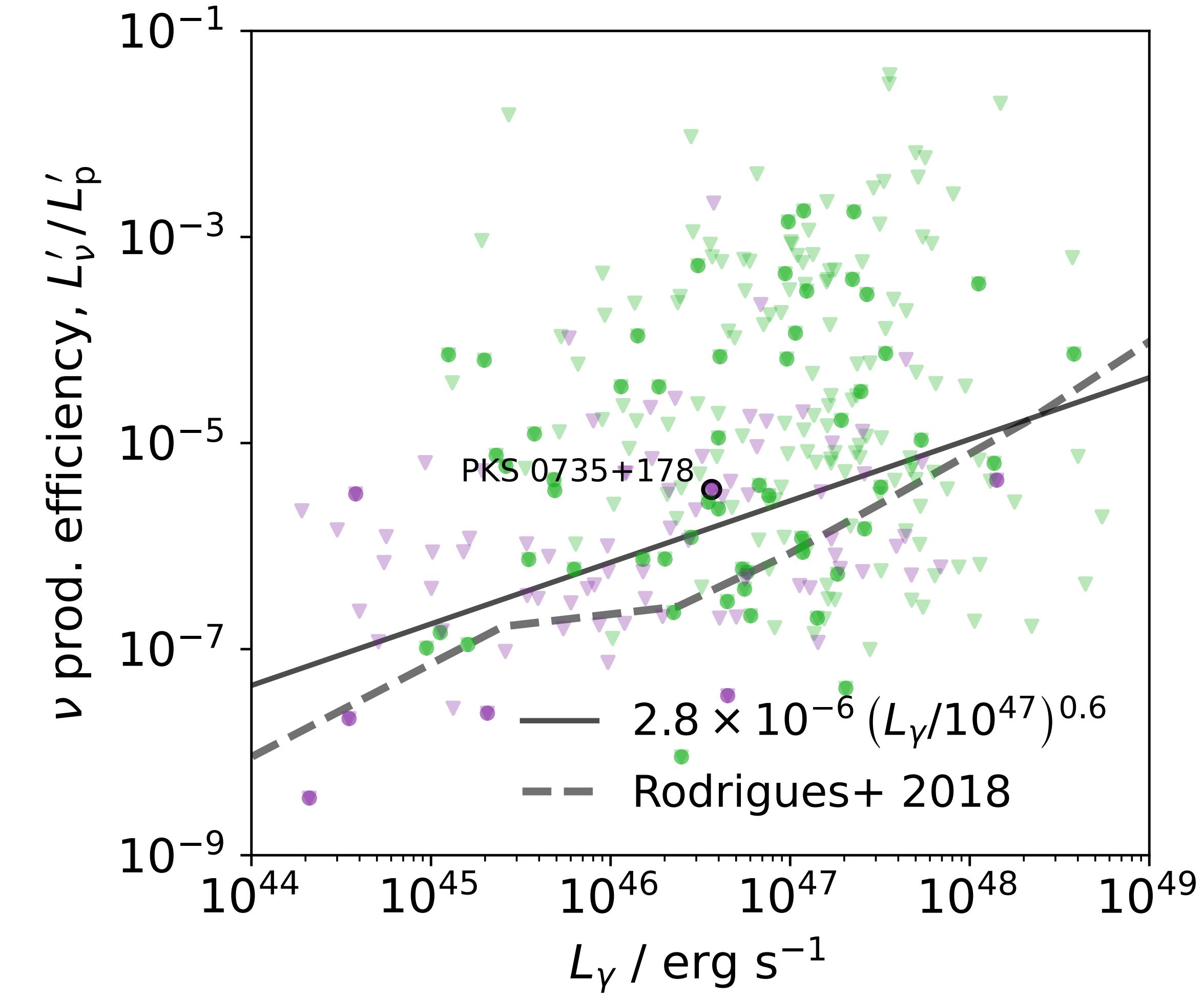




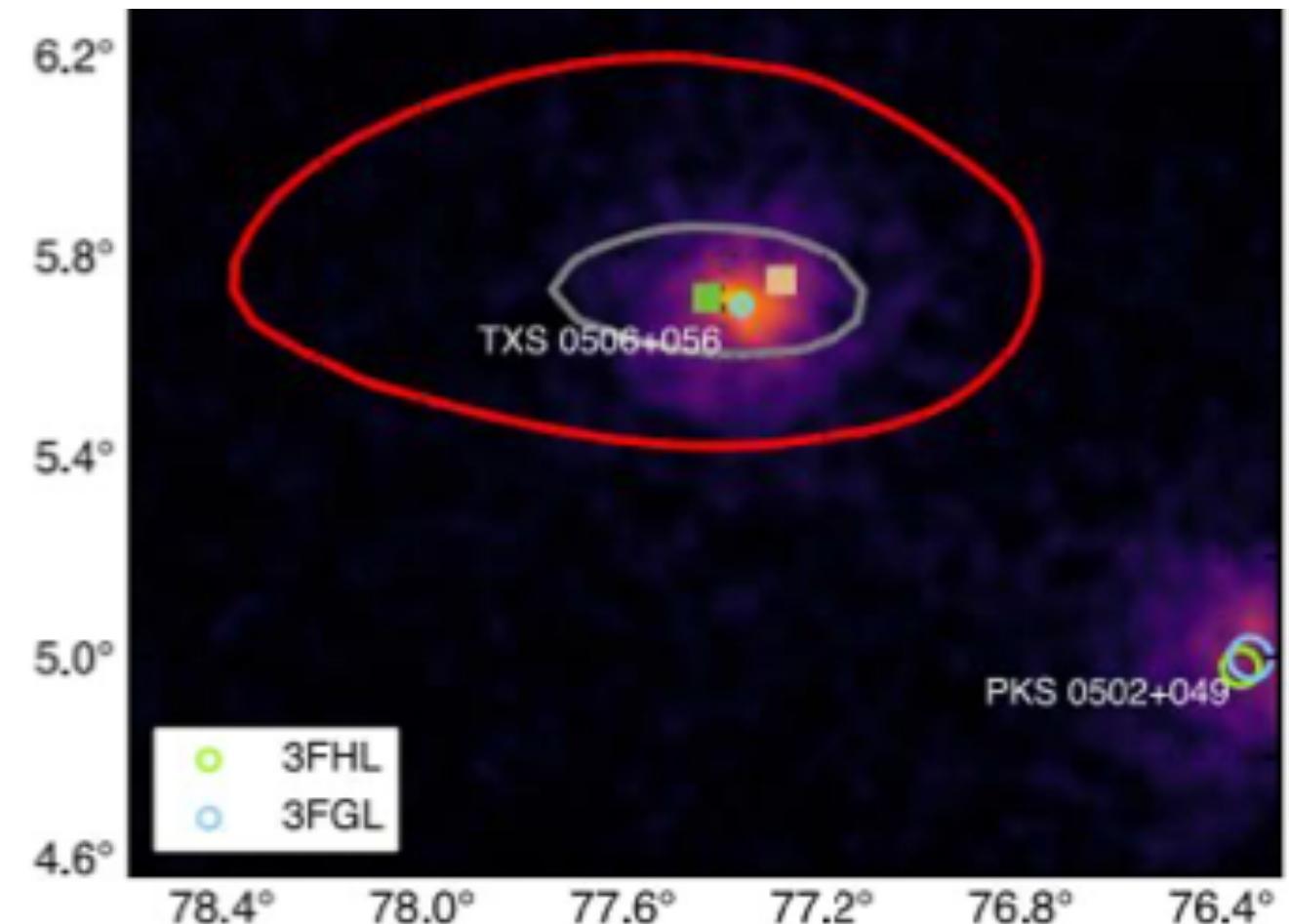
Best-fit baryonic loading ($\equiv L_p / L_e$) scales inversely with L_γ



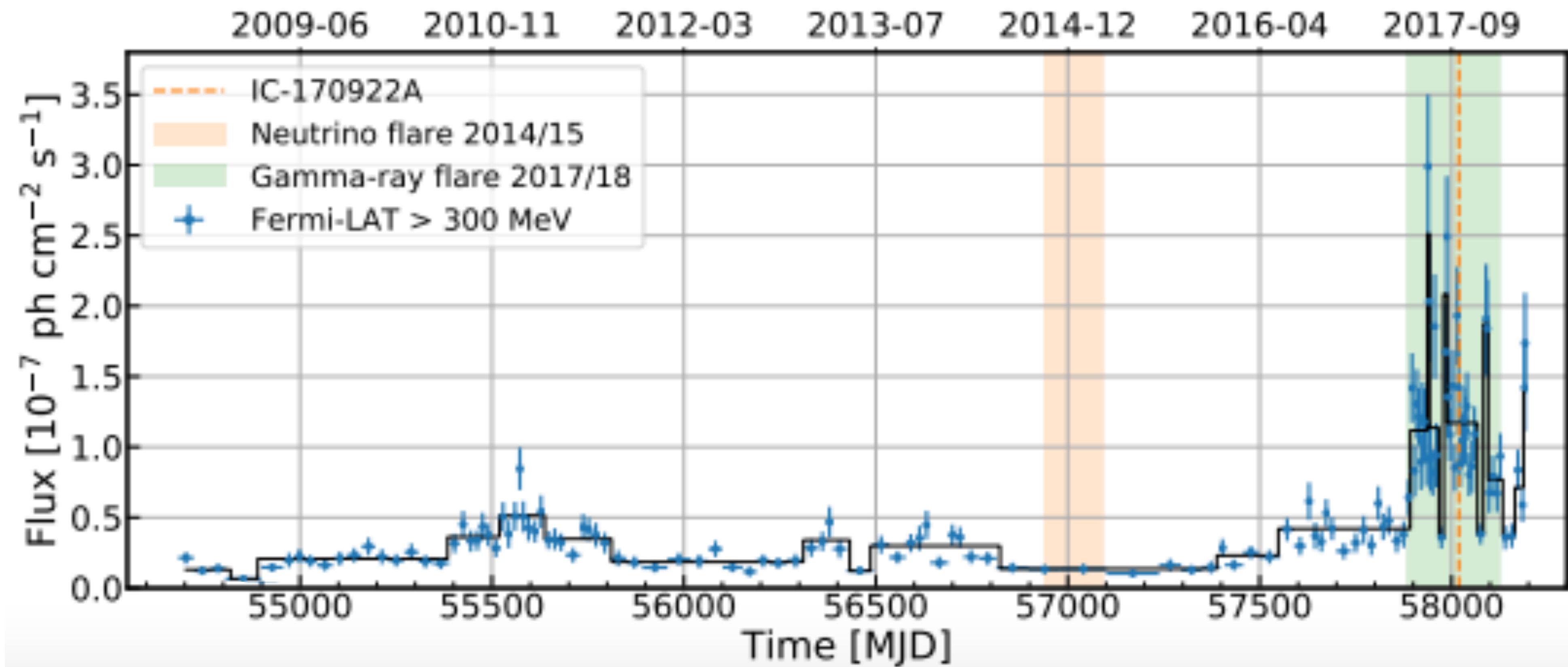
Neutrino efficiency scales positively with L_γ



Will we find IceCube blazars in GeV γ -rays?

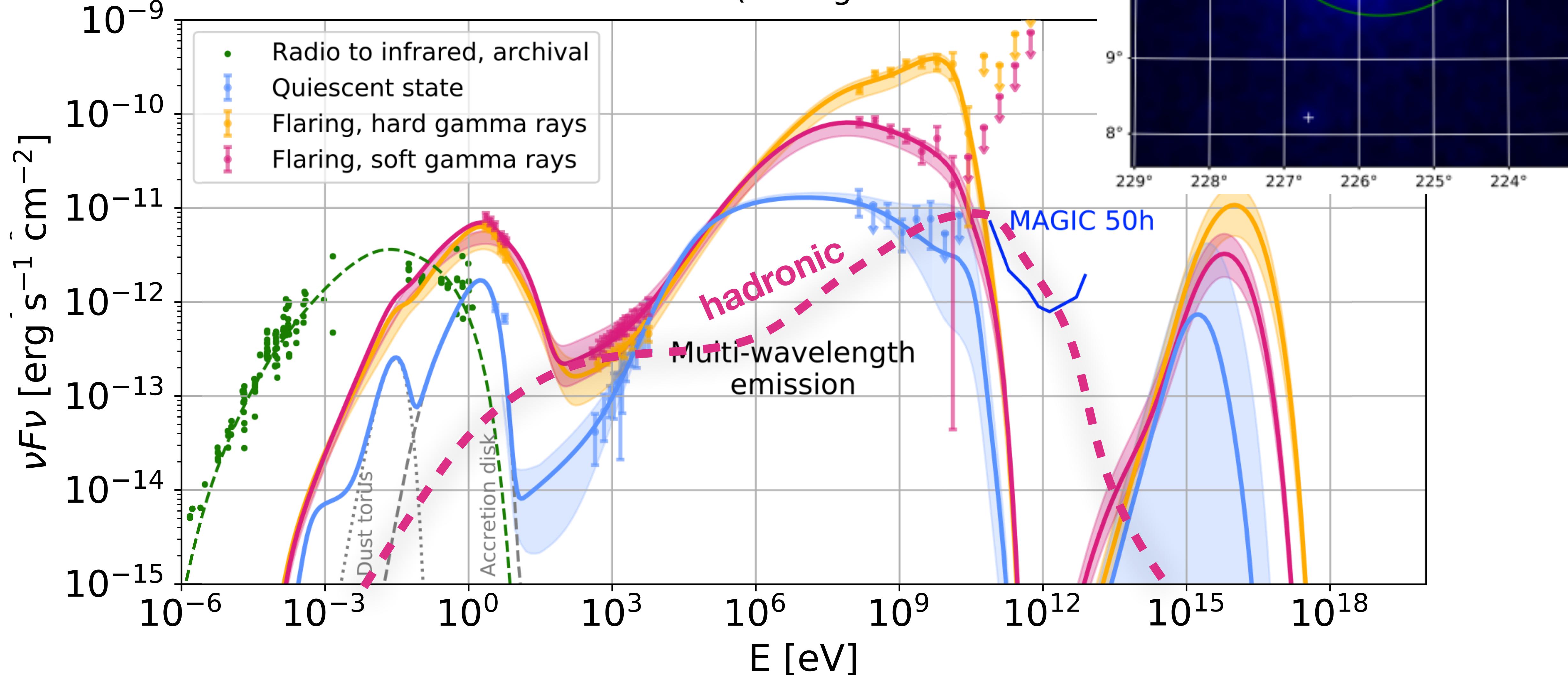


TXS 0506+056 (September 2017)



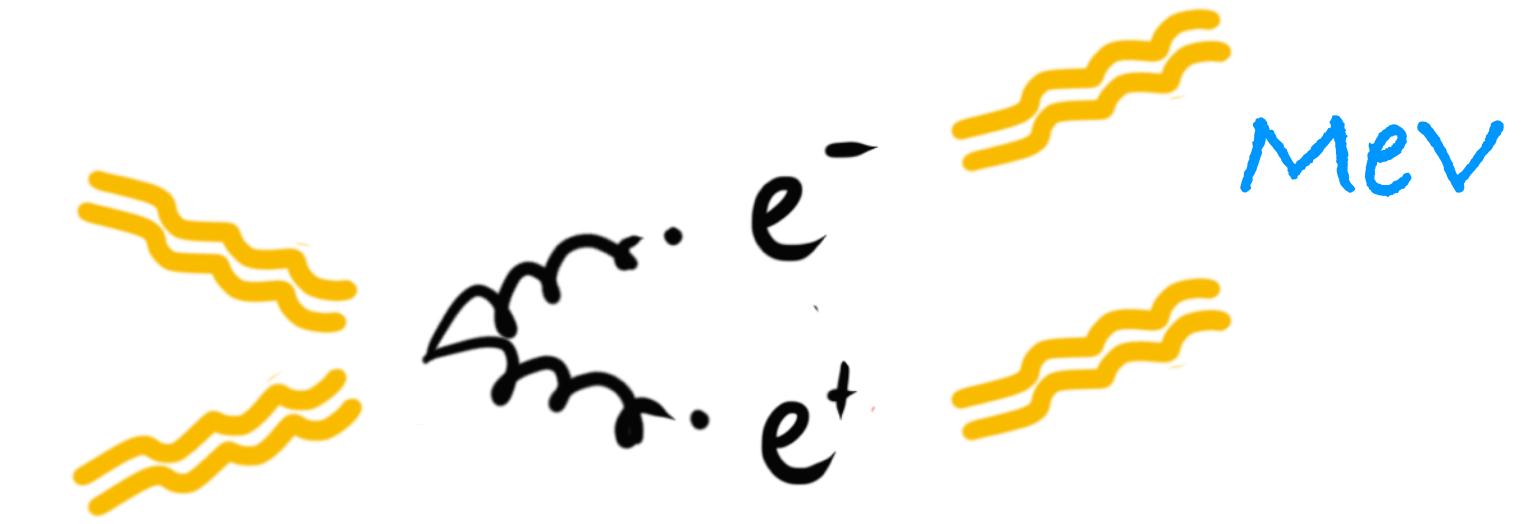
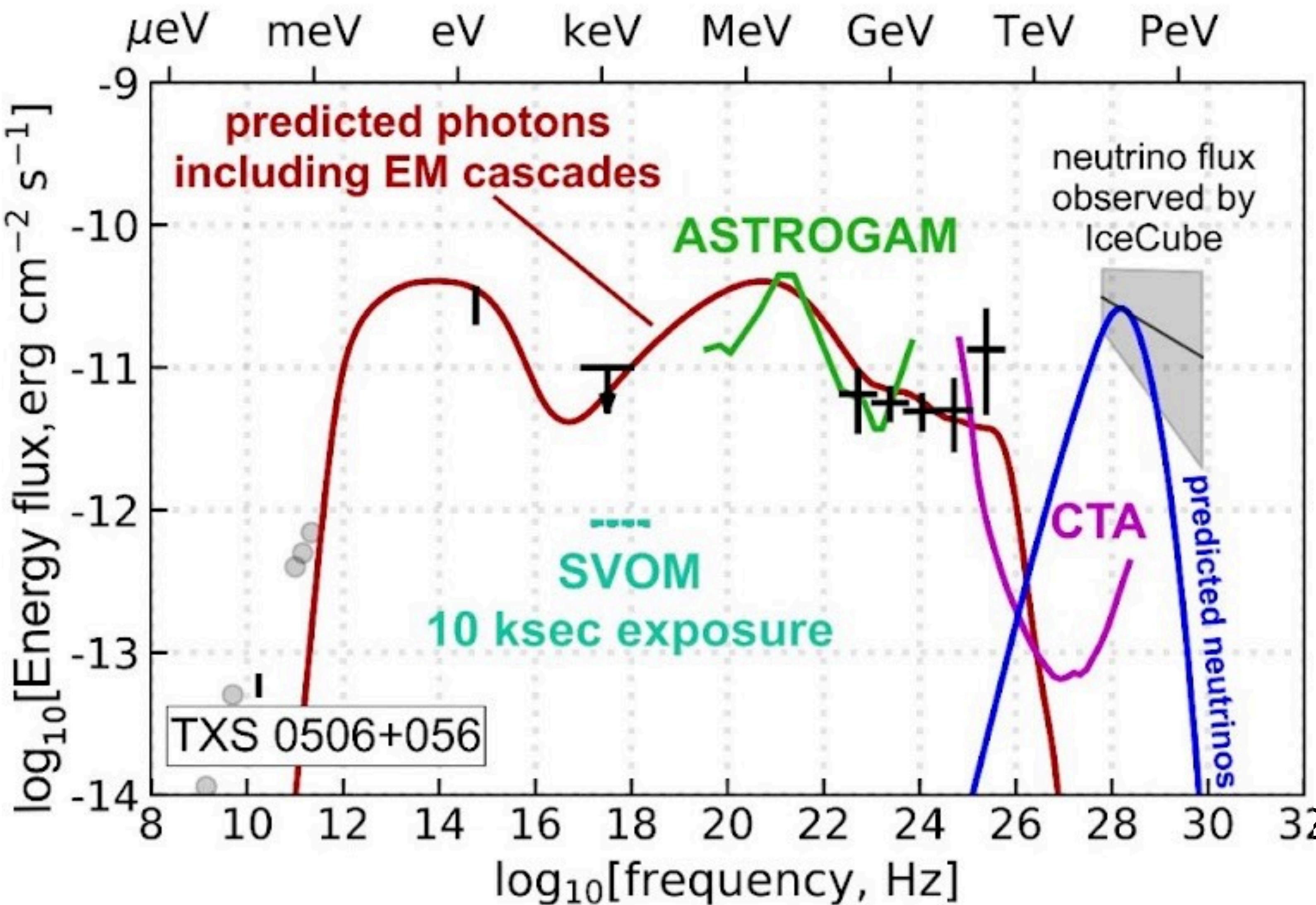
What is a hadronic ‘signature’?

PKS 1502+106 (August 2019)



Rodrigues, Garrappa, Gao, Paliya, Franckowiak and Winter, ApJ 912 (2021)

Will we find IceCube blazars in MeV gamma rays?

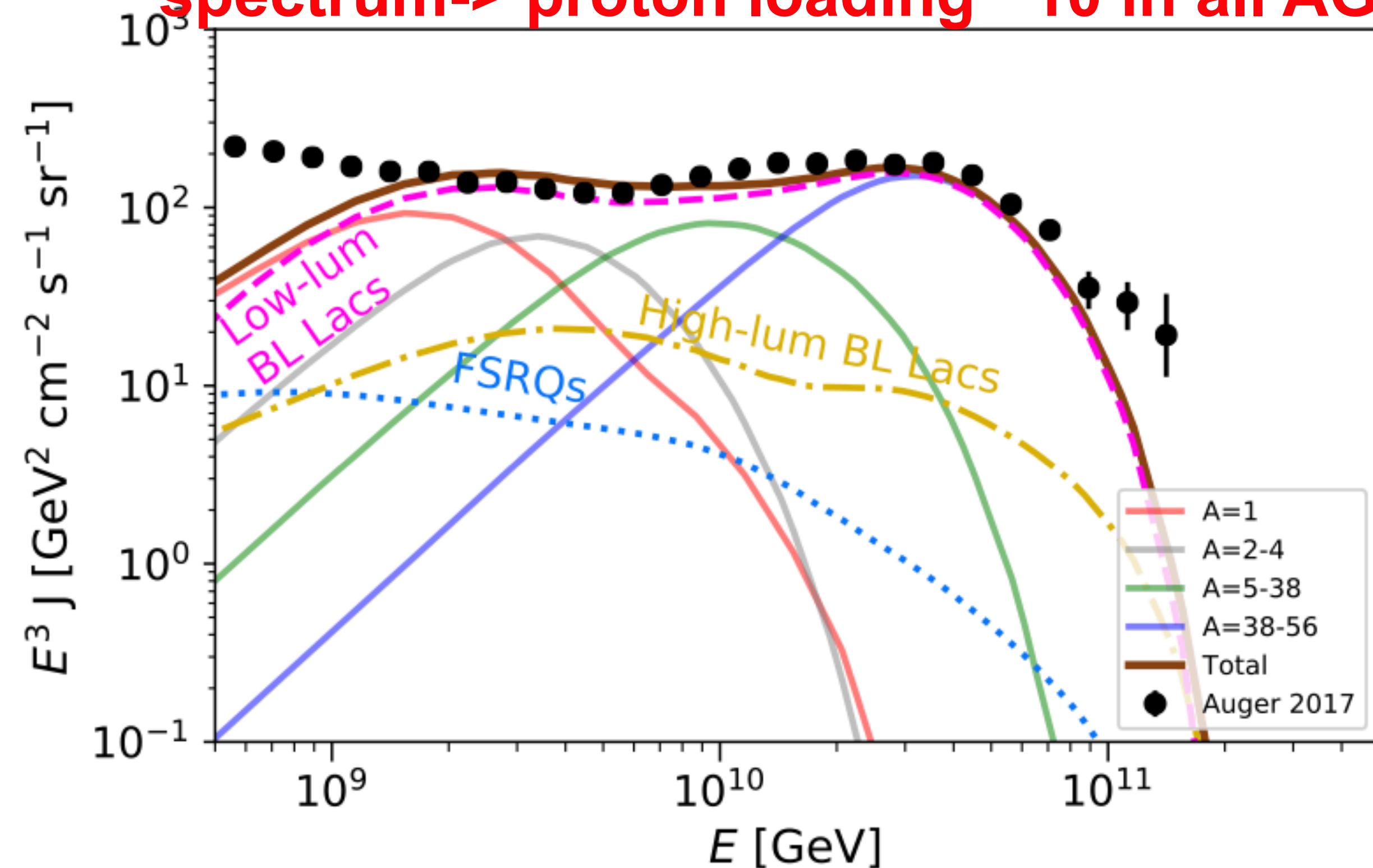


Rodrigues, Gao, Fedynitch, Palladino, Winter, ApJ L874 (2019)

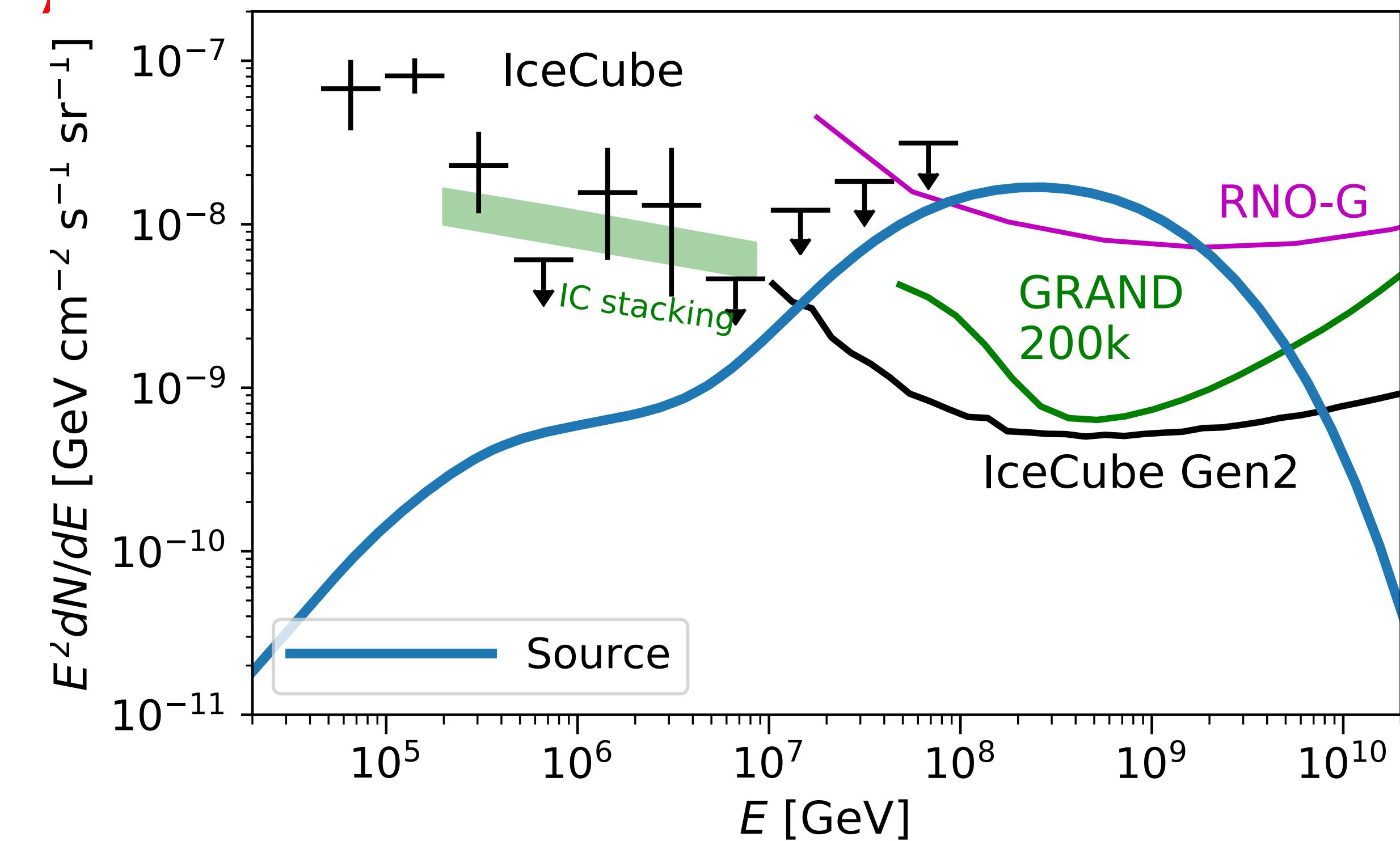
What about the ultra-high energies?

Assuming AGN are accelerators
of UHECRs...

(Best-case scenario, AGN exhaust the Auger
spectrum-> proton loading ~10 in all AGN!)



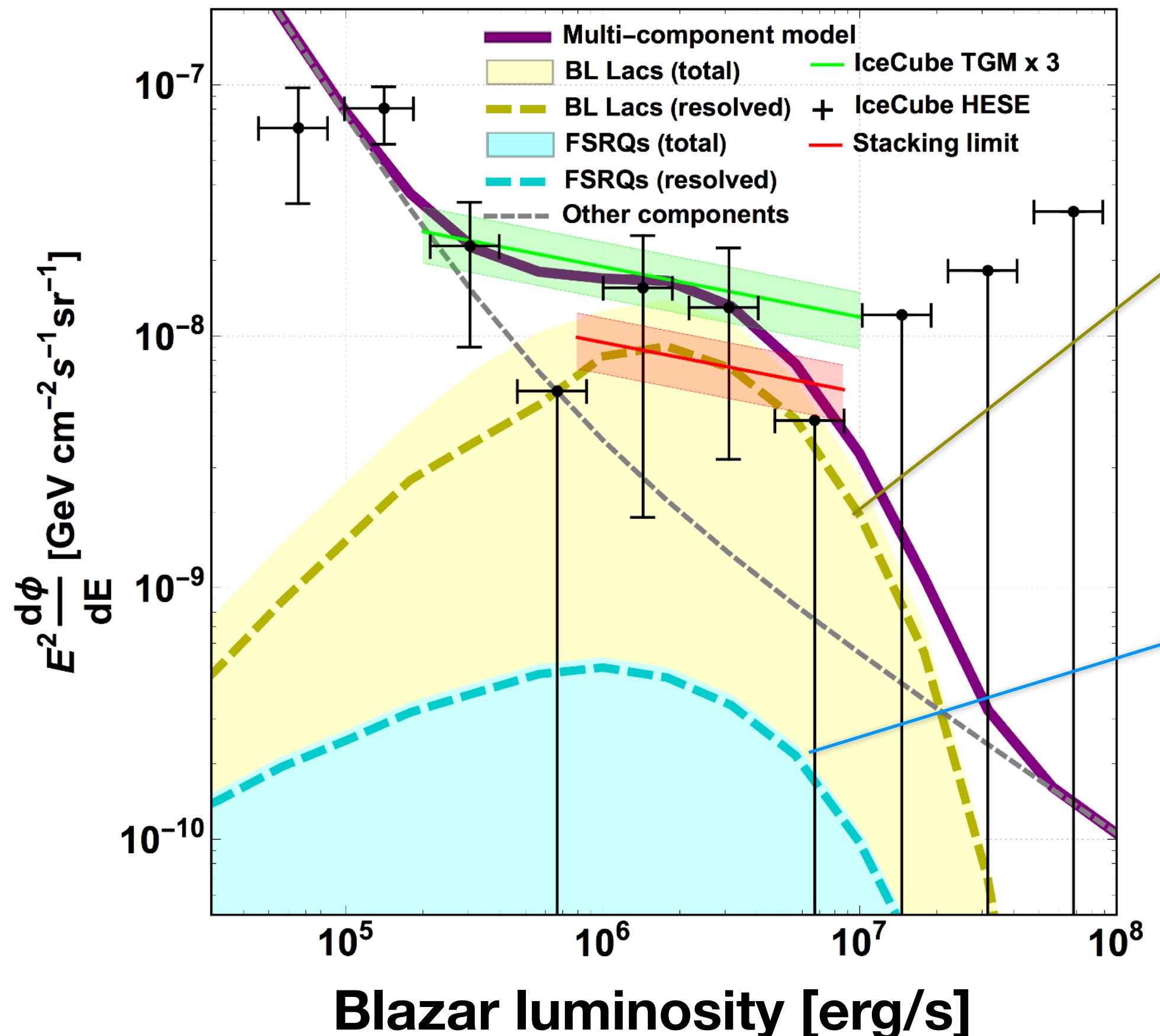
...we may currently be missing the
bulk of their multi-messenger
emission.



Blazars as accelerators of PeV cosmic rays

Palladino, XR, Gao & Winter, ApJ 871 (2019) no.1, 41

Diffuse neutrino flux



Baryonic loading

