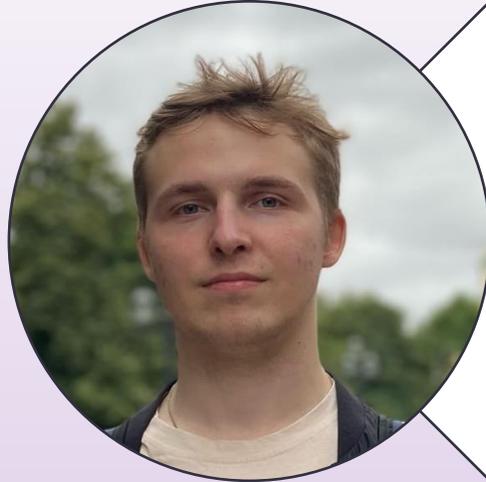


**Energy-dependent  
flavor ratios,  
cascade/track  
spectrum tension and  
high-energy  
neutrinos from  
magnetospheres of  
supermassive black  
holes**



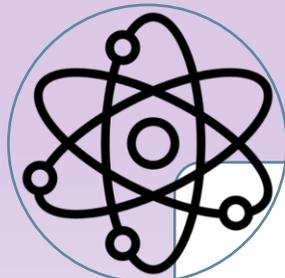
Riabtsev Kirill  
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(Telegram)



Sergey Troitsky  
INR, Moscow



arXiv:2204.09339



IceCube neutrinos ( $E > 10000$  GeV)



a mild tension between spectra obtained in different analyses

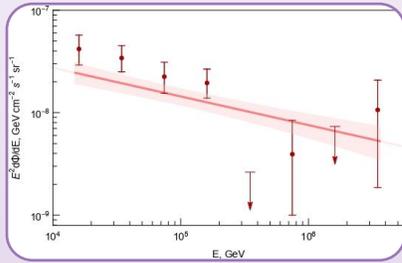


change of the flavor content of astrophysical neutrinos with energy?

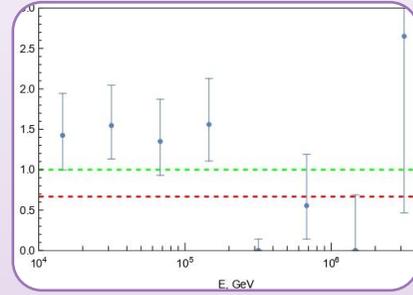


The origin of high-energy astrophysical neutrinos?

# Analysis



Observed spectra



Flavor ratios (at the detector and at the source, taking into account neutrino oscillations)

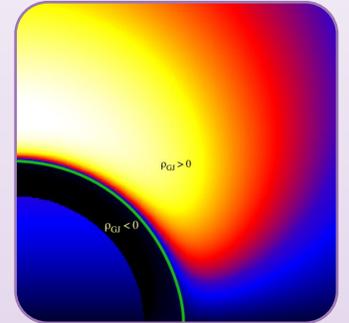


*pp*-interactions:  
 $p + p \rightarrow p + p + \text{many} \times (\pi^+ + \pi^- + \pi^0)$

*p $\gamma$* -interactions:  
1.  $p + \gamma \rightarrow \Delta^+$   
2.  $\Delta^+ \rightarrow n + \pi^+$  or  $\Delta^+ \rightarrow p + \pi^0$ .

Decays following *pp*- and *p $\gamma$* -interactions:  
1.  $\pi^0 \rightarrow \gamma + \gamma$ ,  $\pi^\pm \rightarrow \mu^\pm + \nu_\mu (\bar{\nu}_\mu)$   
2.  $\mu^\pm \rightarrow e^\pm + \nu_e (\bar{\nu}_e) + \bar{\nu}_\mu (\nu_\mu)$ .

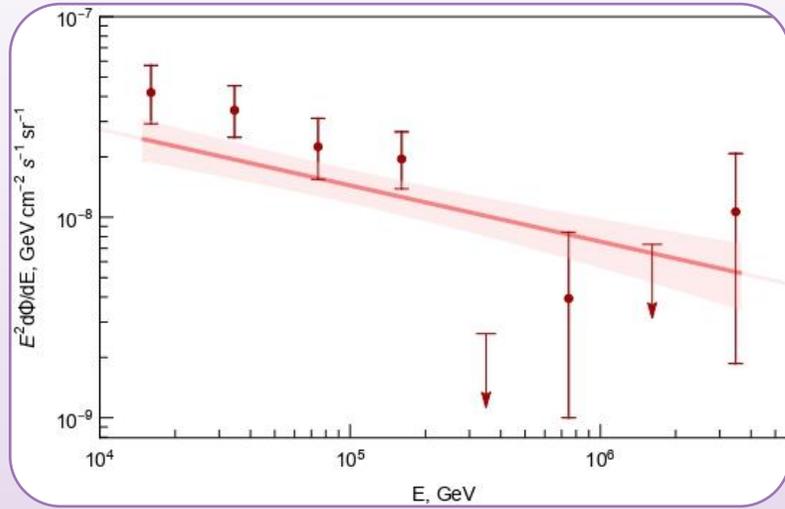
Physical conditions at the sources



The class of the sources

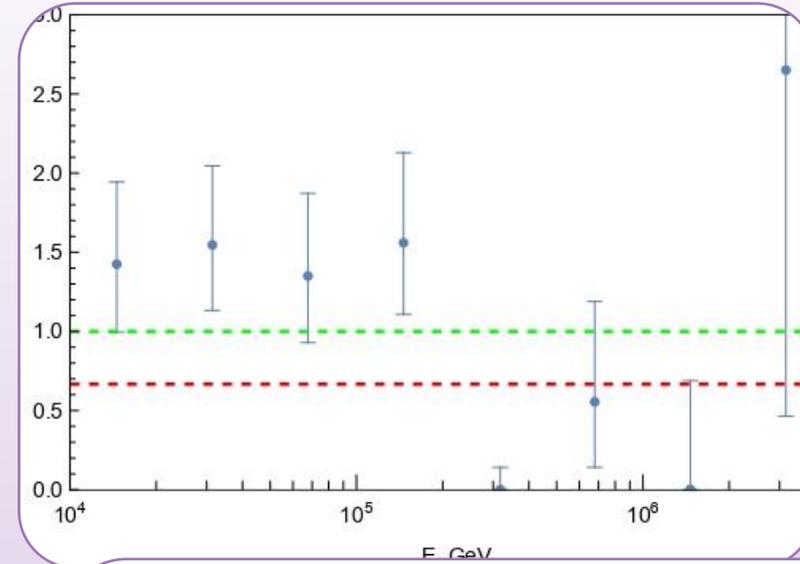


# Analysis



## Observed spectra

- Tau plus electron neutrinos (dots with error bars)
- Mu neutrinos (solid line)

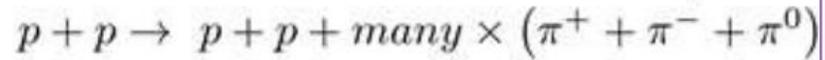


## Flavor ratios (at the detector and at the source, taking into account neutrino oscillations)

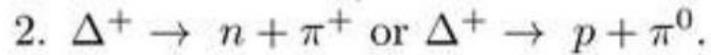
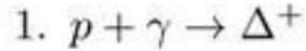
- The case of flavor equipartition (dashed green line)
- The case of muon damp (dashed red line)



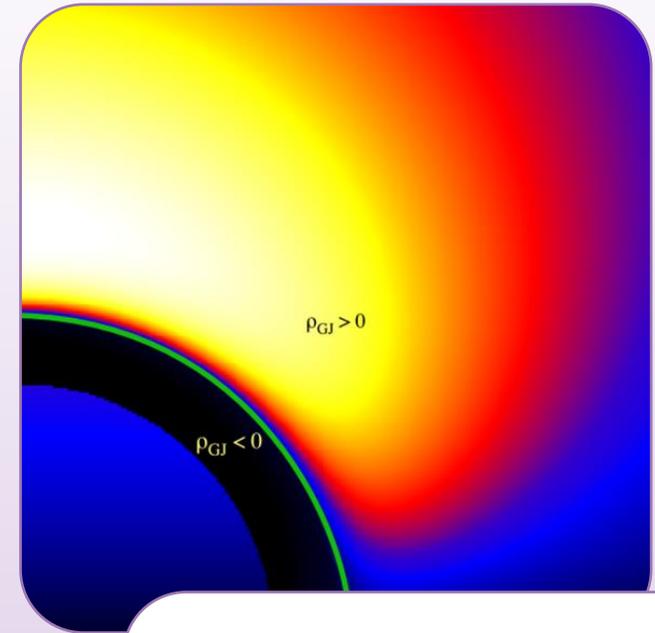
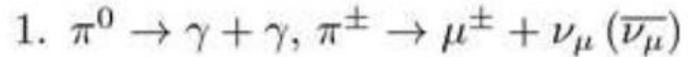
*pp*-interactions:



*p* $\gamma$ -interactions:



Decays following *pp*- and *p* $\gamma$ -interactions:



## Physical conditions at the sources

- In the case of damped muons the neutrinos from the last equation are “missing”, changing the flavor ratios
- “Muon damp” corresponds to specific magnetic fields

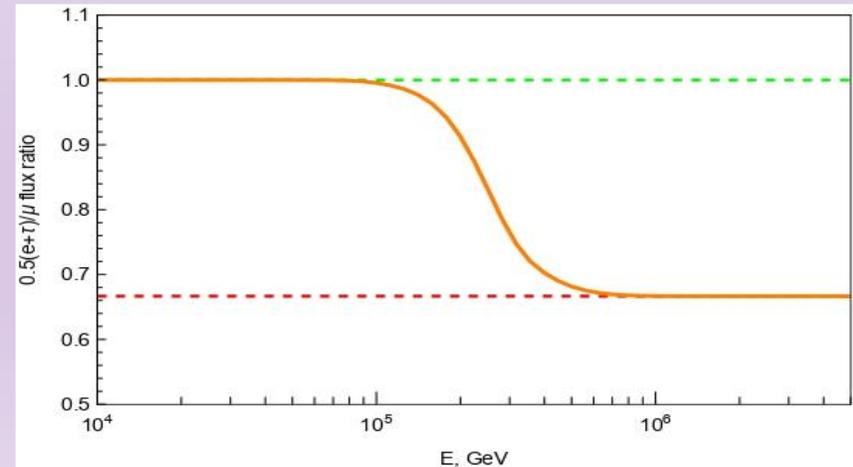
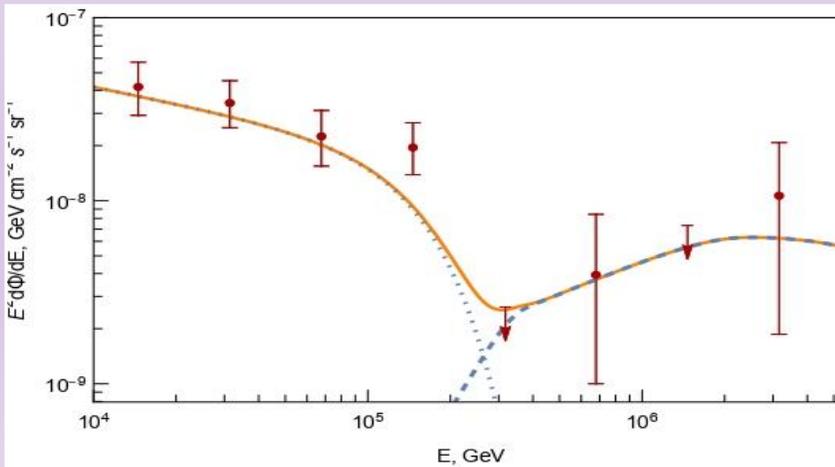
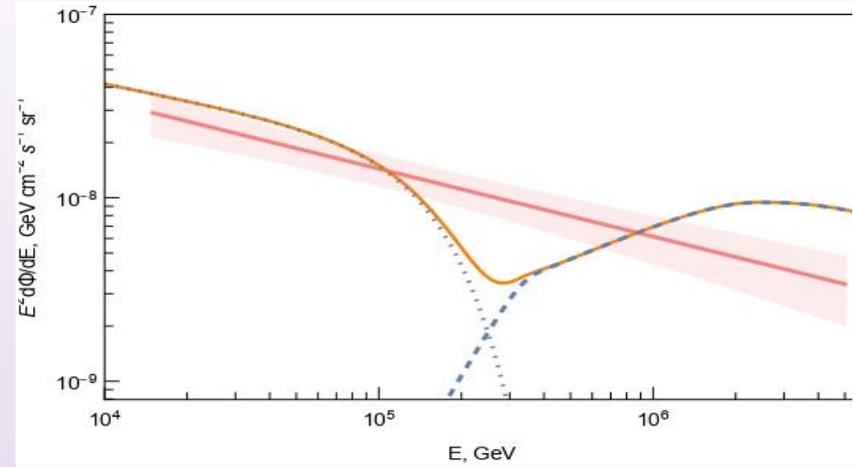
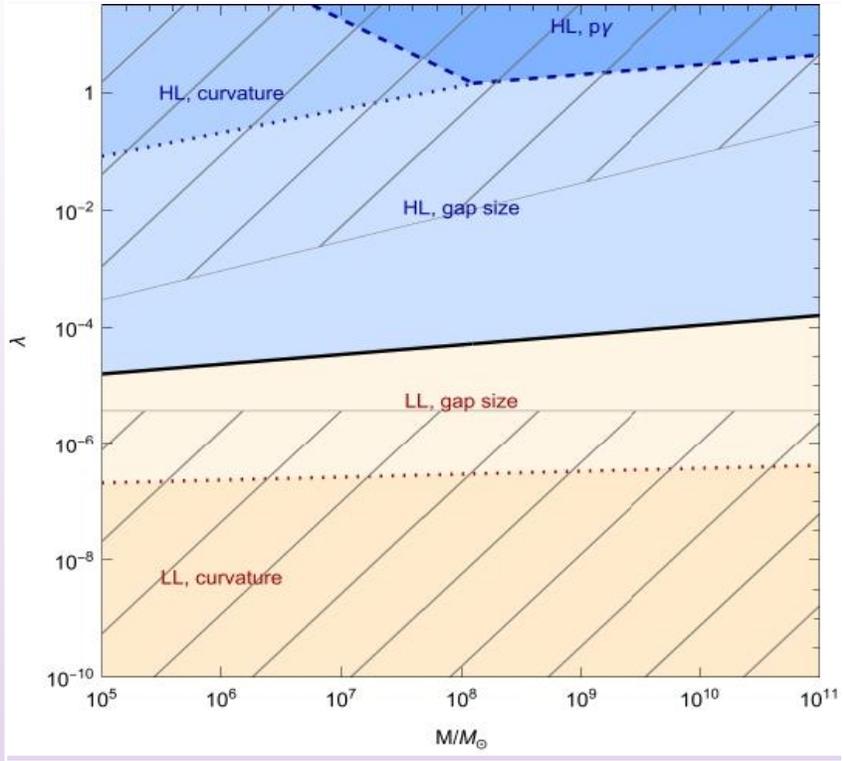


## The class of the sources

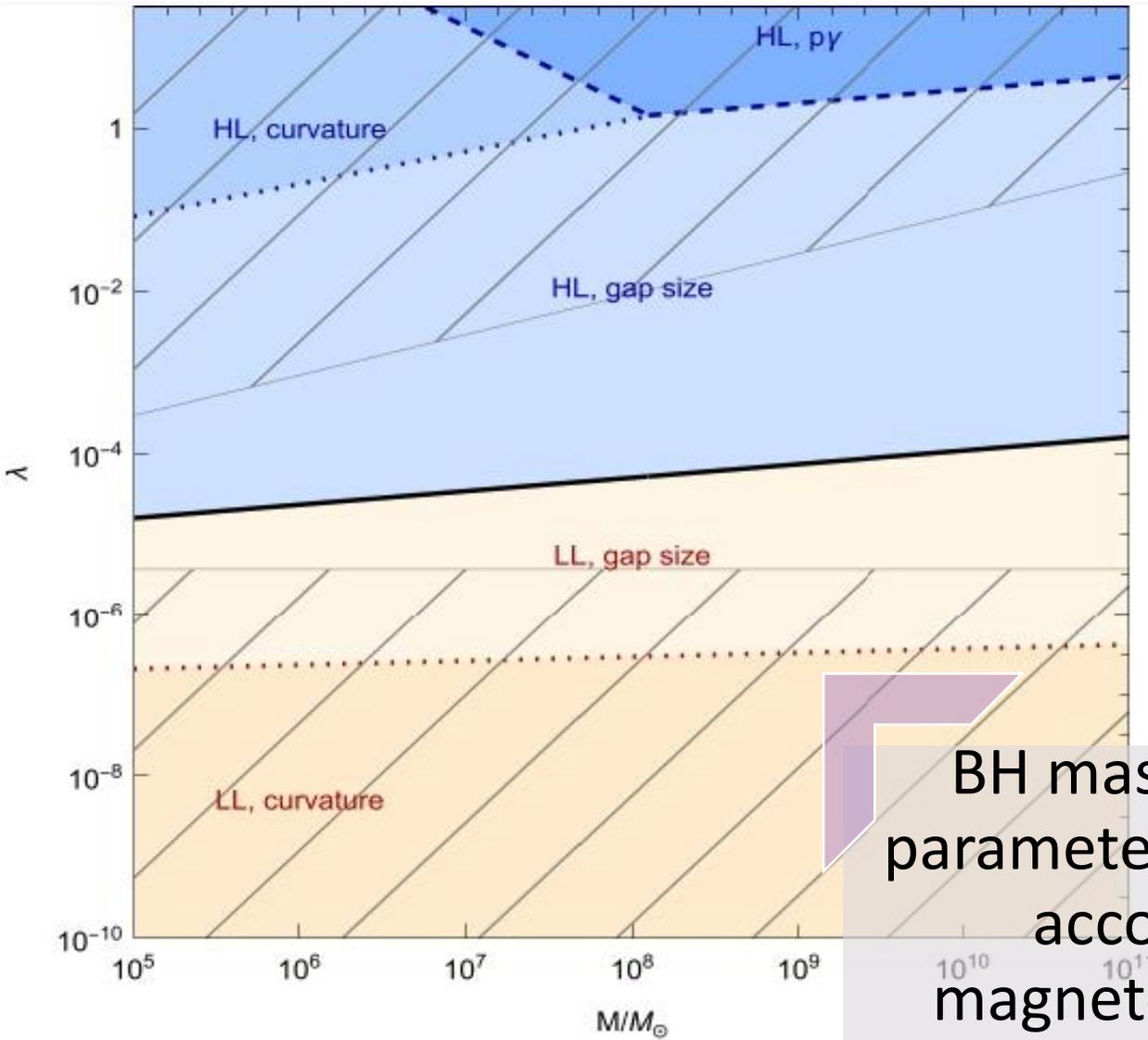
- Black holes
- ~~Gamma-ray bursts~~



# SMBH toy model

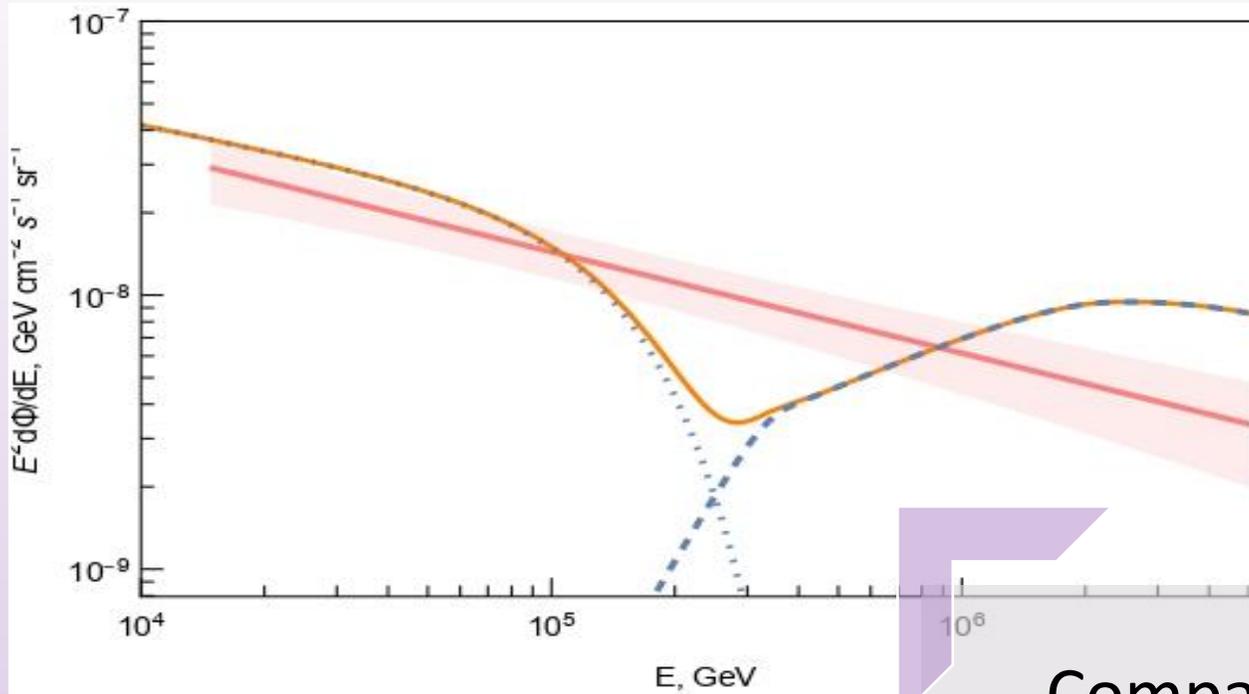


# SMBH toy model



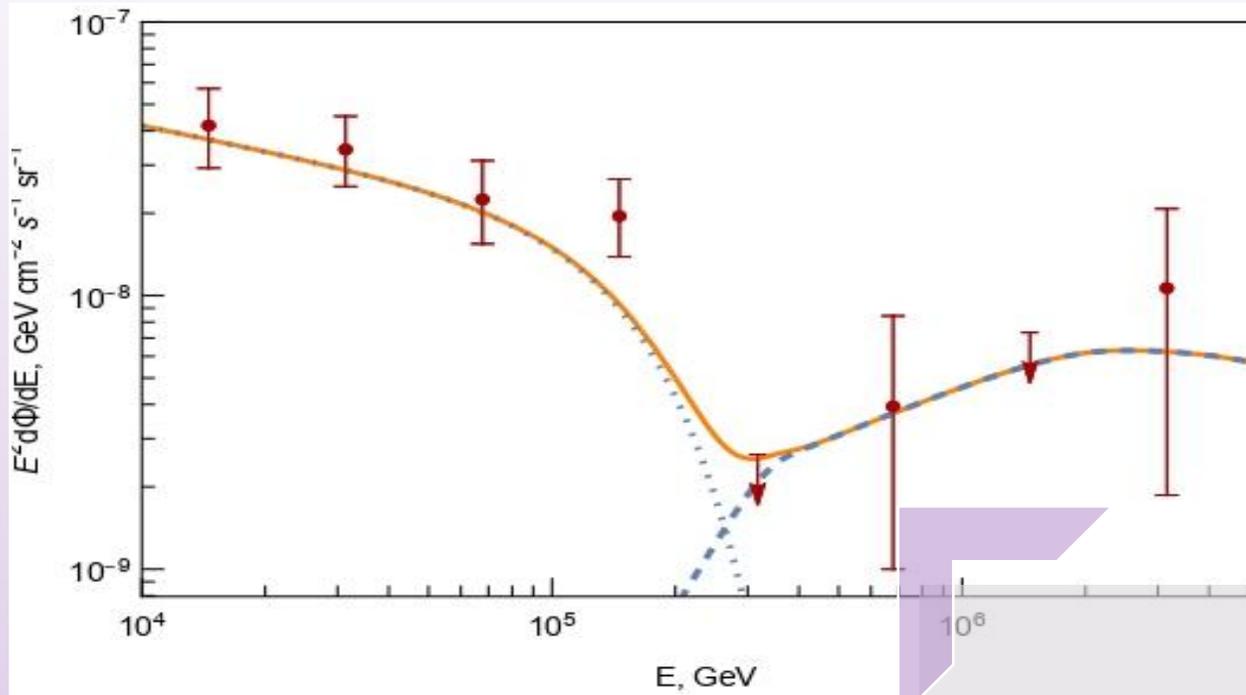
BH mass - Eddington ratio parameter space, calculated in accordance with BH magnetosphere toy model, which gets to estimate proton energies and finally provide a prediction of neutrino spectra

# SMBH toy model



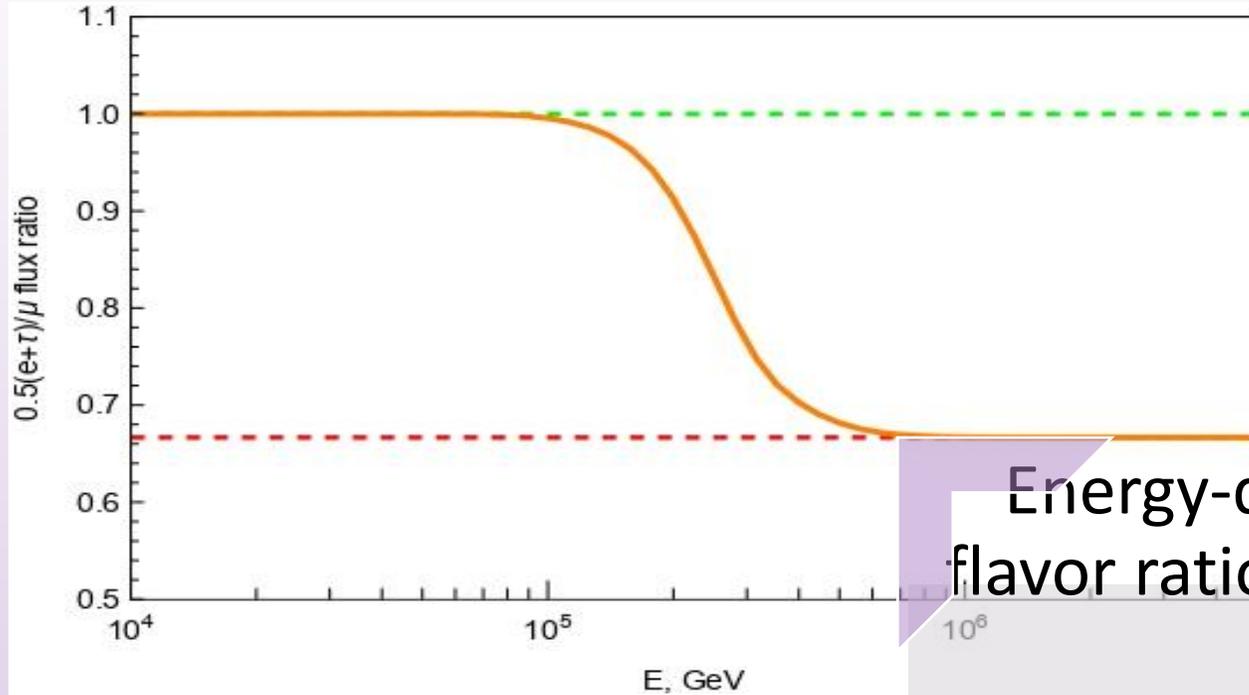
Comparison of the muon neutrino spectrum determined by IceCube and predictions of the toy model discussed in the text

# SMBH toy model



Comparison of the e+tau neutrino spectrum determined by IceCube and predictions of the toy model discussed

# SMBH toy model



Energy-dependent neutrino flavor ratio predicted by the toy model

discussed in the text (solid curve). The dashed green line represents flavor equipartition, while the dashed red line corresponds to  $2/3$ , predicted in the muon damping case

# Conclusions



0

It is presently unclear, whether the tension is caused by systematic uncertainties or by physical reasons.



1

We assumed that the reason for the discrepancy is related to the change of flavor composition



2

Then we estimated the magnetic field at sources required for this switch



3

We constructed a quantitative toy model



4

We found that this model describes well the spectra provided an additional component with standard flavor content is added at low energies



5

Detailed studies of energy-dependent flavor ratios will become possible only with the next-generation neutrino telescopes

Thank you for  
your attention!

Questions?

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Bibliography <https://arxiv.org/abs/2111.10299>

(mu neutrinos data)

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<https://arxiv.org/abs/2001.09520>

(e+tau neutrinos data)

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<https://arxiv.org/abs/1510.04023>

(SMBH magnetospheres)

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