Neutrinos from AGN Coronae

The case of TXS 0506+056

Federico Testagrossa (DESY Zeuthen)
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Based on:
Can the Neutrinos from TXS 0506+056 Have a Coronal Origin?
Fiorillo, **Testagrossa**, Petropoulou, Winter, ApJ 985 (2025)

HELMHOLTZ

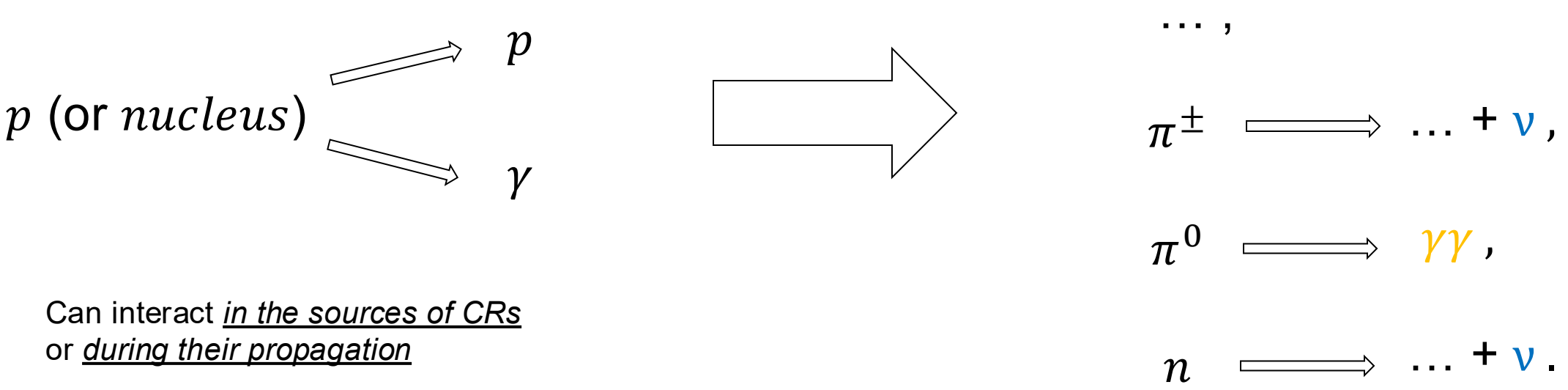
DESY.

High-energy neutrinos from the cosmos

Neutrinos and γ-rays from cosmic ray interactions

High-energy cosmic rays (CRs) + target

High energy gamma rays and neutrinos!



Can interact *in the sources of CRs*
or *during their propagation*

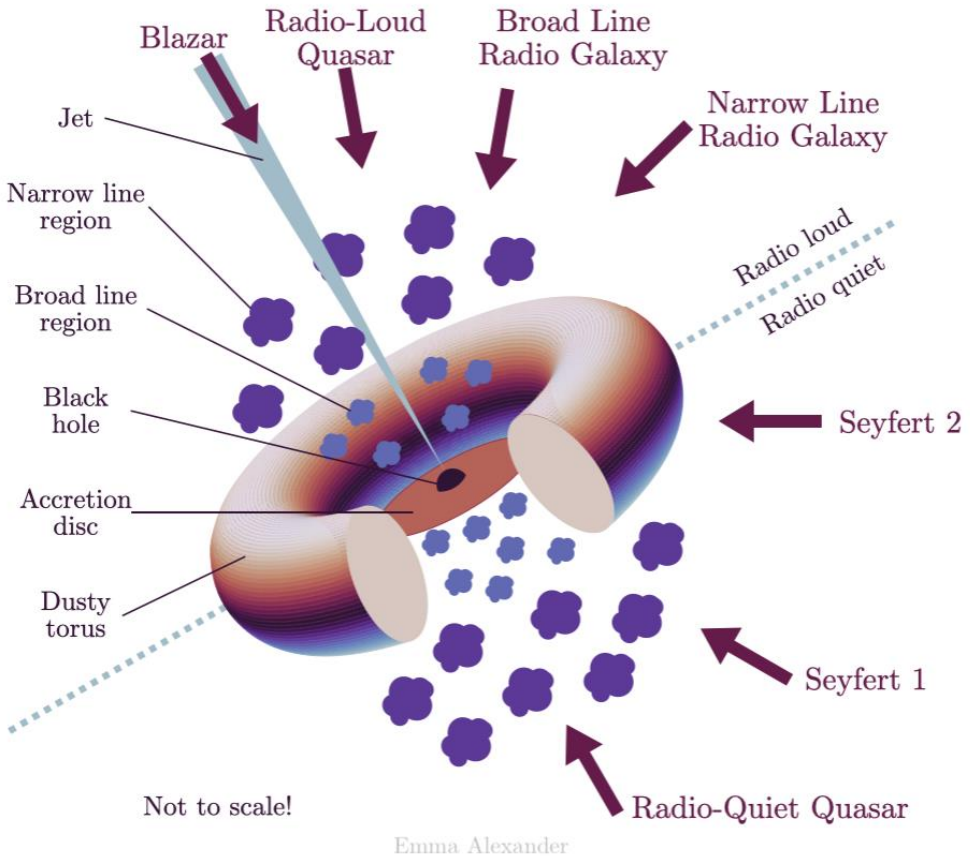
"Astrophysical" neutrinos

First observed by IceCube in 2013.
Diffuse flux from all sky, but hard to resolve point sources.
No clear picture of neutrino origin!

What are the sources of the IceCube neutrinos?

An open question

Few candidate sources identified; most promising class is **Active Galactic Nuclei (AGNs)**

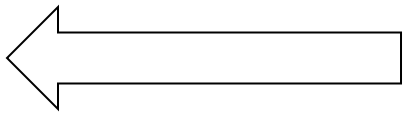


[**Unified model of AGNs**: from Emma Alexander's website]

AGN

Compact region with photon emission over broad frequency range, as well as neutrinos; powered by accretion on supermassive black hole.

AGNs are observed with very diverse properties.



Unified Model:

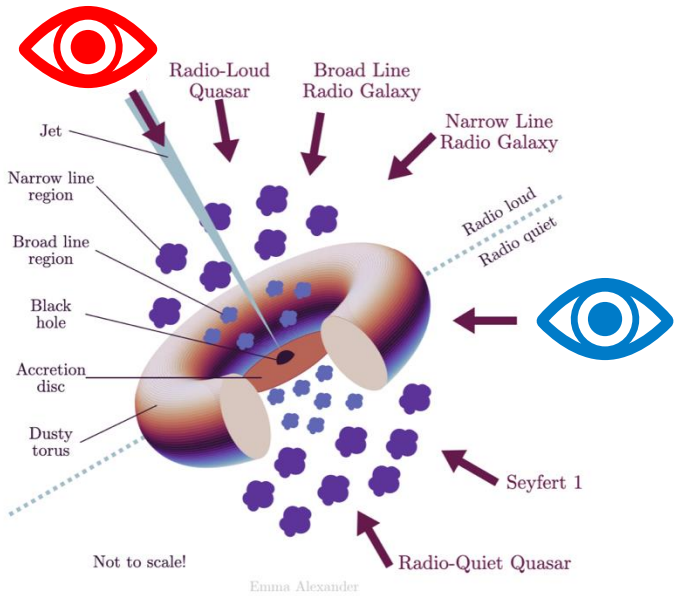
It's the same system, viewed from different angles!

What are the sources of the IceCube neutrinos?

A few AGNs are identified as point sources of neutrinos

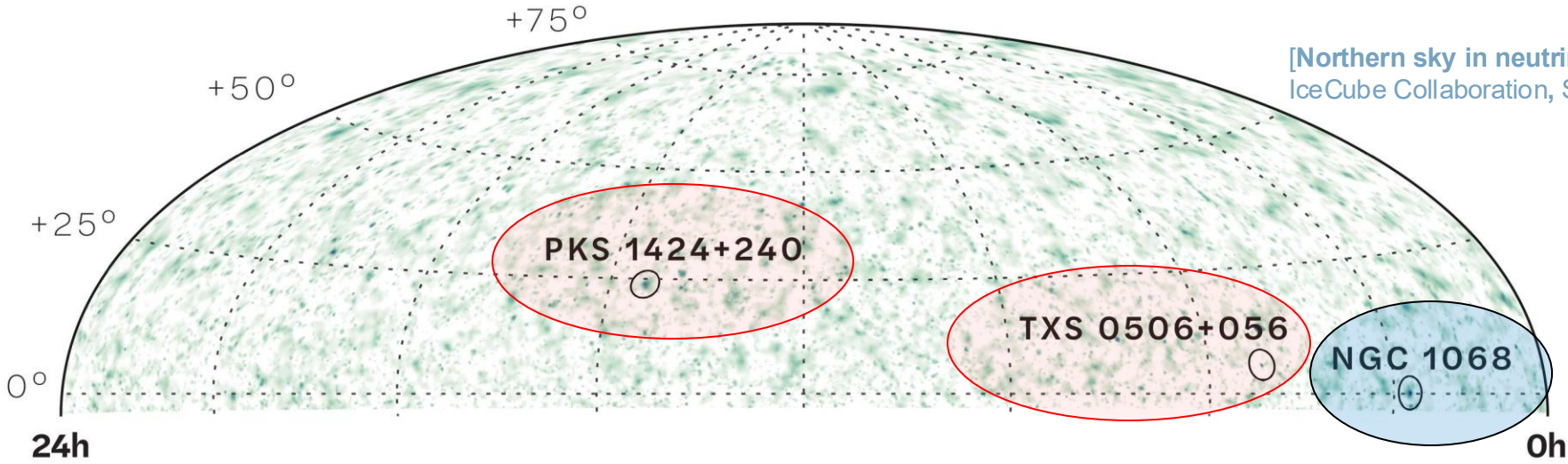
Blazar

- Powerful relativistic jet
- Observed along the jet
  - Bright in γ-rays



Seyfert II galaxy

- Weak or absent jet
- Partially obscured by torus
  - Faint γ-ray emission



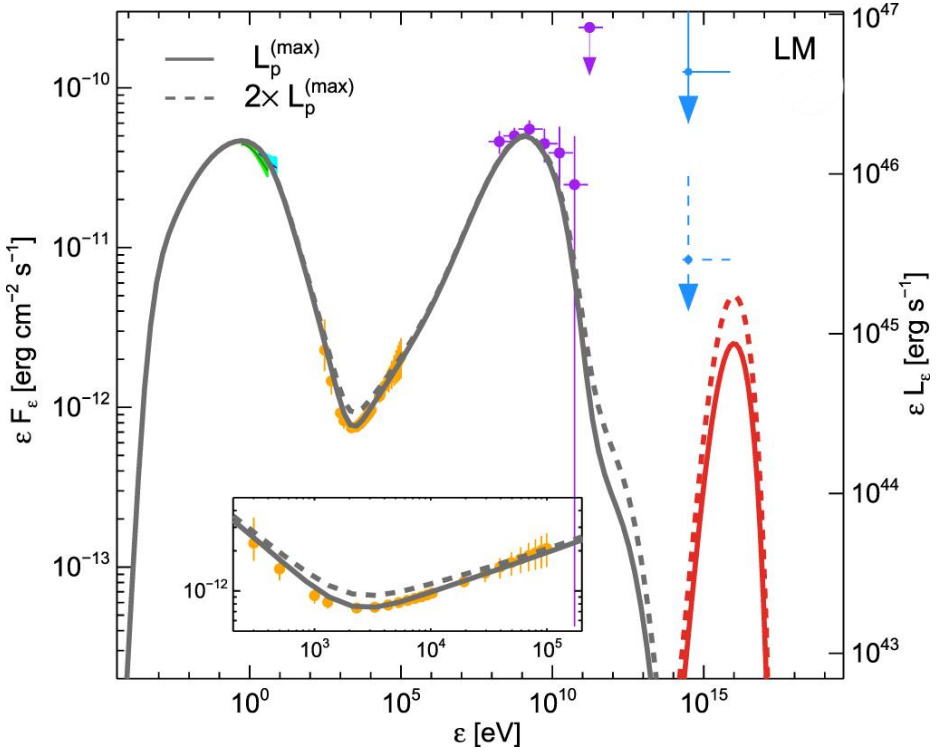
[Northern sky in neutrinos. Equatorial coordinates. IceCube Collaboration, Science 378 (2022)]

Where are neutrinos produced in AGNs? - Jet

The “jet paradigm” of blazars

Blazar TXS 0506+056: the first identified neutrino source

Discovery: neutrino excess during enhanced γ-ray emission (”flare”)
⟹ **Neutrino-photon correlation**
⟹⟹ **Same radiation zone? Natural candidate for blazars: jet!**



[Jet model of TXS 0506+056: Keivani et al., ApJ 864 (2018)]

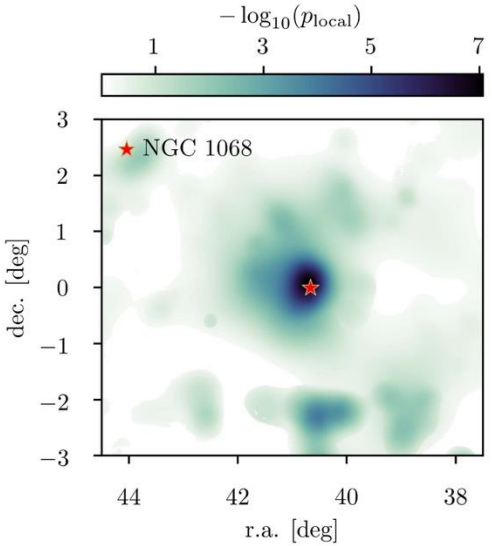
[Science issue 361 (2018)]

So far multimessenger emission (photons + neutrinos) **interpreted assuming production in the jet**

Cosmic rays **accelerated in relativistic blazar jet.**
Relativistic beaming enhances luminosity and energy.
High-energy protons produce high-energy neutrinos!

Where are neutrinos produced in AGNs? – AGN core

A closer look to NGC 1068



[NGC 1068 seen in neutrinos: IceCube coolaboration, Science 378 (2022)]

Seyfert II galaxy NGC 1068: hottest spot in the neutrino sky

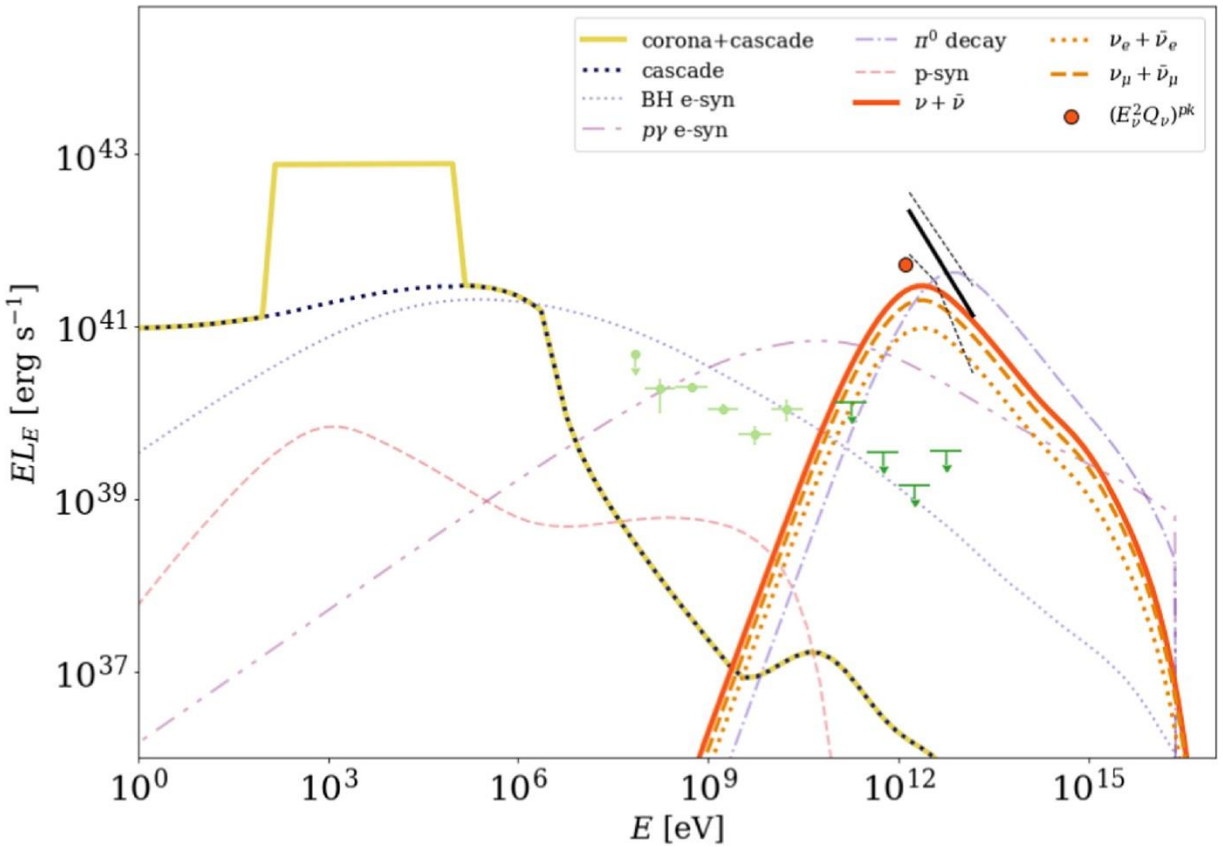
Neutrinos are produced together with γ-rays

But no comparable flux of γ-rays has been observed from this source

$\Longrightarrow$ The production site must be opaque to γ-rays.

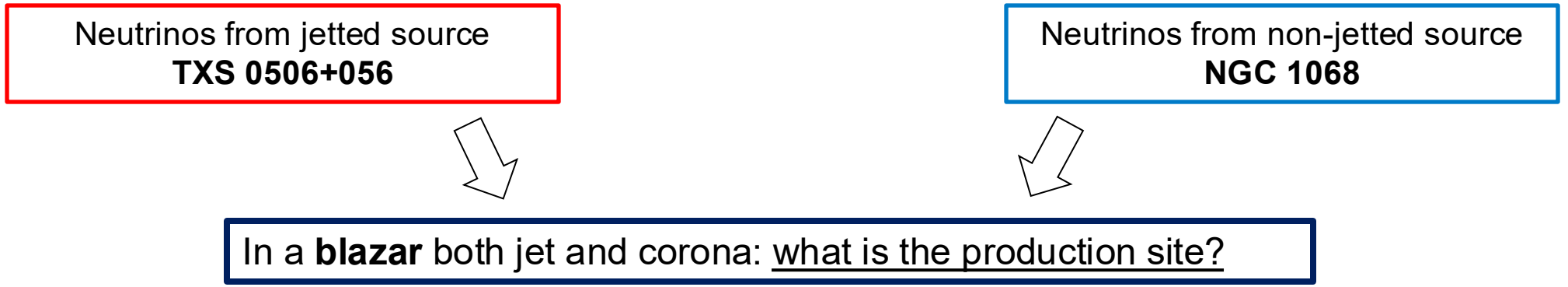
Interpreted assuming production in the AGN corona.

AGN corona: inner region of AGN with dense X-ray field.
High-energy protons scatter with X-rays producing **γ-rays and neutrinos**.
γ-rays absorbed by X-rays (annihilated into pairs)**, so no photon signal!**



[Corona model of NGC1068: Fiorillo et al., ApJL 961 (2024)]

Another possibility…



What if the neutrinos from TXS 0506+056 are produced in the AGN corona?

We try to explain observations in a model in which:

- **The observed electromagnetic radiation is dominated by the jet emission**
- **Neutrinos are produced in the AGN corona of the blazar**

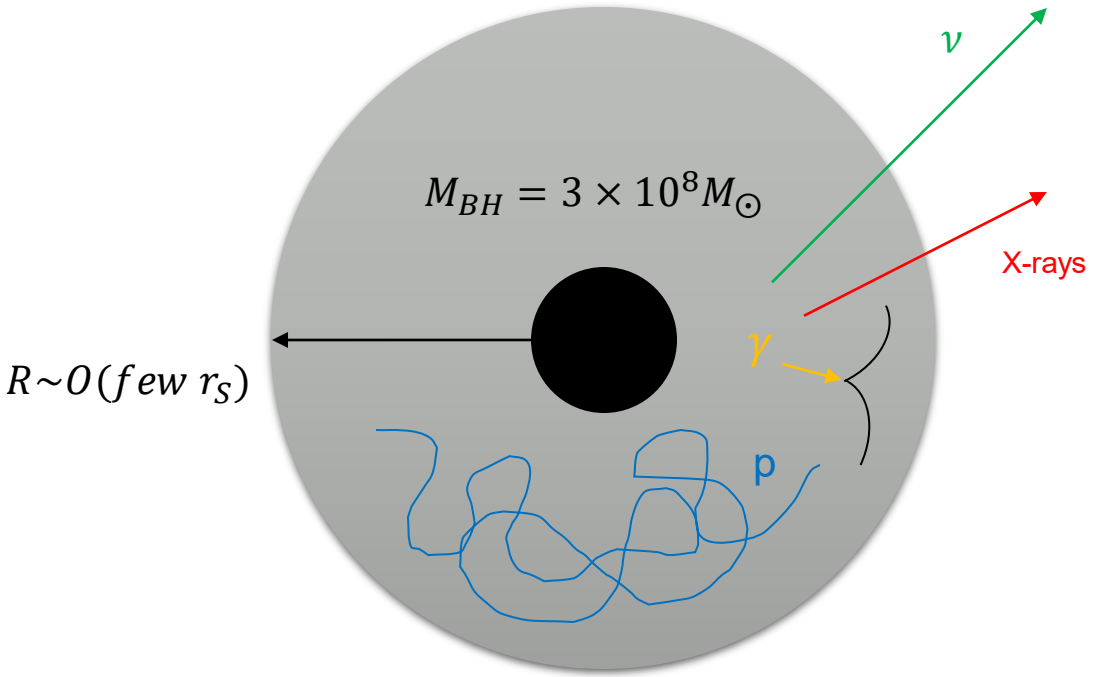
Requirements:

1. Model of the blazar corona (note: we don't observe that directly!)
2. The acceleration mechanism of protons should explain energies of observed neutrinos (up to PeV)
3. Electromagnetic emission from corona should be < observations. Neutrino emission = observations

Corona model

Geometry and particle injection

Spherical blob with x-rays, protons, and homogenous magnetic field



X-rays:
Compton scattering on low-energy photons

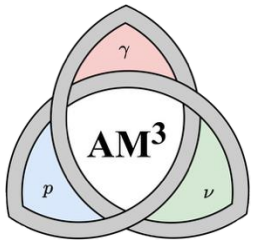
- Power-law injection $(0.1\ keV - 100\ keV)$
- Luminosity L_X inferred from observation of lines (corona "covered" by the jet!)

Protons:
Accelerated (How?)

- Injection until the energy at which losses are dominant

Magnetic field
$\approx$ equipartition $L_p \propto L_X \propto U_B$

Particle interactions simulated numerically ($\boldsymbol{AM^3}$)
Evolution of the system simulated up to steady state



Info and installation: here

Corona model

Inferring the x-ray luminosity of the corona from observations

Bright x-ray emission from the blazar jet dominates corona: difficult to measure directly the coronal properties

To infer the x-ray power output of the corona of TXS 0506+056
We use direct measurements of emission lines + empirical relations between lines and accretion-driven emission

We consider **3 benchmark values for L_X of the corona**:

- Low Luminosity (LL: conservative value from this estimate)
- High Luminosity (HL: optimistic value from this estimate)
- Extreme Luminosity (EL: saturates upper limit of the 2014 flare)

Table 1
Astrophysical Parameters for TXS 0506+056, in the Three Scenarios Discussed in the Text

Parameter	TXS (LL)	TXS (HL)	TXS (EL)
L_X [10^{43} erg s^{-1}]	4	40	2×10^3
L_p [10^{43} erg s^{-1}]	0.8	80	4×10^3
B [kG]	2.6	8.1	57.3
η_p	0.1	1	1

[Fiorillo, **FT** *et al*., ApJ 985 (2025)]

The x-ray luminosities we estimate for the corona are 1-2 magnitudes smaller than those observed from the blazar
(due to jet+core)

Explaining the neutrino energies

Can protons be accelerated sufficiently fast? – Magnetic reconnection scenario works!

Protons accelerated until $E_{p,max}$, at which acceleration efficient as energy loss
Neutrinos from TXS 0506+056 have E_ν up to a few $PeV \Longrightarrow E_{p,max} \gtrsim 20\ PeV$

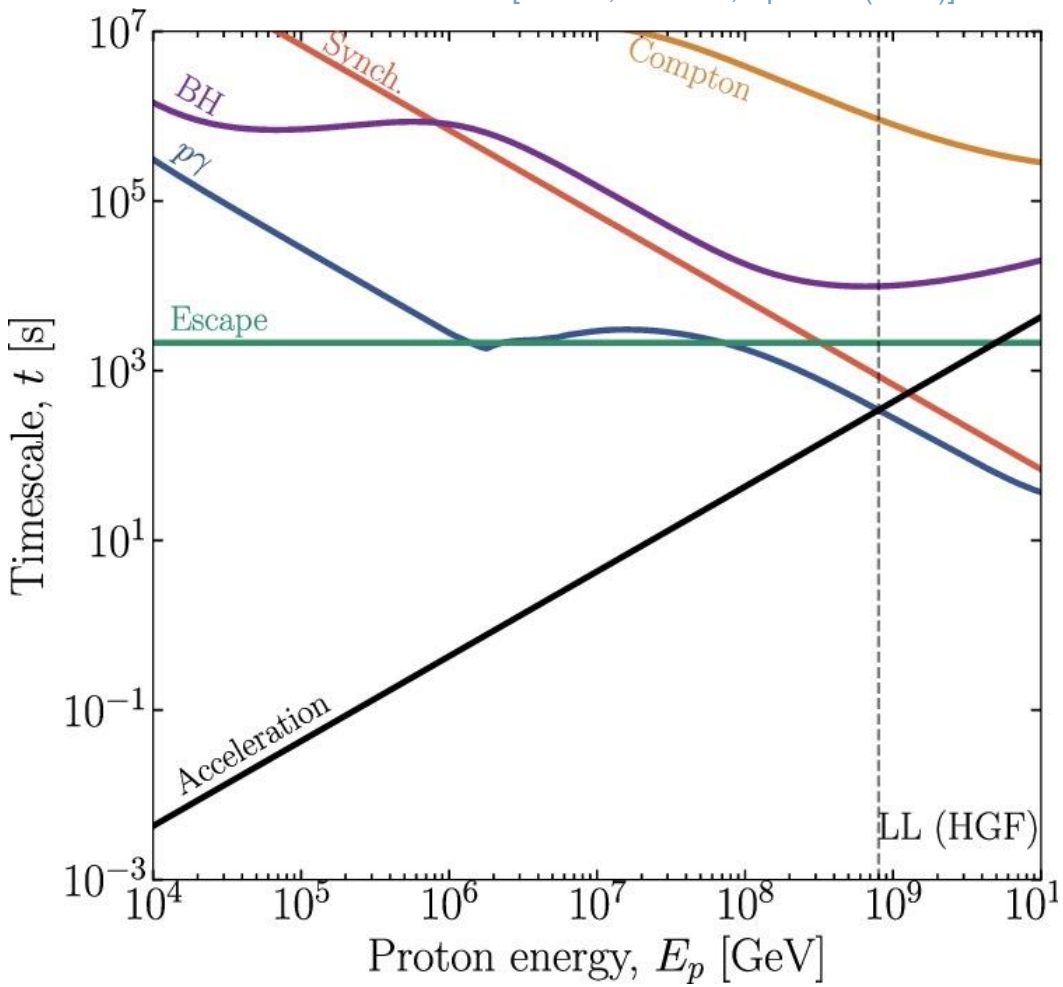
Acceleration by magnetic reconnection

The field lines of the magnetic field are rearranged and part of the energy stored in magnetic fields is converted to kinetic energy of particles

In our model acceleration happens in the reconnection layer, then the accelerated protons flow in our spherical blob and interact

In all three cases (LL, HL, EL), magnetic reconnection yields $E_{p,max} \gtrsim 20\ PeV$

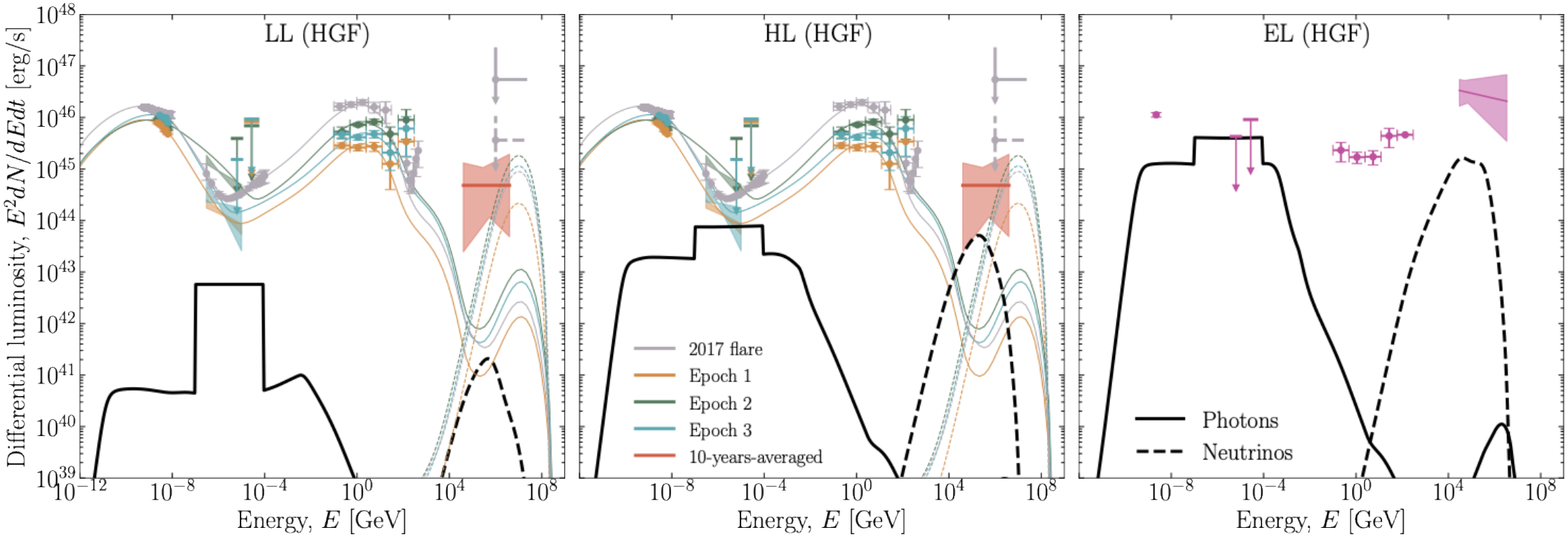
[Fiorillo, **FT** *et al.*, ApJ 985 (2025)]



Multimessenger emission from the corona of TXS 0506+056

Simulation results

Numerical simulations in the magnetic reconnection scenario confront multiwavelength data and neutrino observations



[Fiorillo, **FT** *et al.*, ApJ 985 (2025)]

Neutrino luminosity from corona too small to match the neutrino flux observed from TXS 0506+056

Conclusions

Can the neutrinos from TXS 0506+056 have a coronal origin?

- Acceleration of protons by magnetic reconnection can explain production of PeV neutrinos in the corona
- Coronal x-ray emission is subdominant compared to the jet emission
- Multimessenger emission from the Corona simulated numerically:
  - predicted neutrino flux is too low to explain the observed neutrino emission
  - electromagnetic cascade only radiative signature from corona → universal shape (work in progress!)

The neutrinos we observed from TXS 0506+056 could not be produced (only) in the AGN corona

Production in the blazar jet is still the preferred explanation of the multimessenger data!