Testing a Two-Zone Leptohadronic model with EHSP BL Lacs and track-like HE-neutrinos

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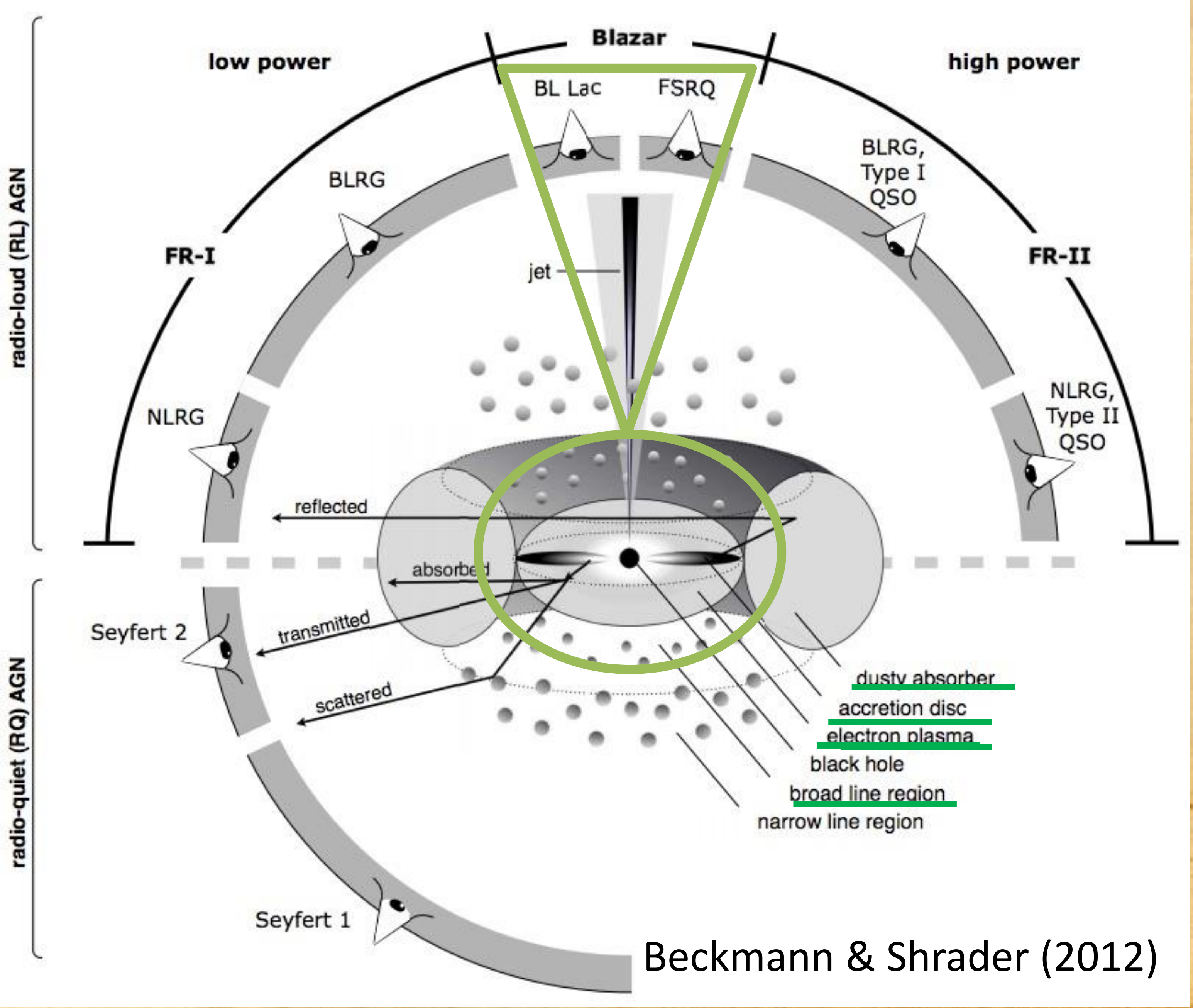
OVERVIEW

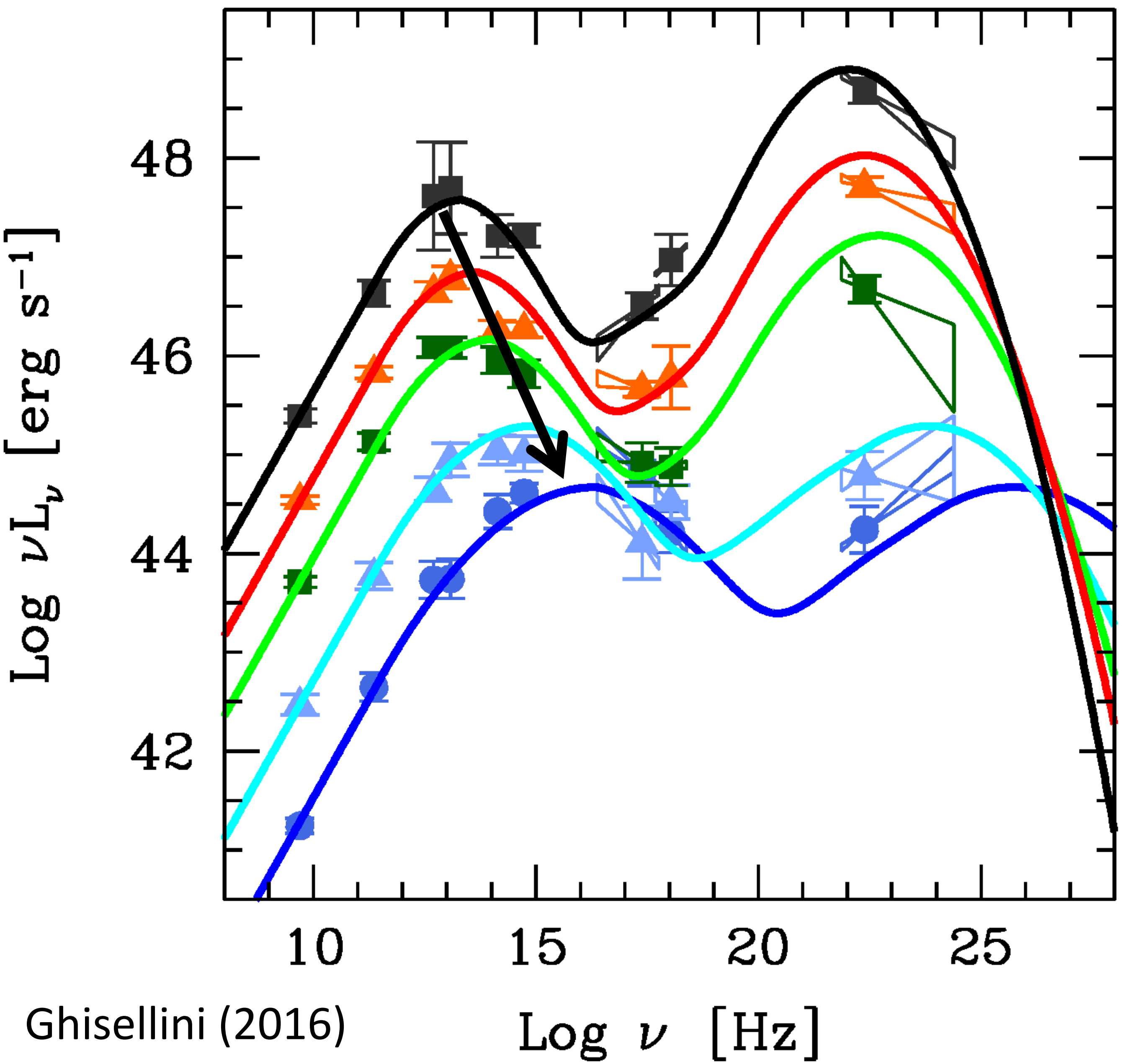
- CONTEXT AND BASIC CONCEPTS
- MOTIVATION FOR THE STUDY
- THE MODEL
- RESULTS
- SUMMARY AND CONCLUSIONS

What is a BL Lac?



Beckmann & Shrader (2012)

Types of BL Lac



Ghisellini (2016)

ν_{syn}

LSP ($< 10^{14}$ **Hz**)

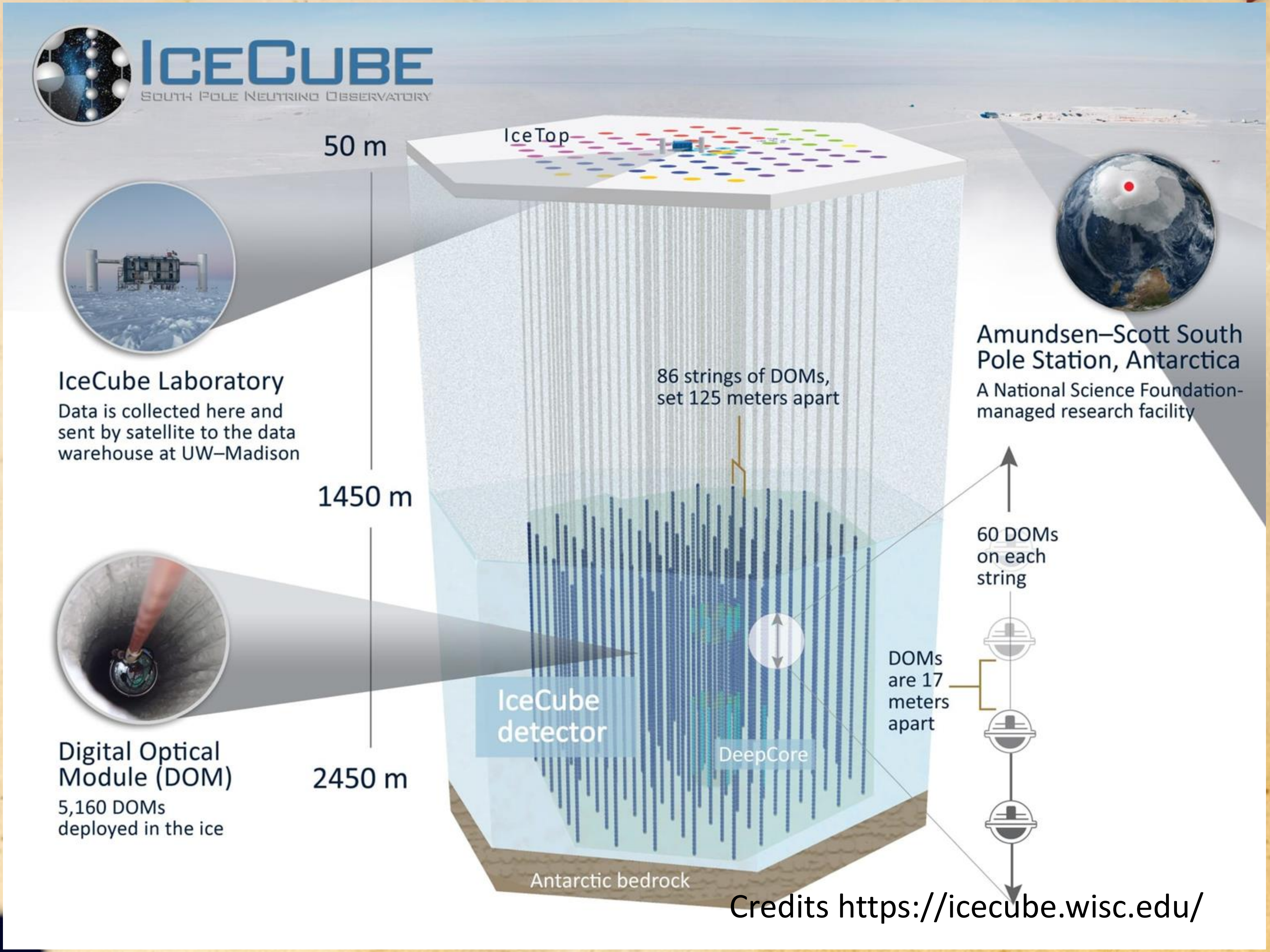
ISP ($10^{14} - 10^{15}$ **Hz**)

HSP ($10^{15} - 10^{17}$ **Hz**)

EHSP ($> 10^{17}$ **Hz**)

L_{syn}

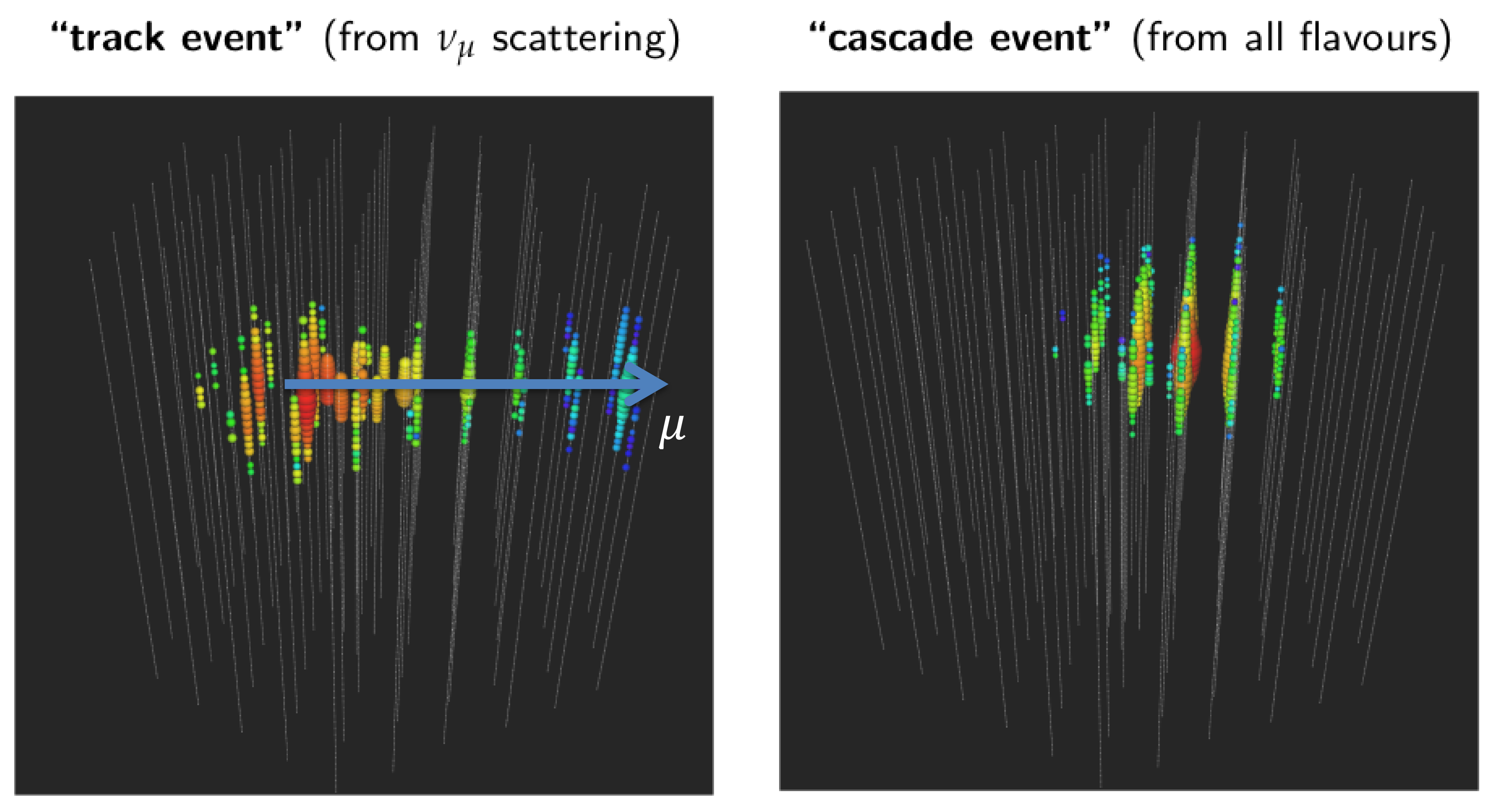
IceCube: The biggest HE-ν detector



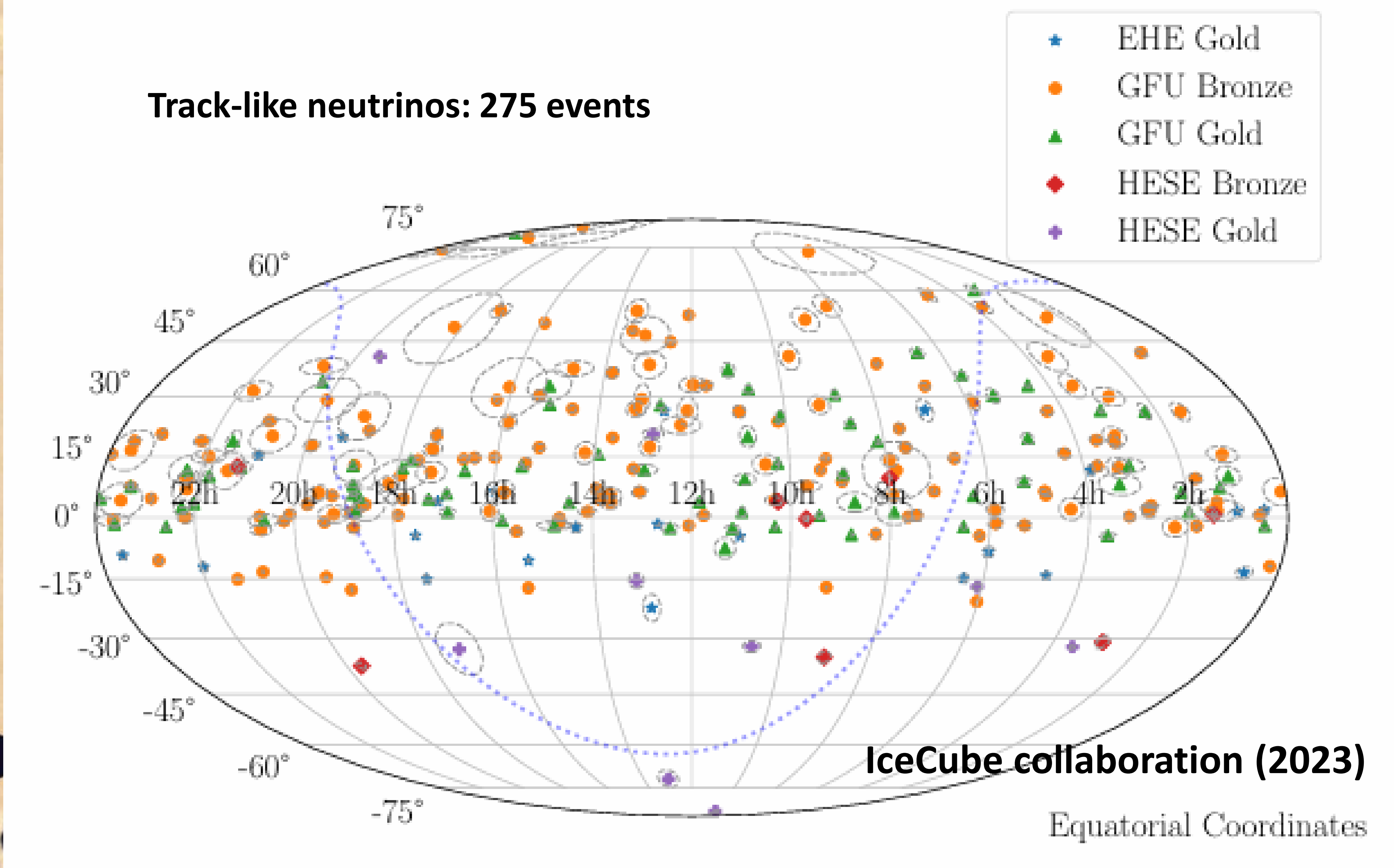
Detection of neutrinos by IceCube

Angular resolution ~1°

Angular resolution ~15°



IceCube: Event detection



Blazars as cosmic accelerators

TXS 0506+056: The first identification of an extragalactic cosmic accelerator

RESEARCH ARTICLE SUMMARY

$E_\nu \sim 290$ TeV

NEUTRINO ASTROPHYSICS

Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†

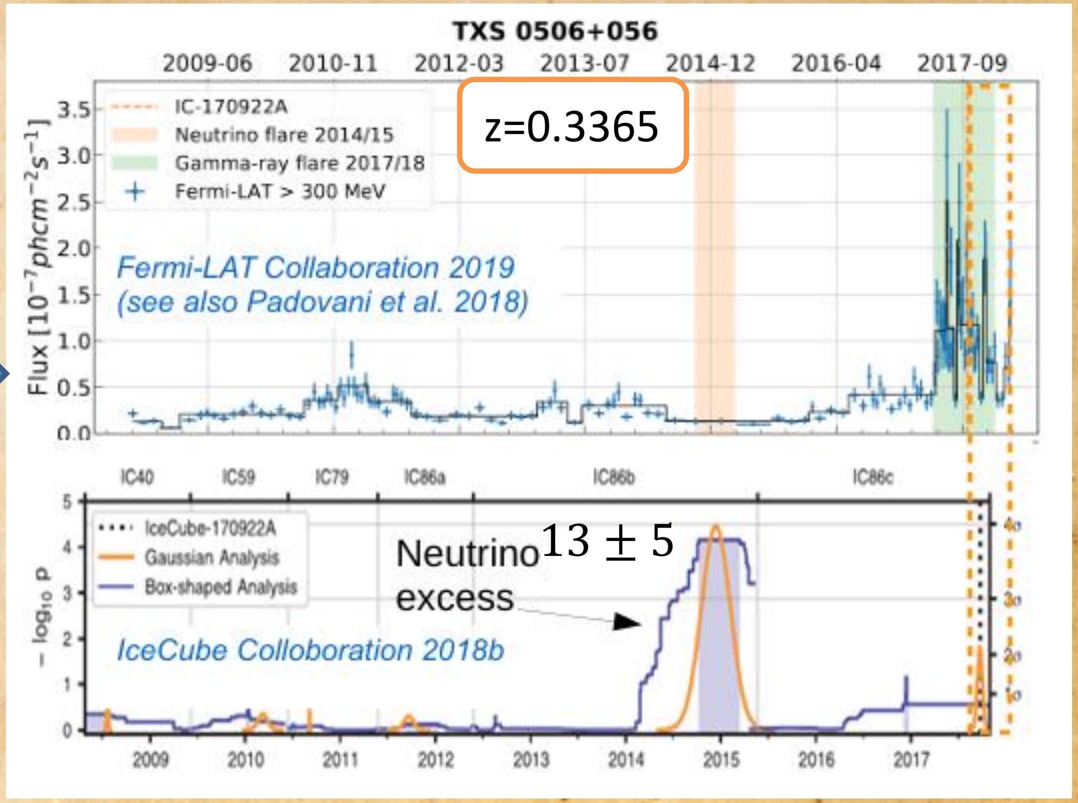
RESEARCH ARTICLE

$\sim$ 6 months in 2014-2015

NEUTRINO ASTROPHYSICS

Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

IceCube Collaboration*†



HE-ν production in astrophysical environments

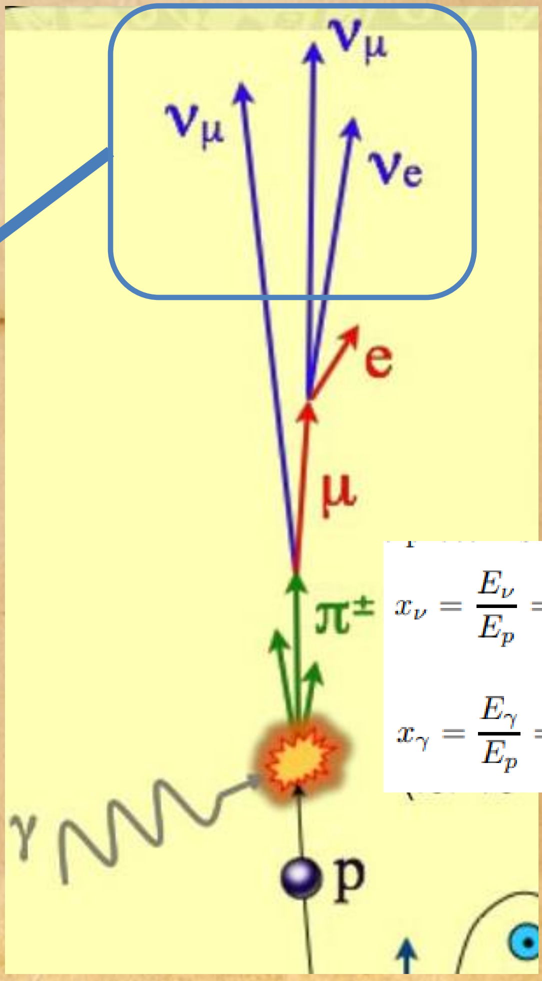
Short-lived particles
$\tau_{\pi^\pm} \approx 2.6 \times 10^{-8}\text{sec}$
$\tau_\mu \approx 2.197 \times 10^{-6}\text{sec}$

Via photomeson production:

$$p + \gamma_{\text{Low}} \rightarrow N_+\pi^+ + N_+\pi^- + N_+\pi^0 + \cdots$$

- $\epsilon_{p,th} > 70\text{ PeV}\left(\frac{\epsilon_\gamma}{1\text{ eV}}\right)^{-1}$

$\pi^0 \rightarrow \gamma\gamma$

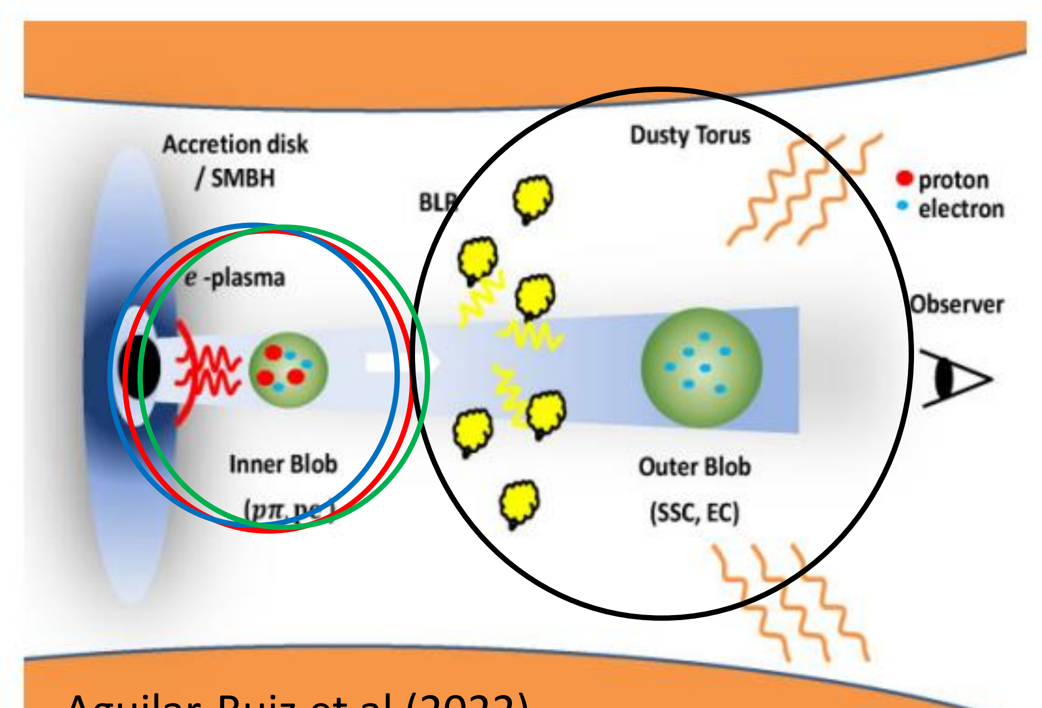


$$x_\nu = \frac{E_\nu}{E_p} = \frac{1}{2}\langle x_{p\rightarrow\pi}\rangle \simeq \frac{1}{20},$$

$$x_\gamma = \frac{E_\gamma}{E_p} = \frac{1}{2}\langle x_{p\rightarrow\pi}\rangle \simeq \frac{1}{10}.$$

Multimessenger astronomy

A two-zone leptohadronic model for blazar (AR2022)



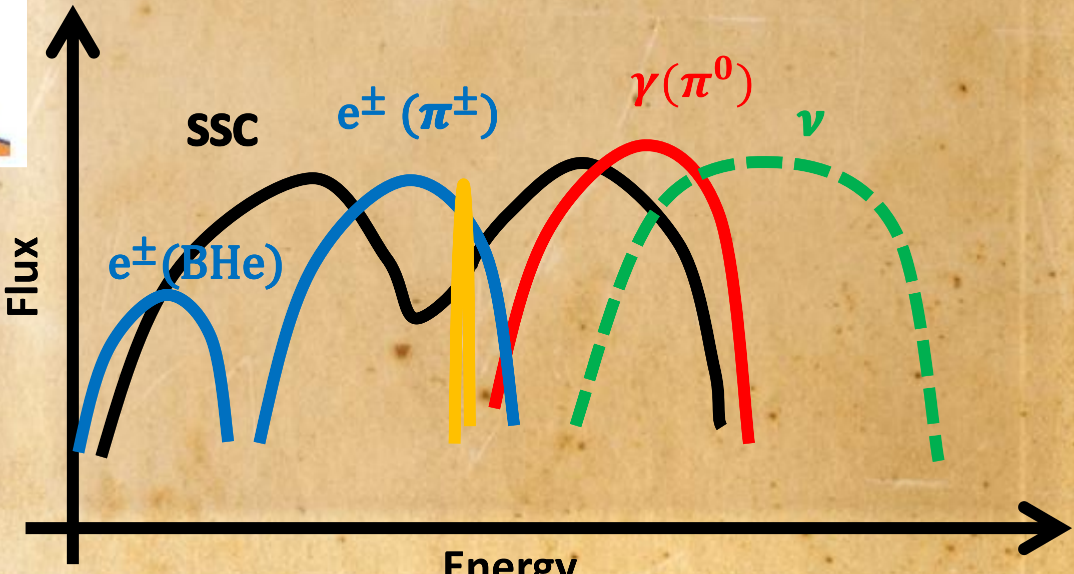
Aguilar-Ruiz et al (2022)

$$E_\gamma^{\rm ob} \gtrsim 75\,{\rm GeV}\,\frac{\Gamma_{\rm rel}\,\mathcal{D}_i}{1+z}\left(\frac{\epsilon_{\rm pl}}{511\,{\rm keV}}\right)^{-1}.$$

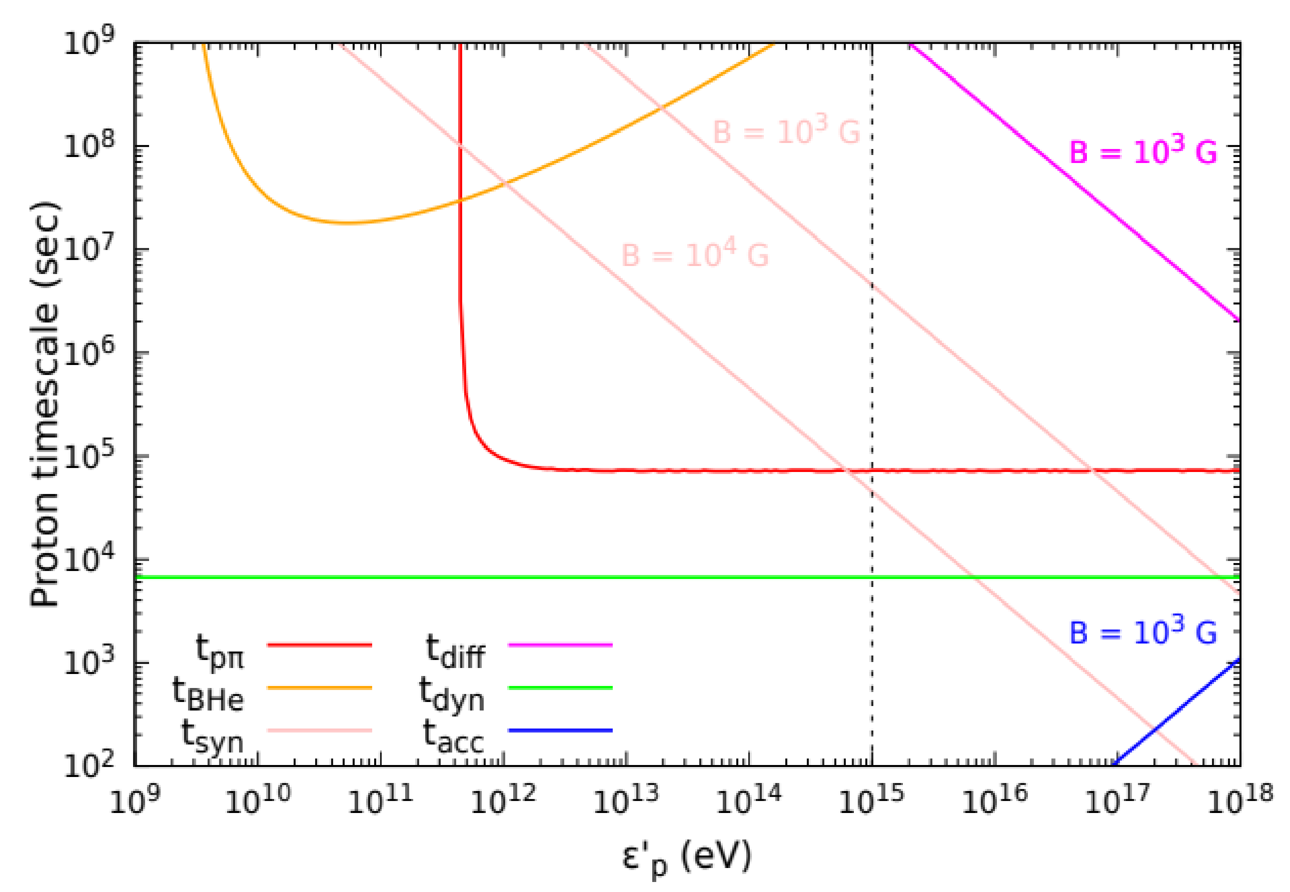
$$E_{\rm syn,BH}^{\rm ob} \gtrsim 8\times10^{-5}\,{\rm eV}\,\Gamma_{\rm rel}^2\left(\frac{B_i'}{100{\rm G}}\right)\left(\frac{\mathcal{D}_i}{3}\right)\left(\frac{\epsilon_{\rm pl}}{511\,{\rm keV}}\right)^2.$$

$$E_{{\rm syn},p\pi}^{\rm ob} \gtrsim 36\,{\rm keV}\,\Gamma_{\rm rel}^2\left(\frac{B_i'}{100{\rm G}}\right)\left(\frac{\mathcal{D}_i}{3}\right)\left(\frac{\epsilon_{\rm pl}}{511\,{\rm keV}}\right)^2.$$

TBL (EHSP which energy peak of HE-bump is located in the TeV band)



Neutrino requirement for the model



Inner blob

- Size of $R_i \sim 10^{14}$ cm
- Inside acceleration zone, $\lesssim 10^{17}$ cm
- Magnetic field conservation along the jet

$$B_i \propto B_o$$

Seed photons
$L_{keV} \sim 10^{44}$ erg s^{-1}
(Belodorov, 1999)

$$\varepsilon'_{p,\max} \gtrsim 0.67\,\mathrm{PeV}(1+z)\left(\frac{E_\nu^{\rm ob}}{100\,\mathrm{TeV}}\right)\left(\frac{\mathcal{D}_i}{3}\right)^{-1}.$$

→ **Minimum value**

$$E_{\nu,\rm br}^{\rm ob} \approx 2\,\mathrm{PeV}\,(1+z)\left(\frac{\mathcal{D}_i}{3}\right)\left(\frac{B'_i}{10^4\,\mathrm{G}}\right)^{-1},$$

→ **Synchrotron of $\mu's$ and $\pi's$**

APPLICATION TO EHSP BL Lacs

HE-Neutrino (1)	E_ν (PeV) (2)	R.A. (deg) (3)	Dec (deg) (4)	$A_{\mu,\mathrm{eff}}$ (m^2) (5)	Coincident EHSP BL Lac (6)	ν_{syn}^{pk} (10^{17} Hz) (7)	z (8)	d_L (Gpc) (9)	$E_\nu L_E\|_{E_\nu^{\mathrm{ob}}}$ (10^{45} erg s^{-1}) (10)
IC190819A	0.113	$148.54^{+2.29}_{-3.30}$	$1.45^{+0.93}_{-0.75}$	29.26	1RXS J09462.5+010459	6.16	0.577	3.476	8.52
IC190922A	3.114	$167.30^{+2.81}_{-2.72}$	$-22.27^{+3.39}_{-3.31}$	128.86	1ES 1101-232	3.40	0.186	0.879	5.48
IC200107A	0.330 [a]	$1480.18^{+2.20}_{-1.83}$	$35.46^{+1.10}_{-1.22}$	20.85	3HSP J095507.9+355101	5 ($\gtrsim$20 [b])	0.557	3.332	32.28

Steady state EHSP
$f_\pi \sim 0.05$

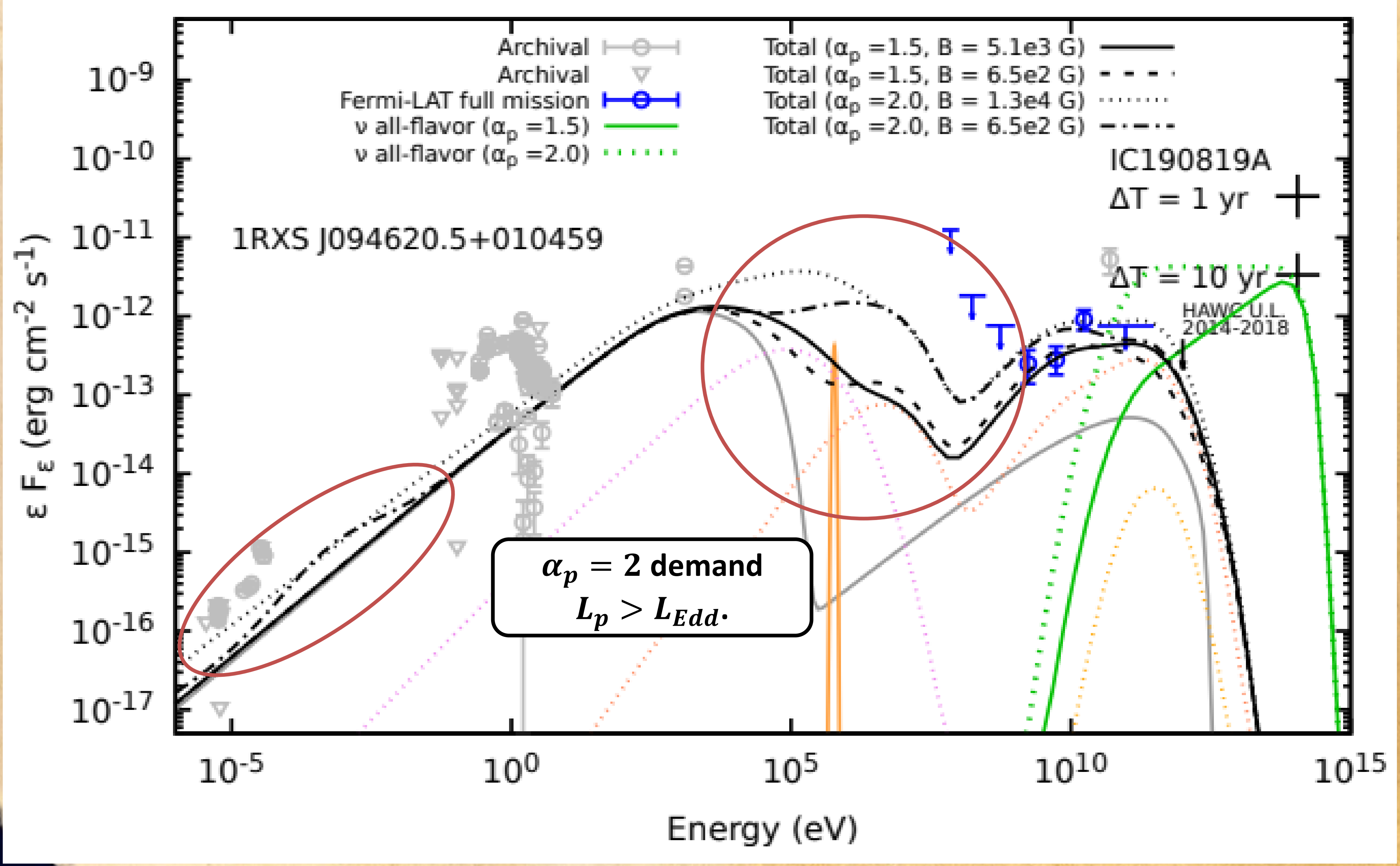
→ **An increase of seed photons** →

Flaring state EHSP
$f_\pi \gtrsim 0.05$

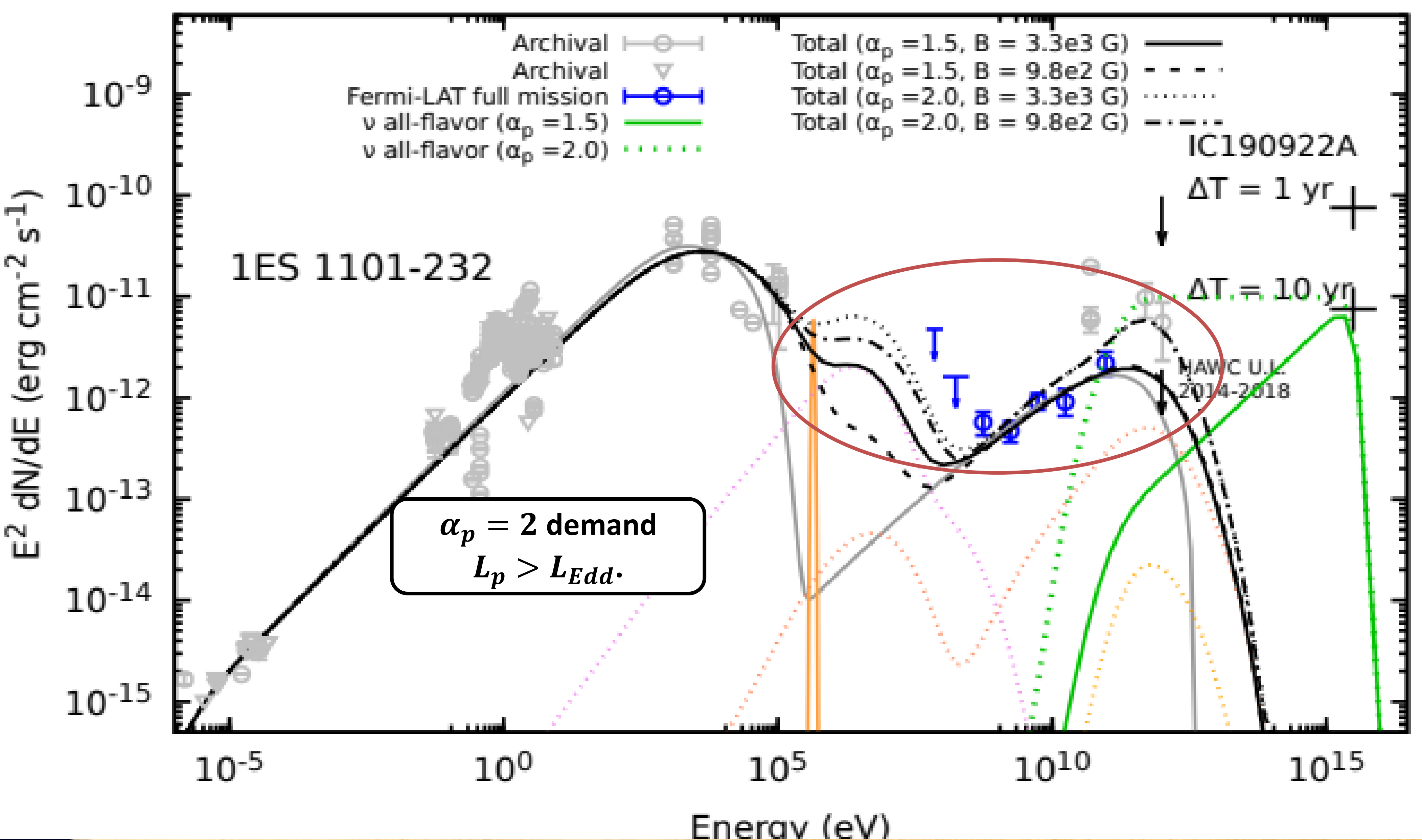
In this work we test two set of parameters

1. $\boldsymbol{\alpha_p = 2}$ and $\boldsymbol{\alpha_p = 1.5}$
2. $\boldsymbol{B_{cons}}$ and $\boldsymbol{B_{eq}}$

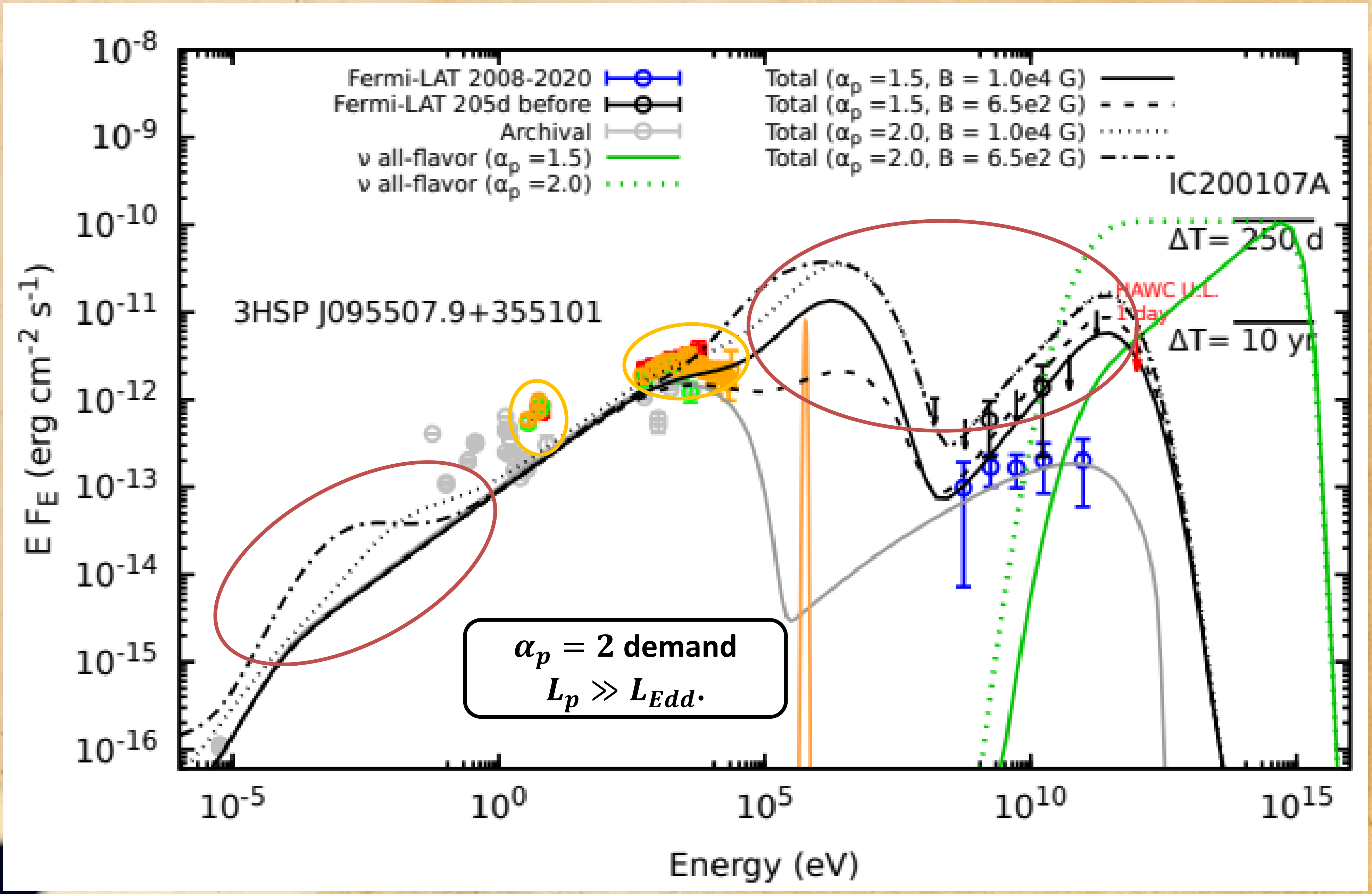
RESULTS: 1RXS J094620.5+010459



RESULTS: 1ES 1101-232



RESULTS: 3HSP J095507.9+355101



SUMMARY AND CONCLUSIONS

- We have studied the association of 3 EHSP (two during steady state and one during flaring state) coincident with track-like HE-neutrino events using a two-zone leptohadronic model.
- Our results indicates that our two zone model may explain the broadband emission of two blazar during steady state, favoring hard spectrum and magnetic field strengths in the range of $B = 10^3 - 10^4$ G. Meanwhile for the blazar during flaring state our model presents difficult and only selecting extreme parameter values our model can partially fit the observations.
- Our two zone model is a feasible alternative and the key to discriminate it among other models are future instruments in the MeV-band.

¡THANK YOU FOR YOUR ATTENTION!

Table 3. Parameters used to model the inner blob of EHSP BL Lac coincident with track-like neutrino events.

	Inner Blob										
	1RXS J09462.5+010459 *(Scenario A)*				**1ES 1101-232** *(Scenario A)*			**3HSP J095507.9+355101** *(Scenario B)*			
Γ_i	1.5				1.5			1.5			
$\mathcal{D}_i$	2.6				2.6			2.6			
R' [10^{14} cm]	3				3			3			
$\varepsilon'_{p,\min}$ [GeV]	1				1			1			
$\varepsilon'_{p,\max}$ [PeV]	10				100			10			
α_p	1.5		2		1.5		2	1.5		2	
K'_p [10^5 cm^{-3} GeV^{-1}]	2.4		2.7×10^3		0.26		1.3×10^3	1.8		3.5×10^3	
L_p [10^{47} erg s^{-1}]	0.68		5.3		0.26		2.3	3.7		26.6	
B'_i [10^3 G]	0.65	10.0	0.65	10.0	0.5	1	1	0.66	10	0.66	10
L_B [10^{46} erg s^{-1}]	0.31	7.1	0.31	7.1	0.0.17	0.69	0.69	0.31	7.1	0.31	7.1
U_B/U_p	4.5×10^{-2}	10.4	5.8×10^{-3}	1.3	6×10^{-2}	0.26	3×10^{-2}	8×10^{-3}	1.9	1.1×10^{-3}	1.9