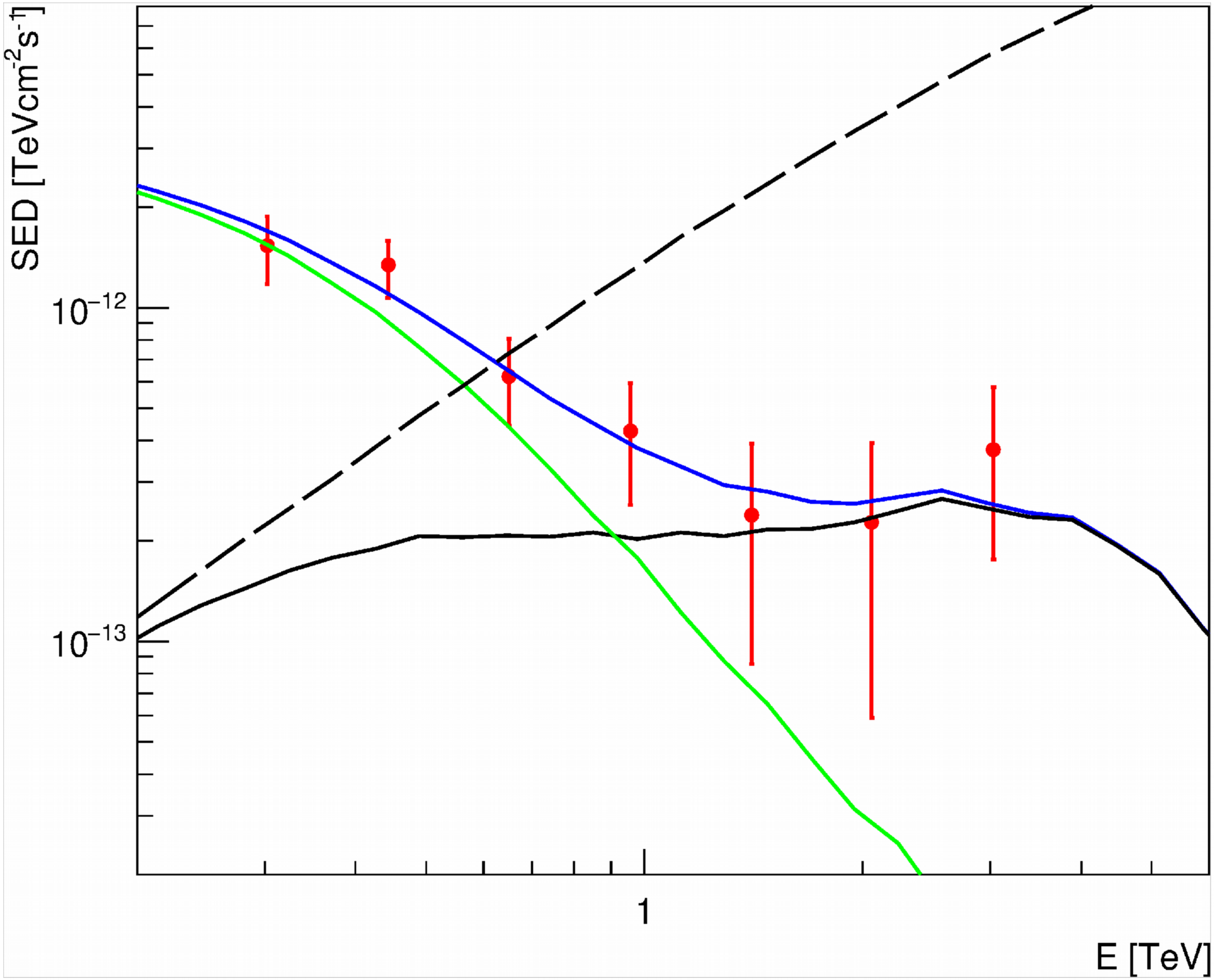
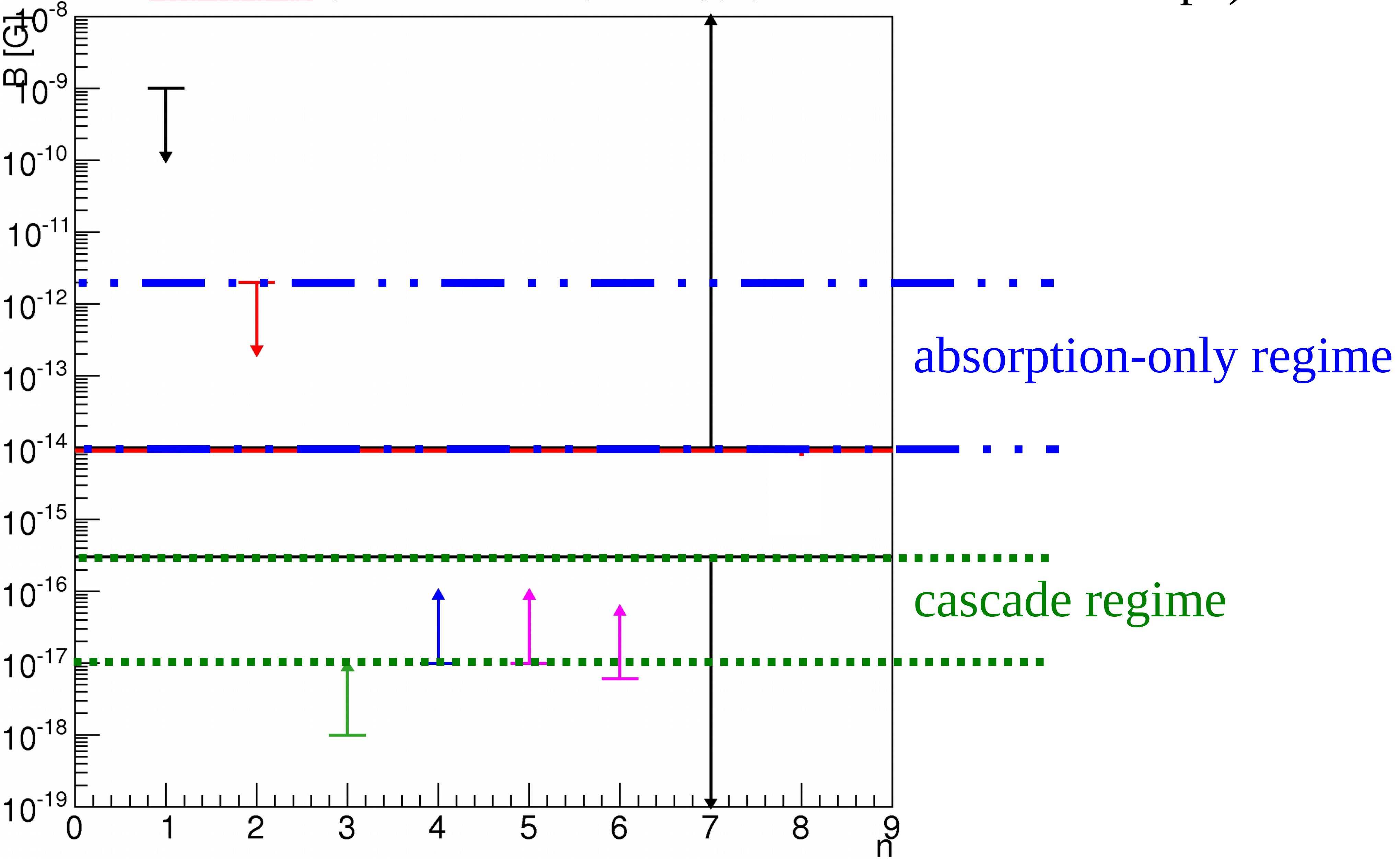
Indications for a cascade component in gamma-ray blazar spectra



S. Baklagin, T. Dzhatdoev, E. Khalikov, A. Kircheva, A. Lyukshin
(SINP MSU) astro-ph/1609.01013

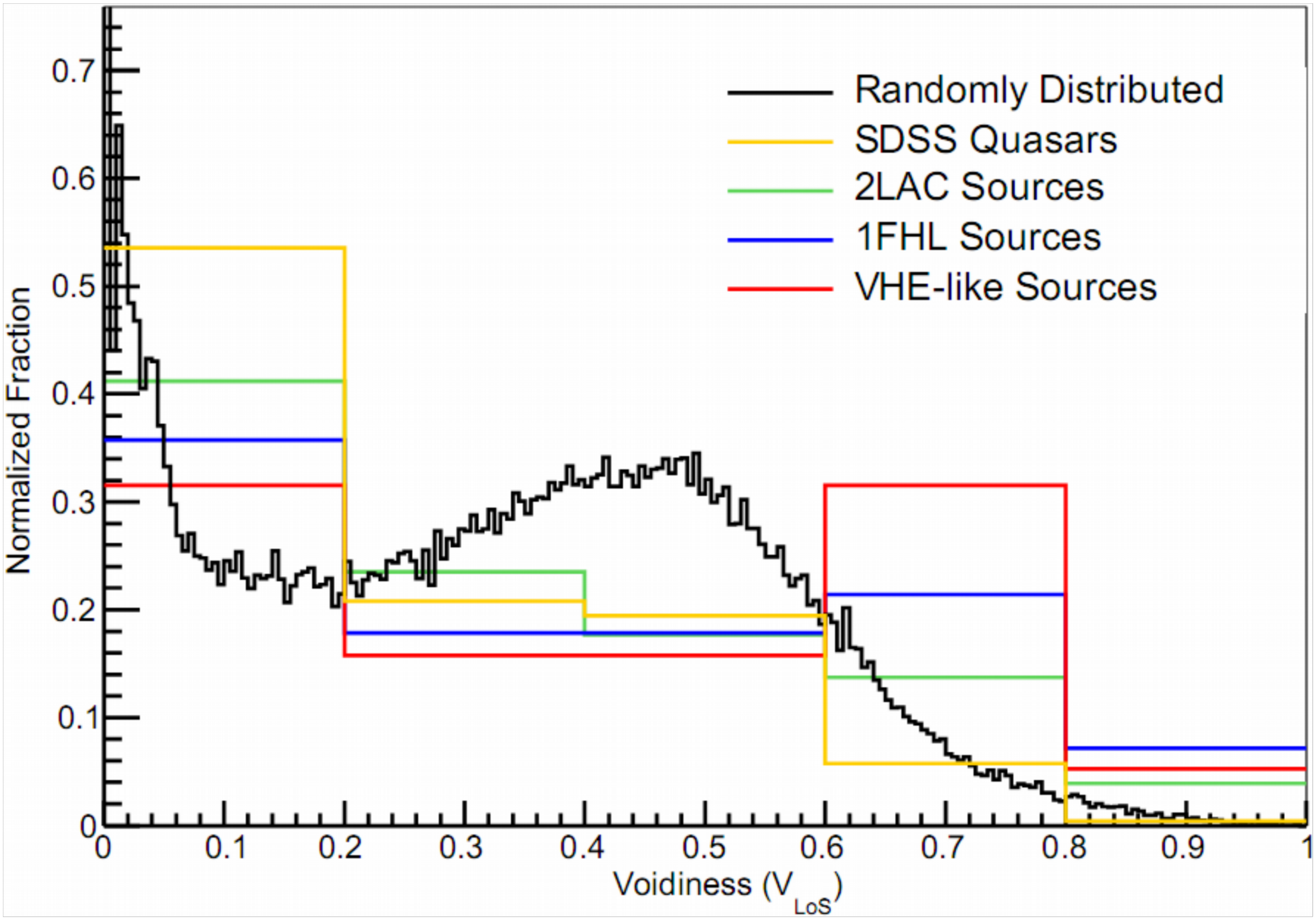
Constraints on the extragalactic magnetic field (EGMF) strength <u>in voids</u> (Dzhatdoev (2015)) (coherence scale 1 Mpc)



For a review of absorption on extragalactic background light (EBL) see talk of G. Sinnis (this conference)

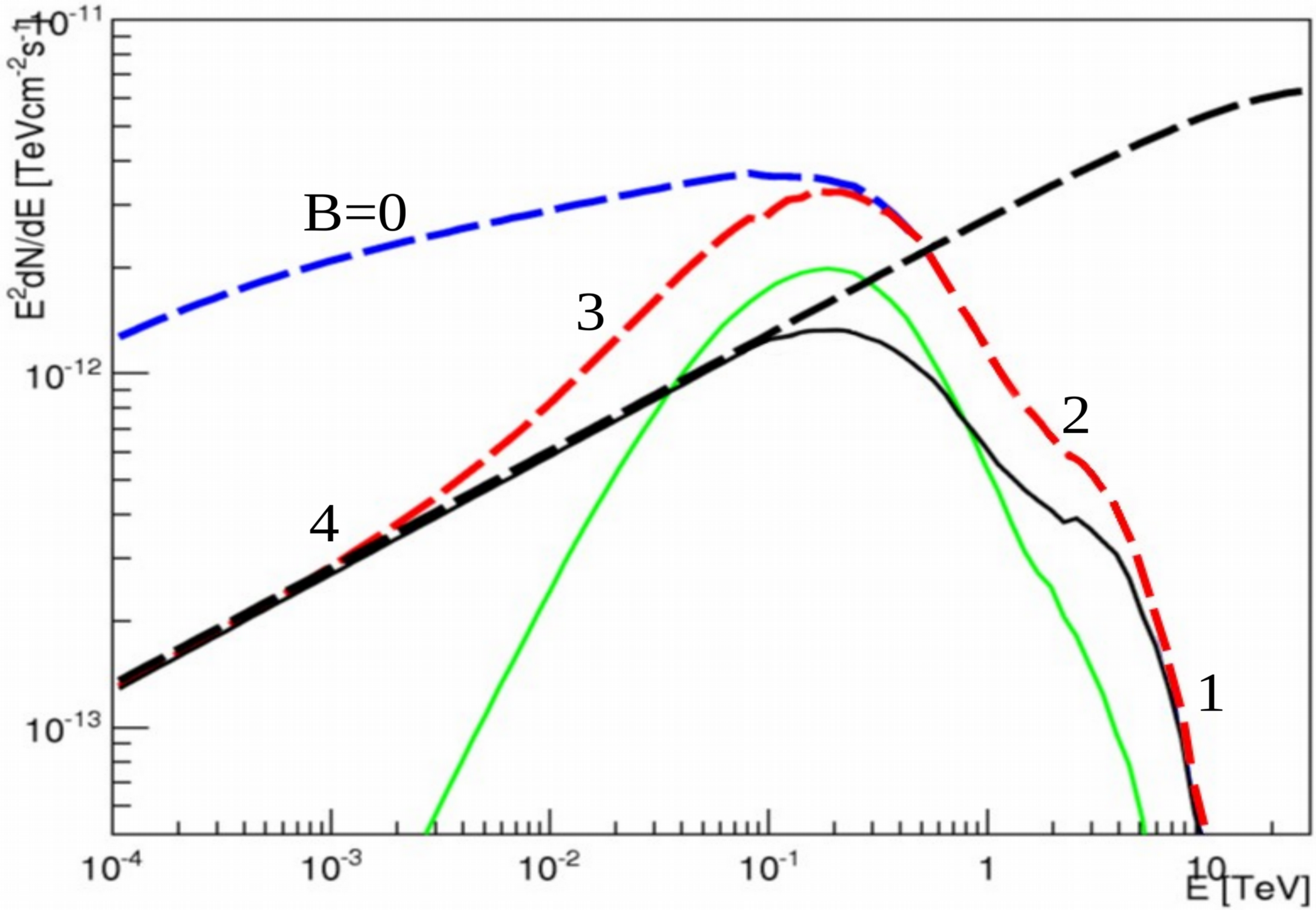
Furniss et al. (2014): hard-spectra blazars (10-300 GeV) are predominantly located towards the voids; significance ~2.5 σ.

Wrong sign of the effect (!?)



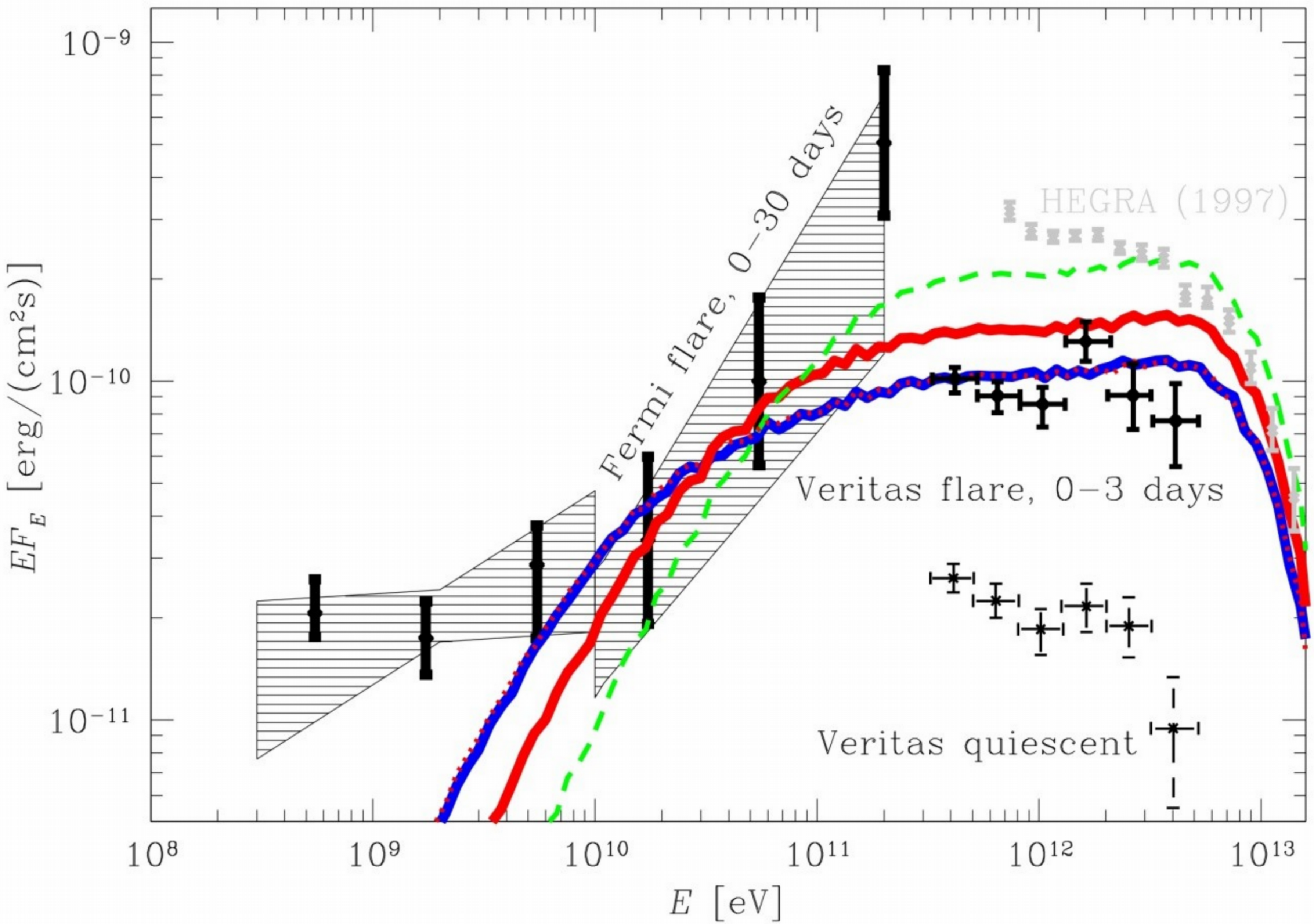
All calculations of EM cascades hereafter with the ELMAG code (Kachelriess et al. (2012))

Signatures of the electromagnetic cascade model (z= 0.14)

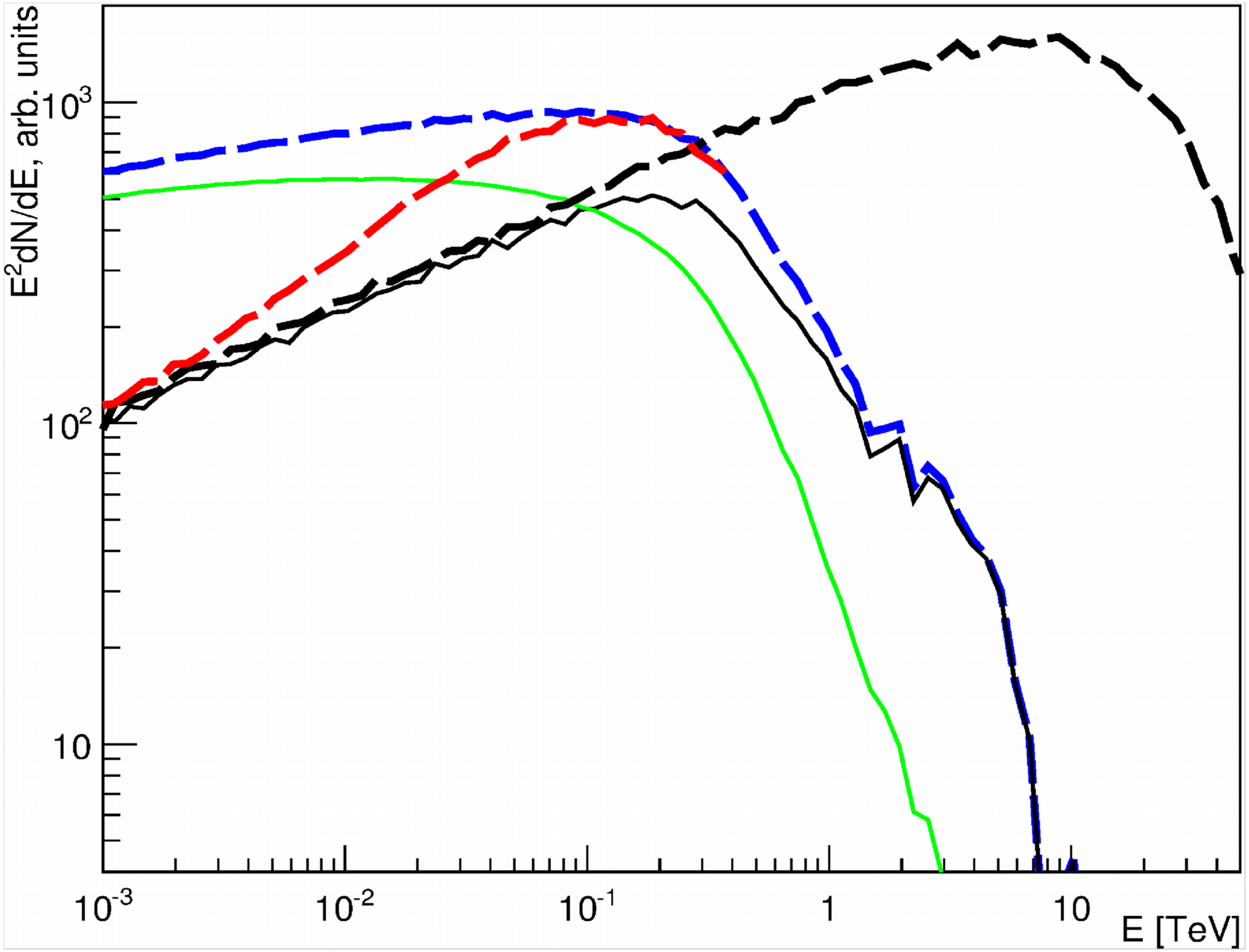


1= high-energy cutoff; 2= ankle; 3= magnetic cutoff; 4= second ankle

Indications for EM cascades: Neronov et al. (2012) +Furniss et al. (2014); Chen et al. (2015); for brief discussion see Dzhatdoev (2015)



The magnetic cutoff effect



Without EGMF (z= 0.14)

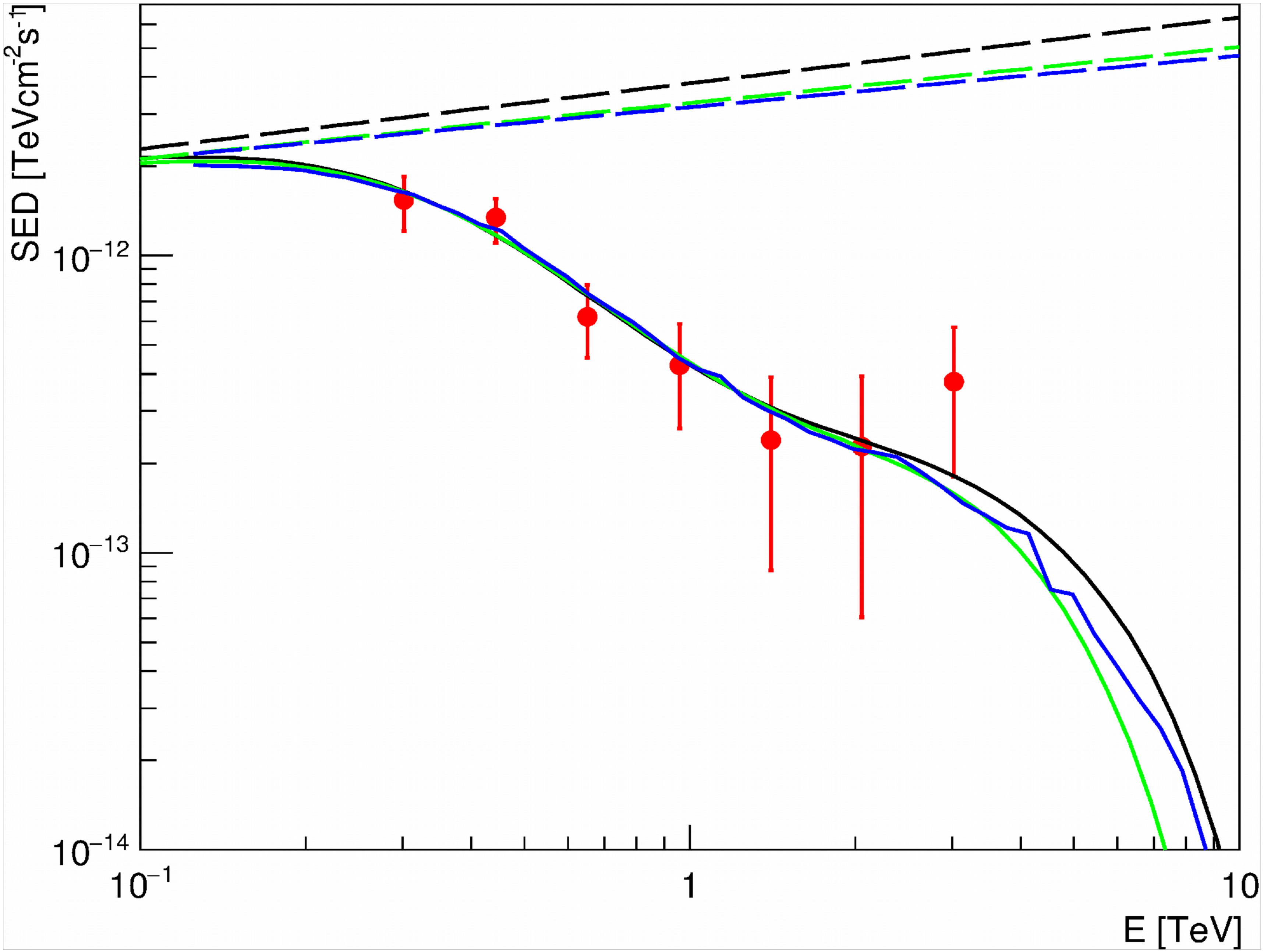
Δγ= γ(prim.)-γ(casc.)= 1.67-1.90= -0.23 wrong sign of the effect (!)

With EGMF (z= 0.14, B= 0.03 fG, max. time delay 3 years)

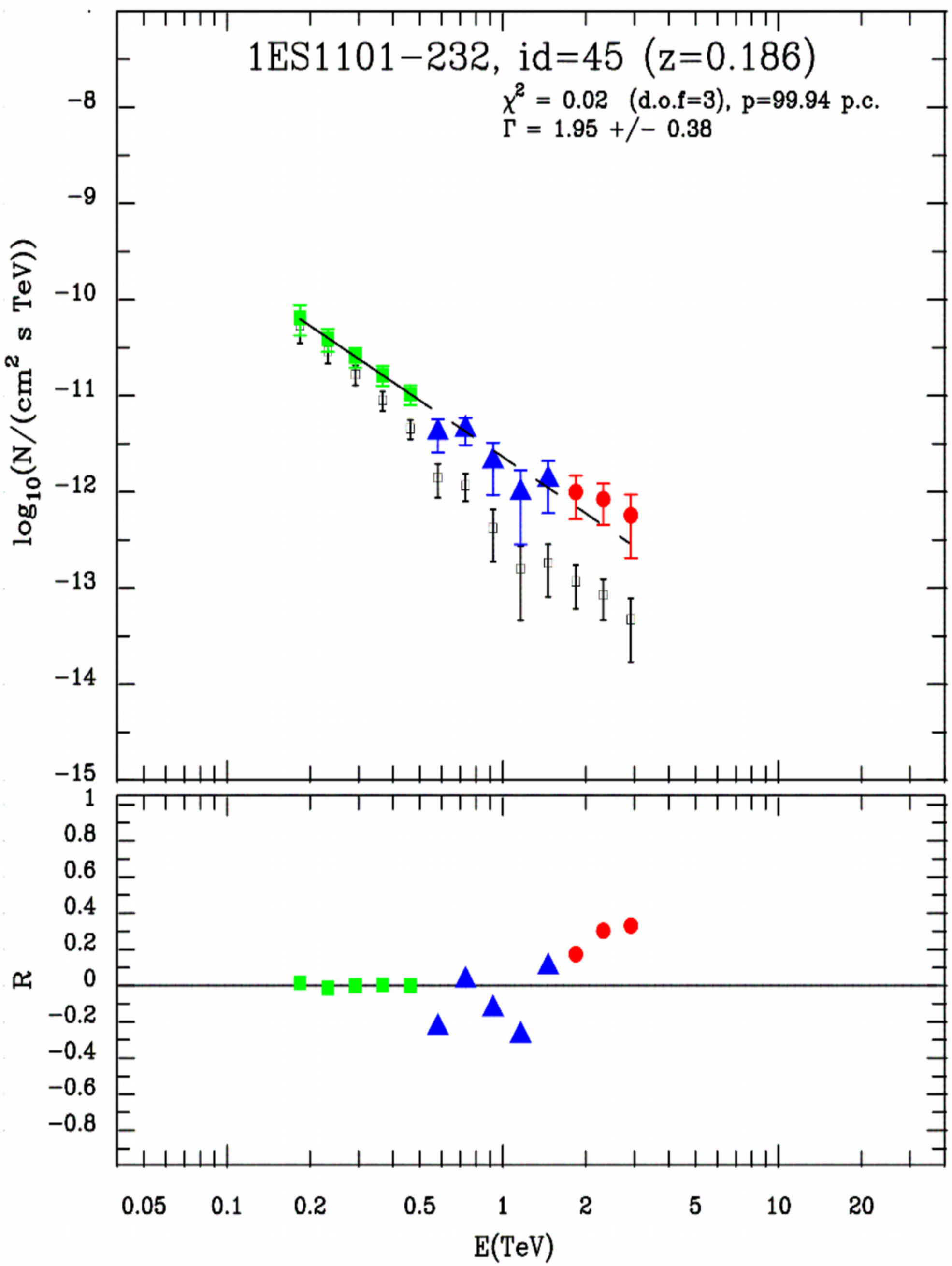
Δγ= γ(prim.)-γ(casc.-mag.)= 1.67-1.46= +0.21 right sign of the effect (!!)

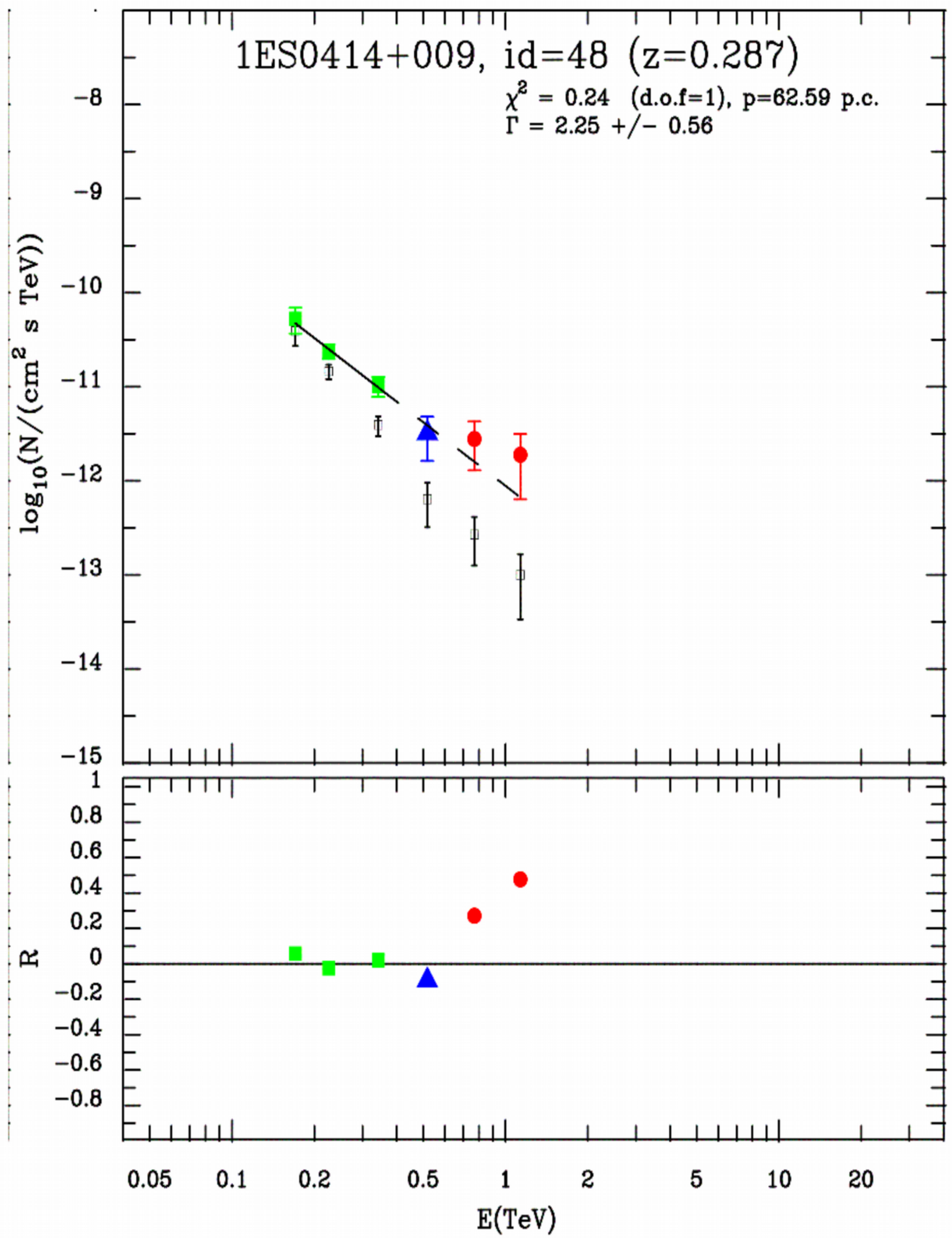
Absorption-only models for 1ES 0347-121 (z= 0.188). Black: EBL model of Gilmore et al. (2012); green --- Franceschini et al., 2008; blue --- Kneiske and Dole (2010) as implemented in the ELMAG code (Kachelriess et al. (2012))

Global (all experimental bins) best fit

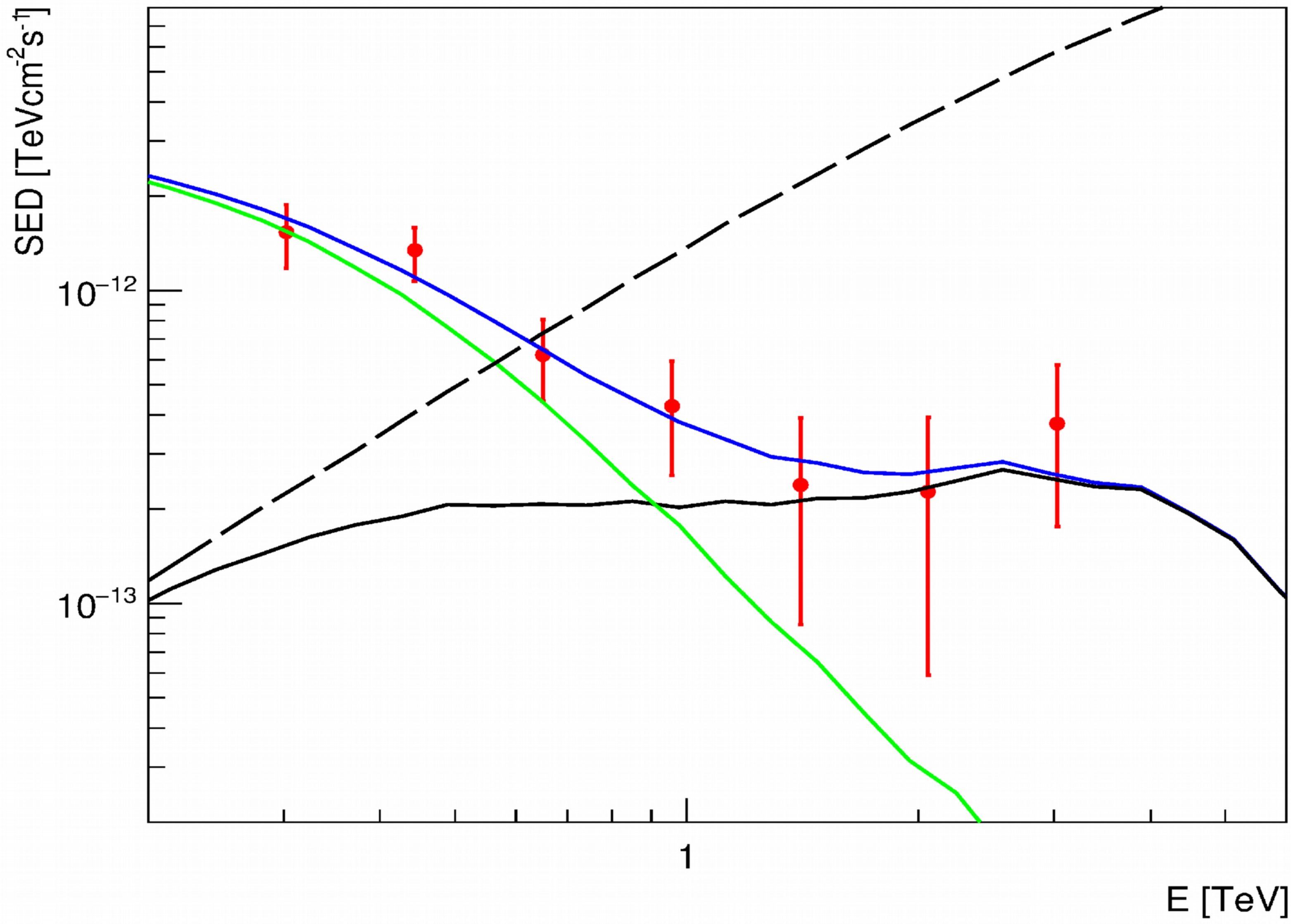


The absorption anomaly (Horns& Meyer (2012); different method: Horns (2016)).



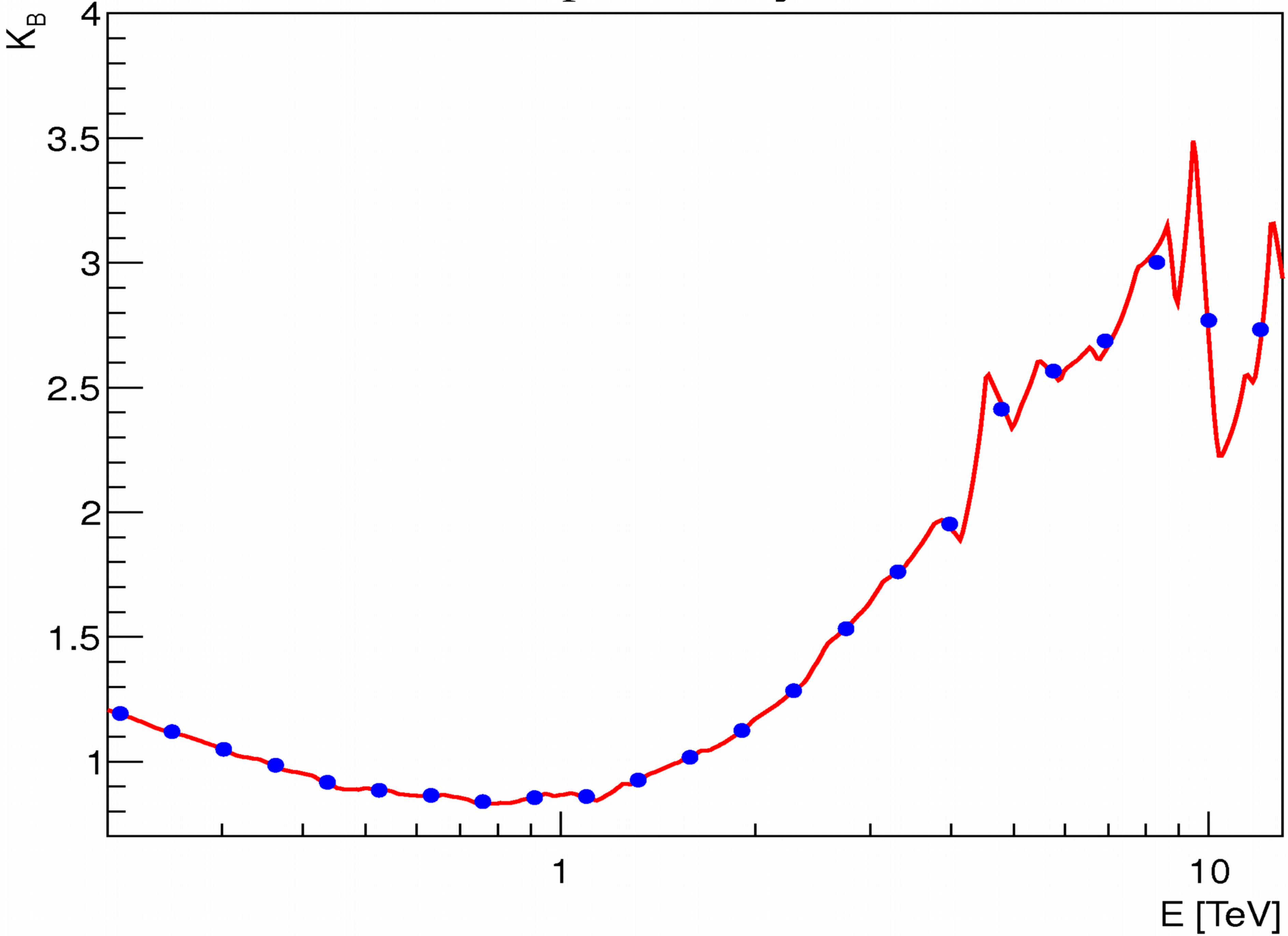


Electromagnetic cascade model (z= 0.188). SED shape at low energy is concealed by the cascade component ("EM cascade masquerade").



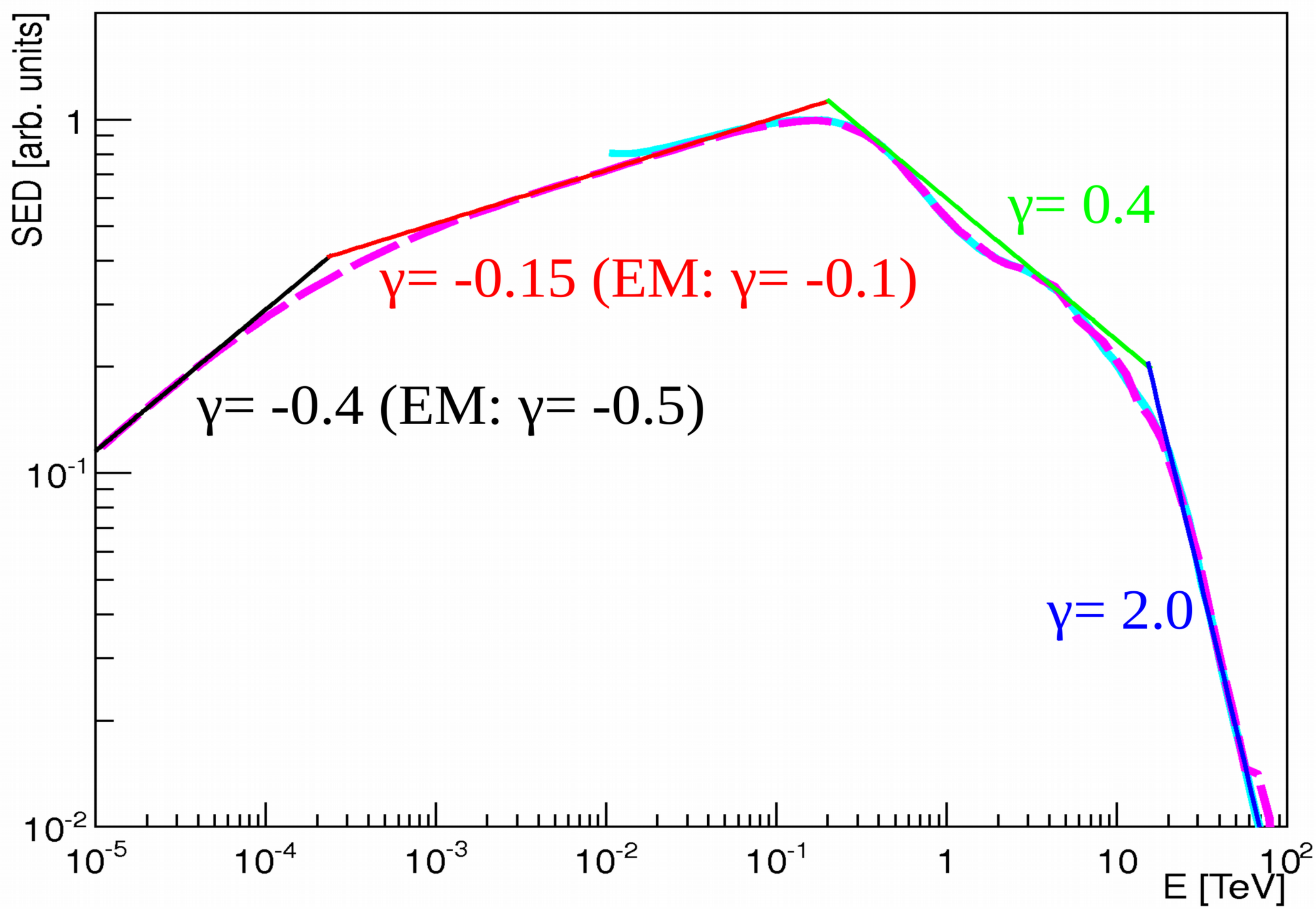
For other options see Aharonian et al. (2002), d'Avezac et al. (2007), Murase et al. (2012)

Flux boost factor vs. energy wrt. the absorption-only model



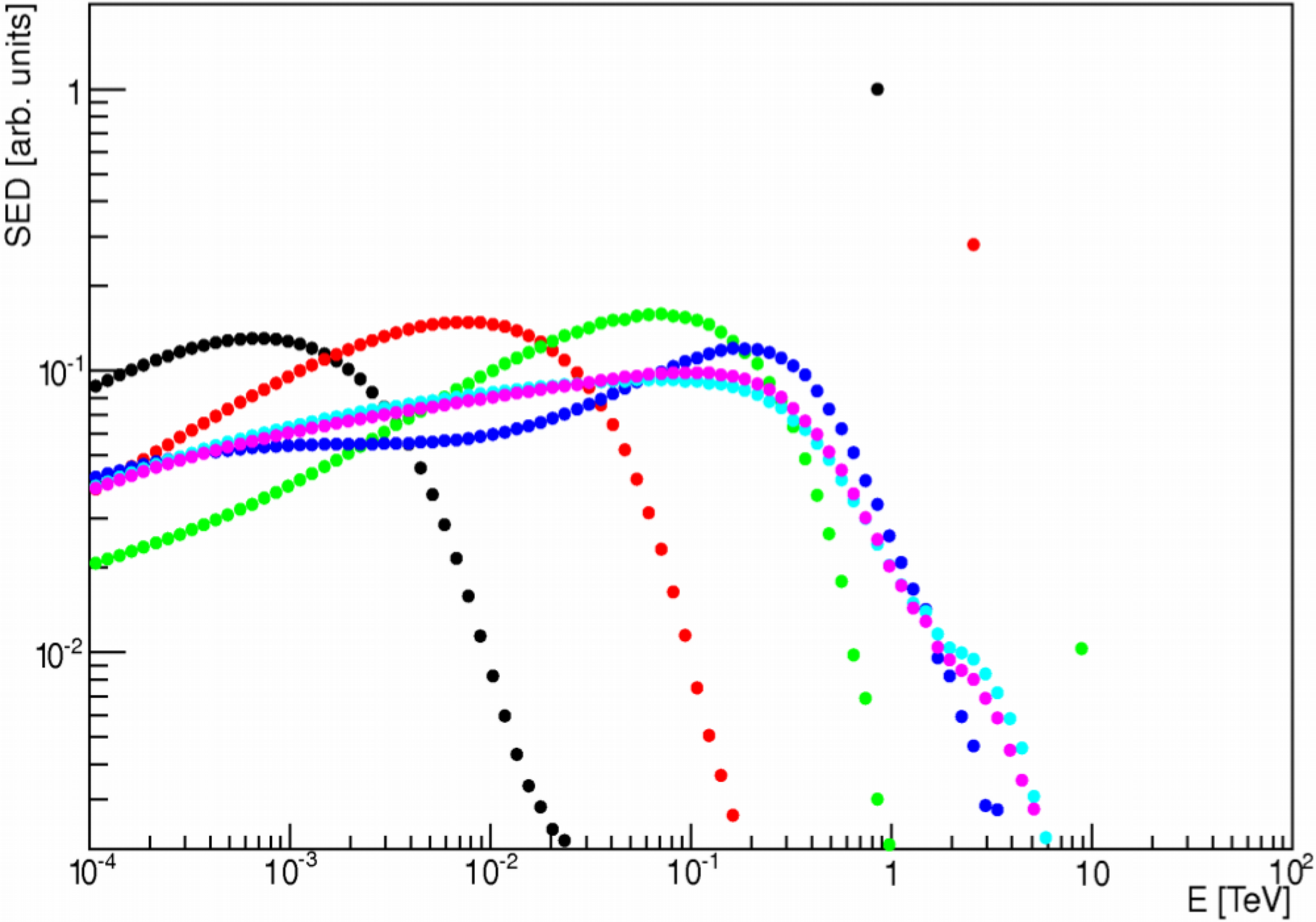
For early hadronic models see Uryson (1998); Essey& Kusenko (2010) (2011)

Hadronic cascade model: spectral signatures
(primary proton energy $E_{p0}= 3\cdot10^{19}$ eV= 30 EeV B=0)



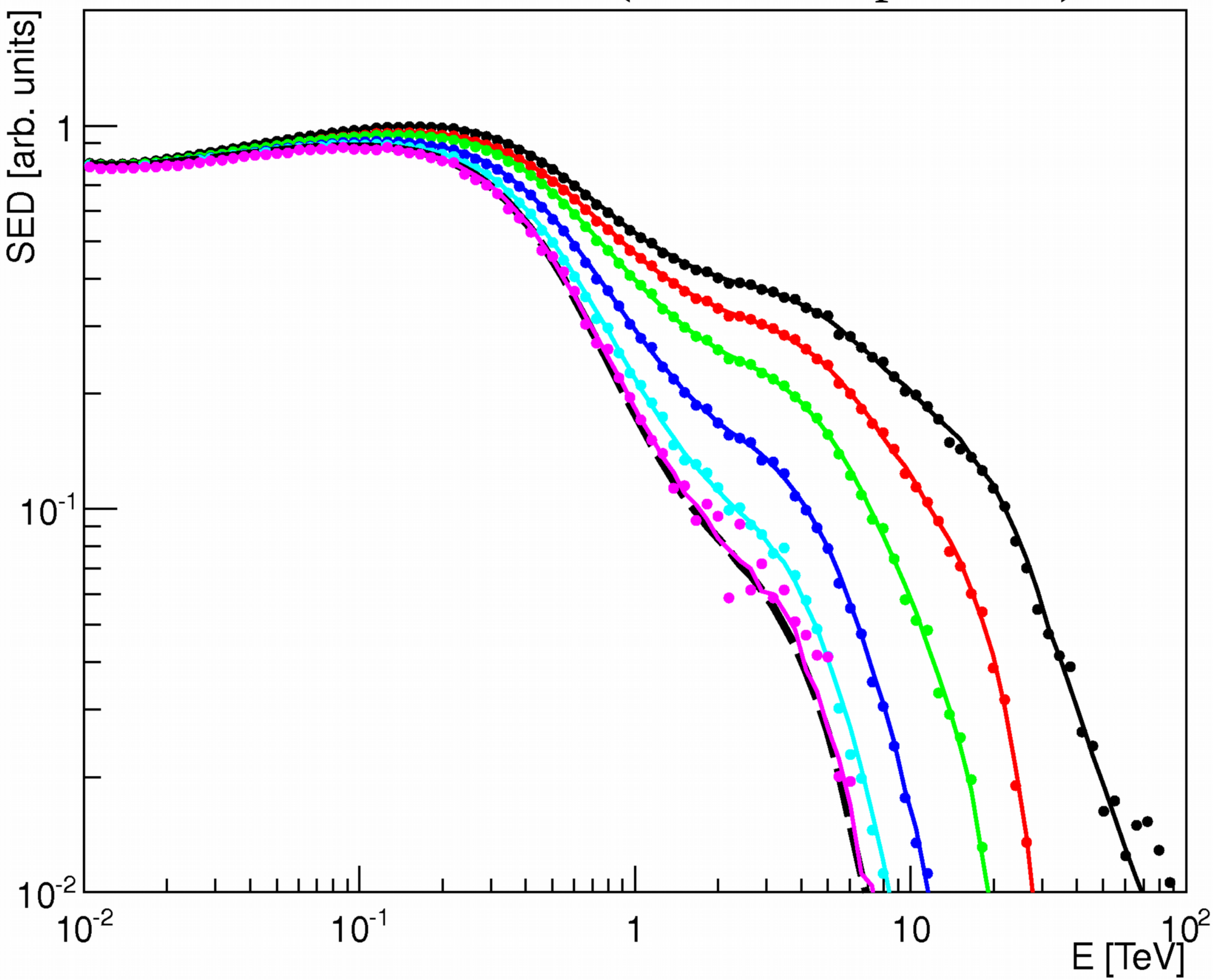
EM (universal regime): numbers from Berezinsky& Kalashev (2016)

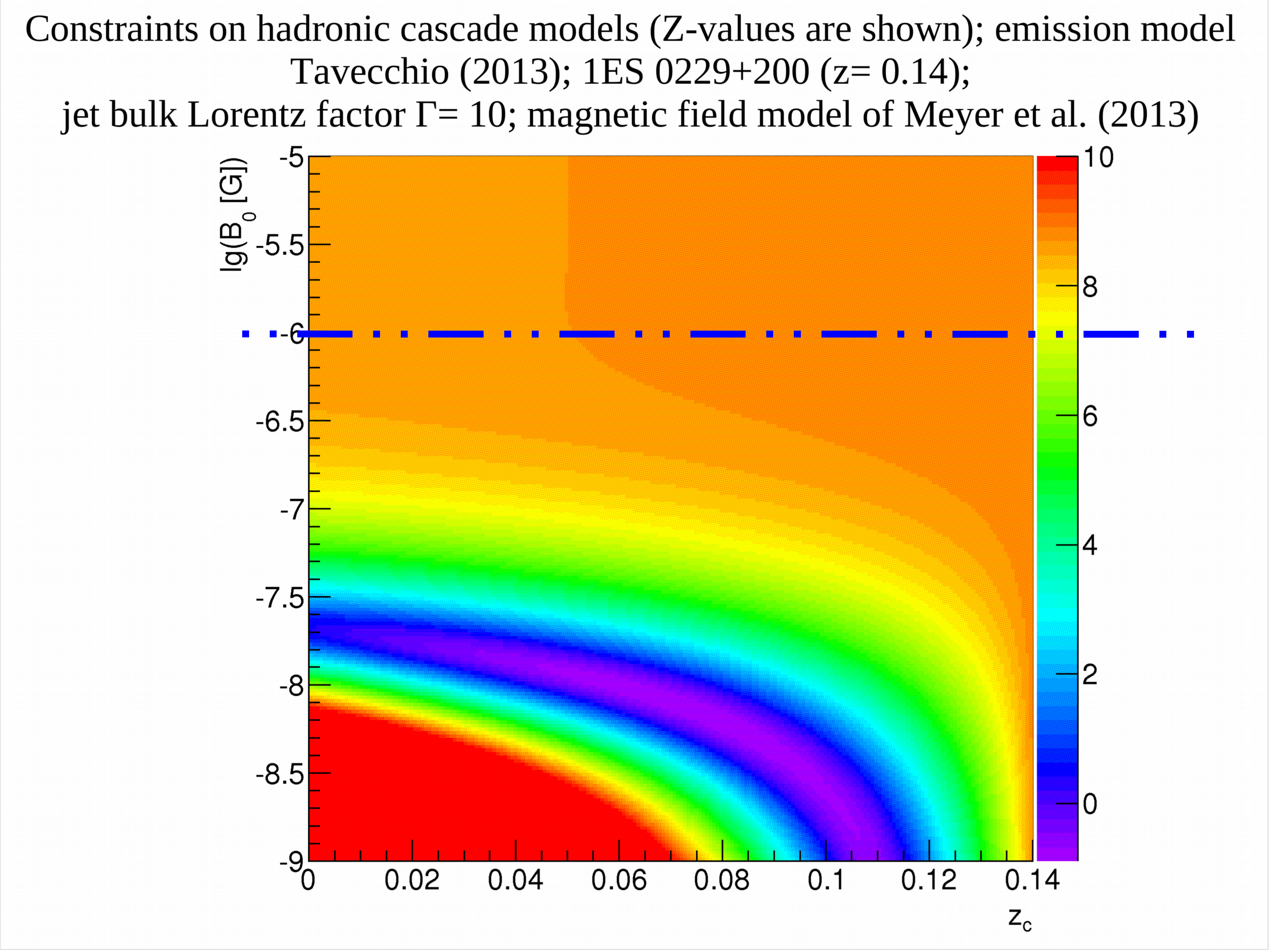
Electromagnetic cascades: one-generation and universal regimes
(z= 0.186; calculations with ELMAG 2.02, Kachelriess et al. (2012))



Hadronic cascade model (beam terminated at z_c=0..z)

lines: universal spectrum approximation; circles: full calculation; dashed: EM cascade (universal spectrum)




Constraints on hadronic cascade models (Z-values are shown); emission model
Tavecchio (2013); 1ES 0229+200 (z= 0.14);
jet bulk Lorentz factor Γ= 10; magnetic field model of Meyer et al. (2013)
lg(B_0 [G])
-5
-5.5
-6
-6.5
-7
-7.5
-8
-8.5
-9
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
z_c
10
8
6
4
2
0

Cherenkov Telescope Array (CTA) − the best instrument to search for intergalactic cascade emission

+HAWC, GAMMA-400, emulsion gamma-ray telescope GRAINE

Conclusions

There are many indications for EM cascades in blazar spectra!

If primary spectra are hard enough, the absorption anomaly may be somewhat relaxed (the “EM cascade masquerade effect”).

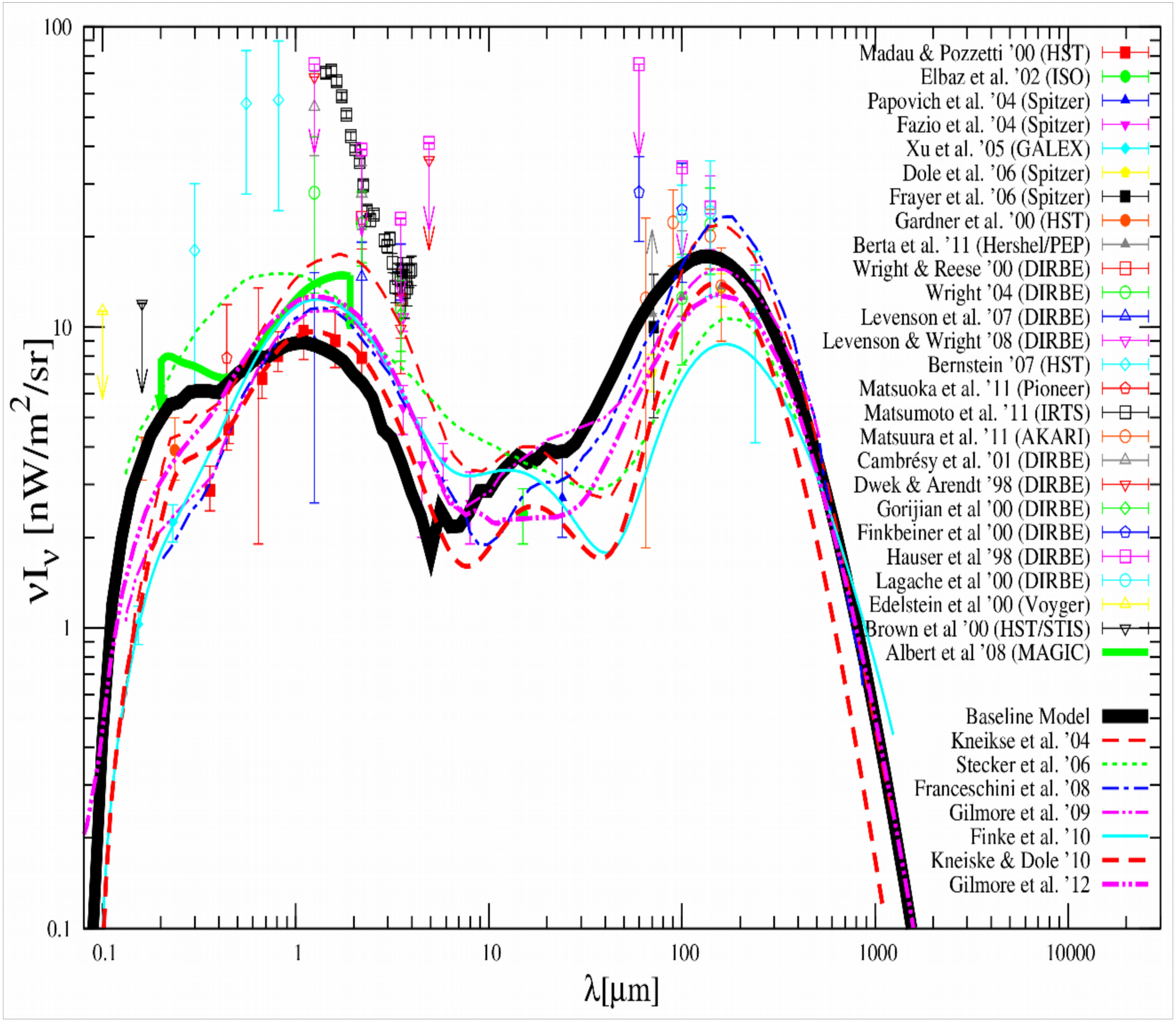
If there is non-zero EGMF, hard-spectra blazars in the 10-100 GeV energy region may be predominantly located towards directions to voids (the “magnetic cutoff effect”).

If blazars are embedded in galaxy clusters with central magnetic field more than 100 nG, simplest hadronic cascade models experience significant difficulties.

This work was supported by the RFBR Grant 16-32-00823.

Additional slides

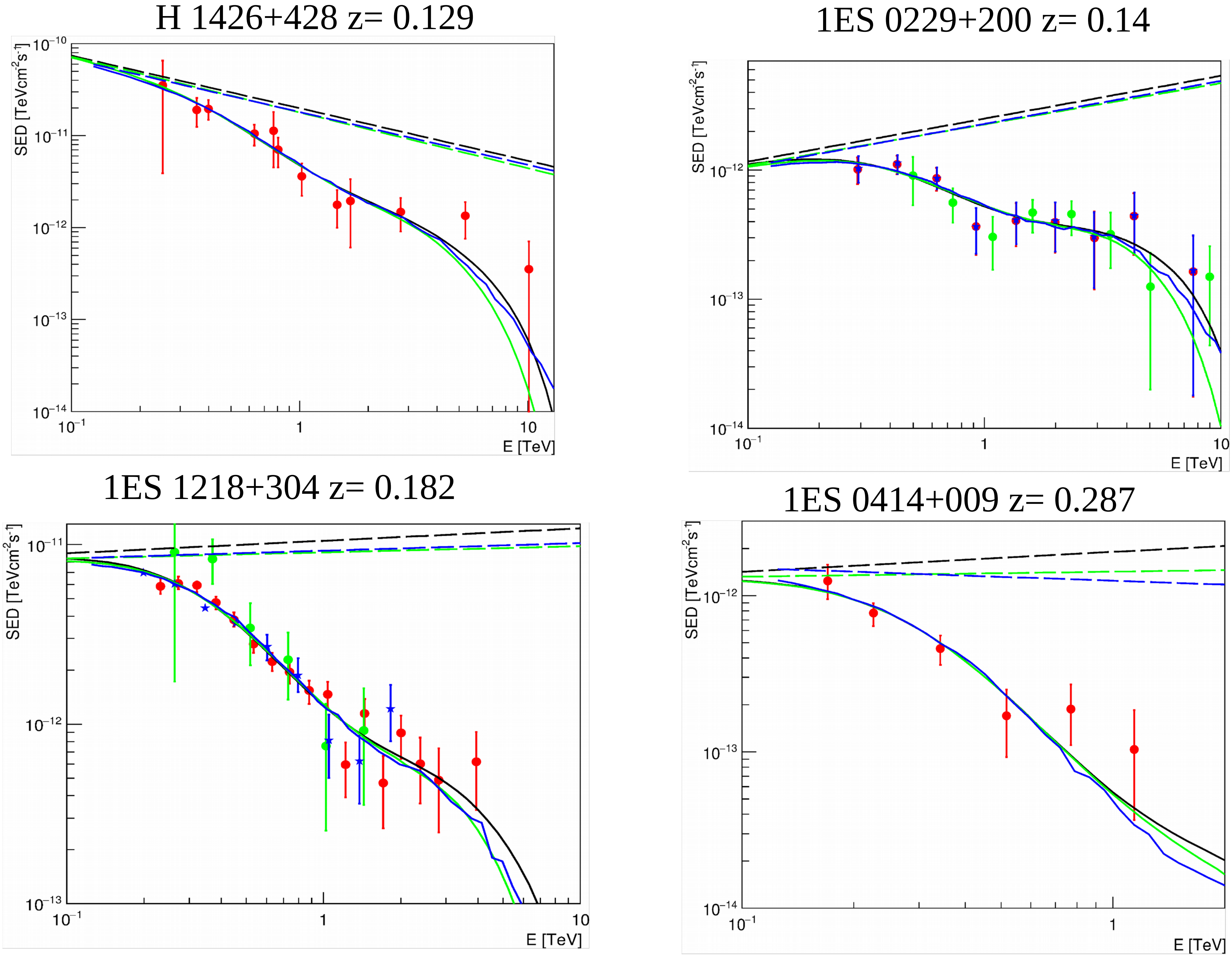
EBL models at z=0 (Inoue+ (2013))



Observations with imaging Cherenkov telescopes used in this work

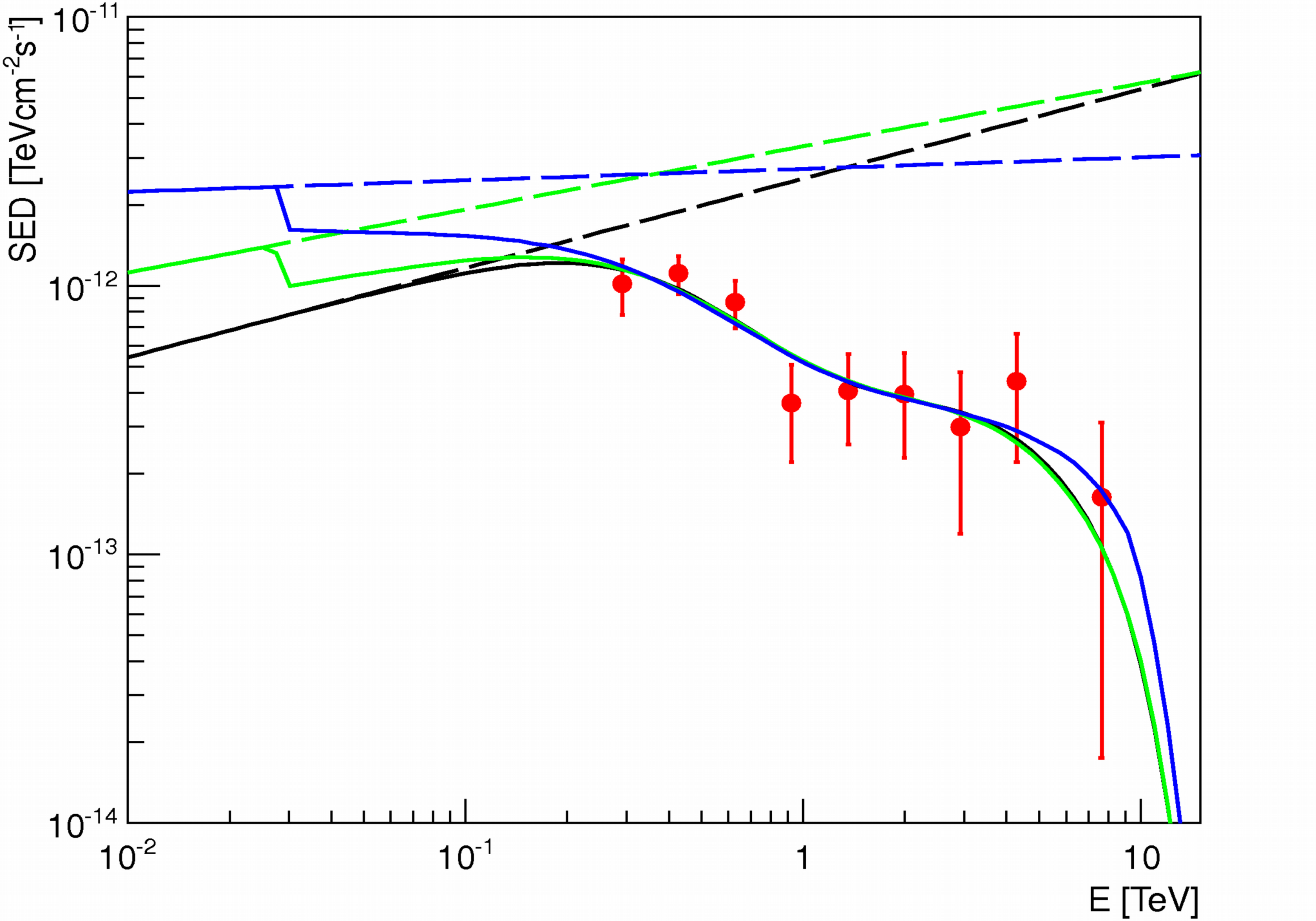
N	Source	z	Observational period	Reference
1	H 1426+428	0.129	1999-2000	Aharonian et al. (2003)
2	H 1426+428	0.129	1998-2000	Djannati-Atai et al. (2002)
3	H 1426+428	0.129	2001	Horan et al. (2002)
4	1ES 0229+200	0.140	2005-2006	Aharonian et al. (2007a)
5	1ES 0229+200	0.140	2010-2012	Aliu et al. (2014)
6	1ES 1218+304	0.182	2012-2013	Madhavan et al. (2013)
7	1ES 1101-232	0.186	2004-2005	Aharonian et al. (2007b)
8	1ES 1101-232	0.186	2004-2005	Aharonian et al. (2006)
9	1ES 0347-121	0.188	Aug.-Dec. 2006	Aharonian et al. (2007c)
10	1ES 0414+009	0.287	2005-2009	Abramowski A. et al. (2012)

+ 4 other observations of 1ES 0229+200 and 1ES 1218+304
(very similar spectral shapes to the ones listed)
largest sample of heavily absorbed extreme TeV blazars
(at least one spectral bin with τ>2) in a single study ever

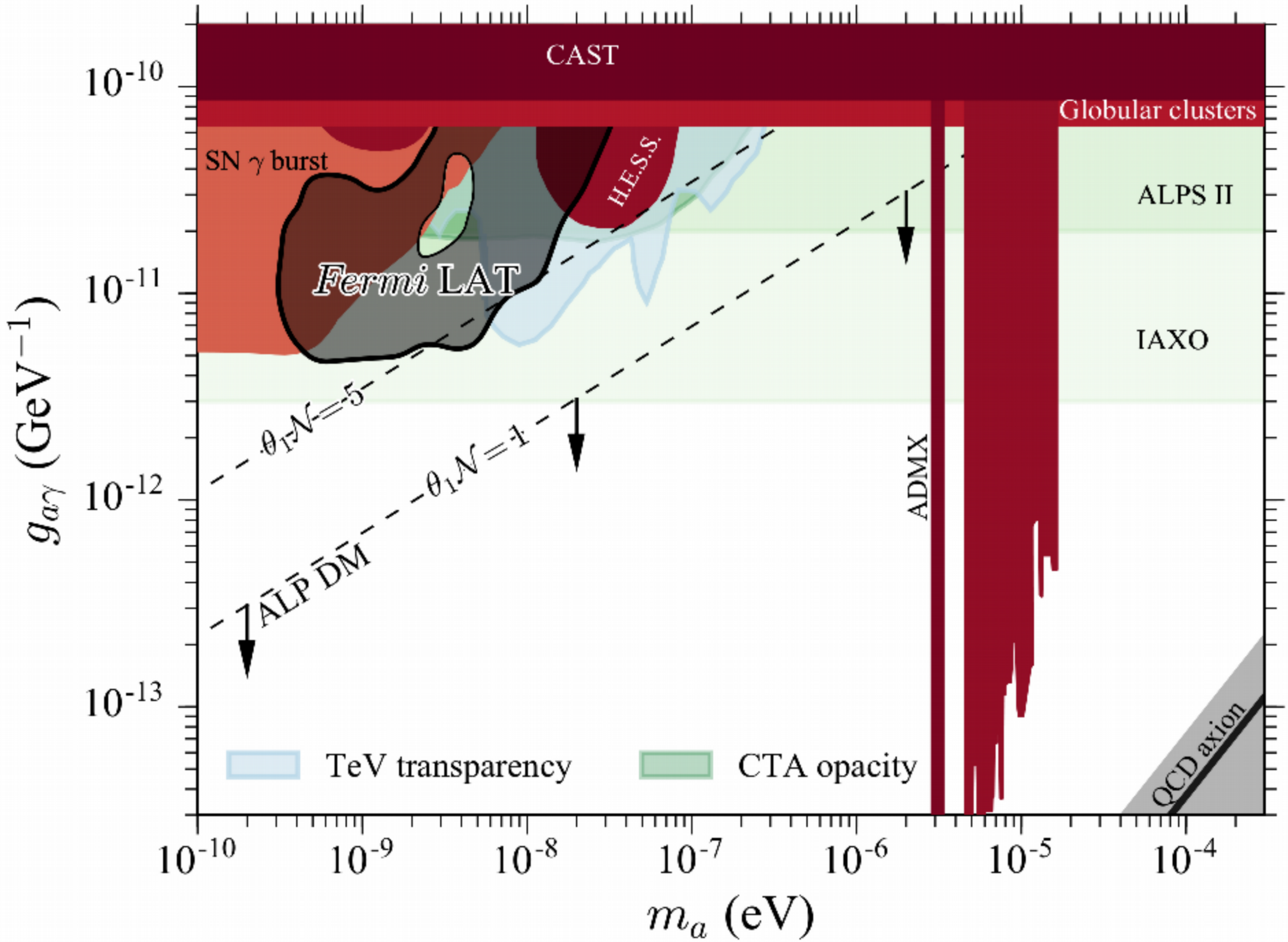


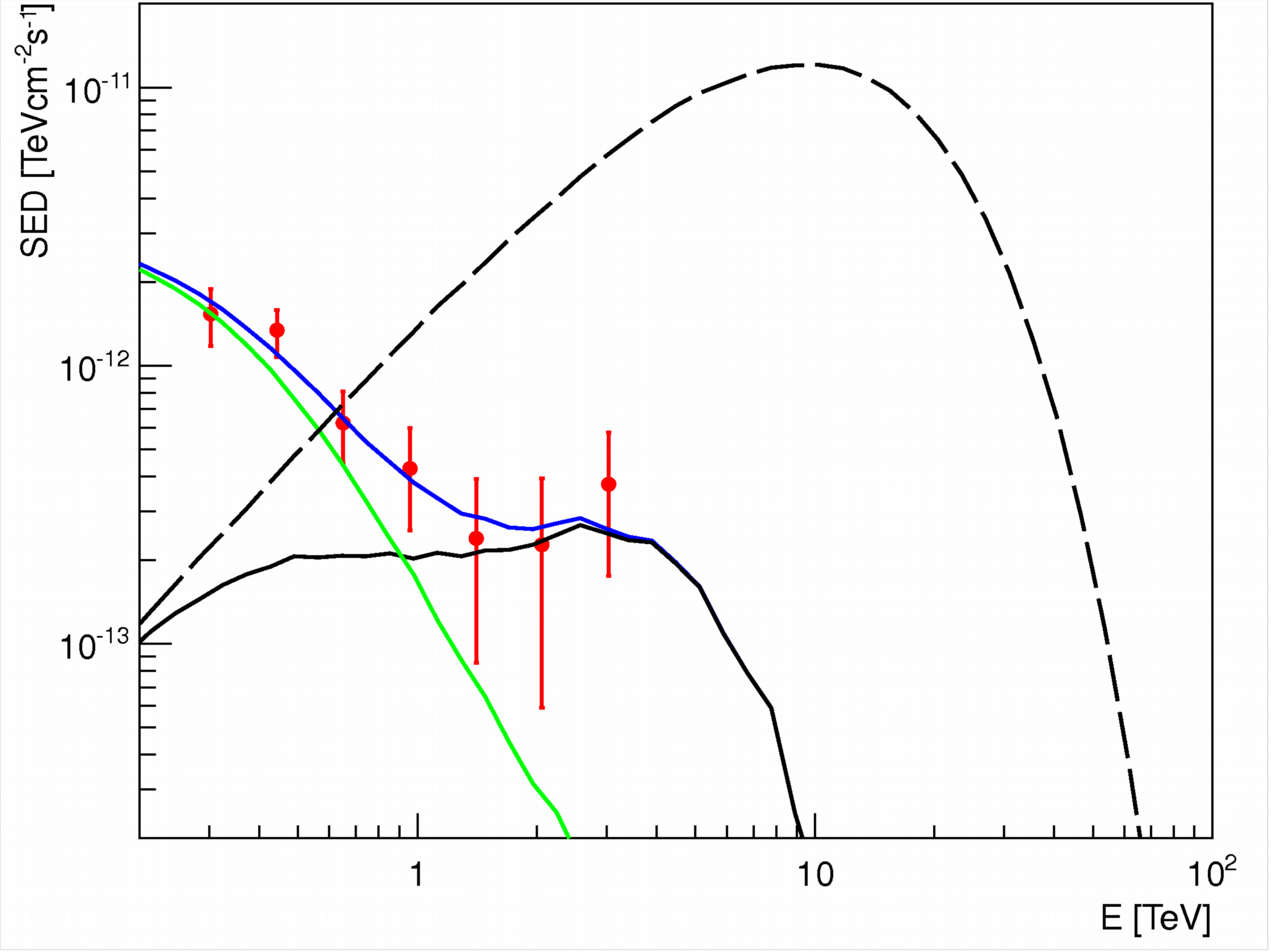
H 1426+428 z= 0.129
1ES 0229+200 z= 0.14
1ES 1218+304 z= 0.182
1ES 0414+009 z= 0.287
SED [TeVcm^{-2}s^{-1}]
E [TeV]

γ- axionlike particle (ALP) mixing: spectral signatures (z= 0.14) (parameters from Sanchez-Conde et al. (2009))



Constraints on the γ-ALP mixing parameters (Ajello et al. (2016))





SED [TeVcm^{-2}s^{-1}]
10^{-11}
10^{-12}
10^{-13}
1
10
10^2
E [TeV]