Blazars & Beyond, Torino, June 2018

On the origin of gamma-rays in broad-lined Blazars:

to BLR or not to BLR ?

Luigi Costamante
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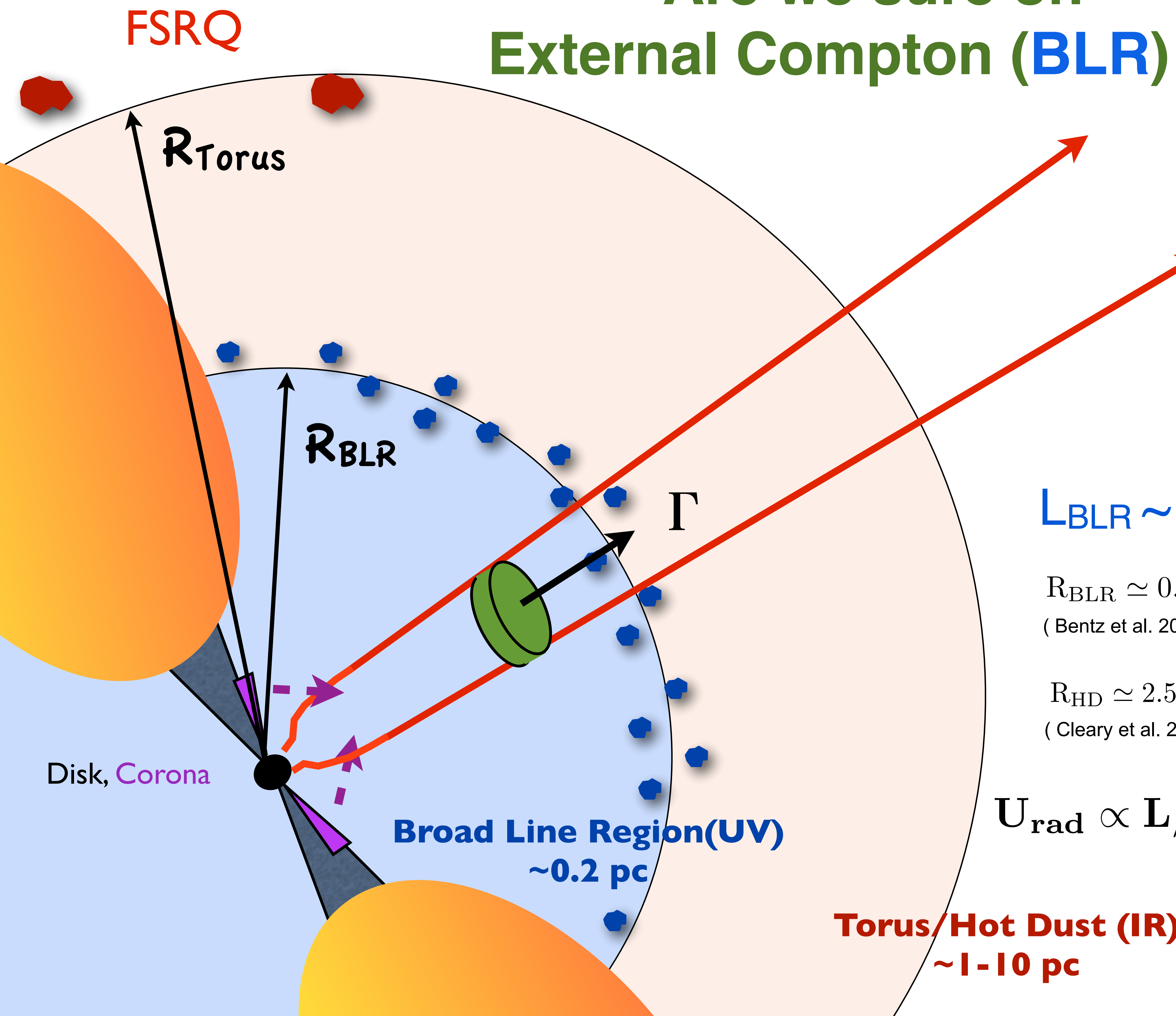
Are we sure on External Compton (BLR) ??



$L_{BLR} \sim 10\%\ L_{disk}$

$$R_{BLR} \simeq 0.1 \times L_{46}{}^{1/2}\ \mathrm{pc}$$

(Bentz et al. 2006 ; Kaspi et al. 2007)

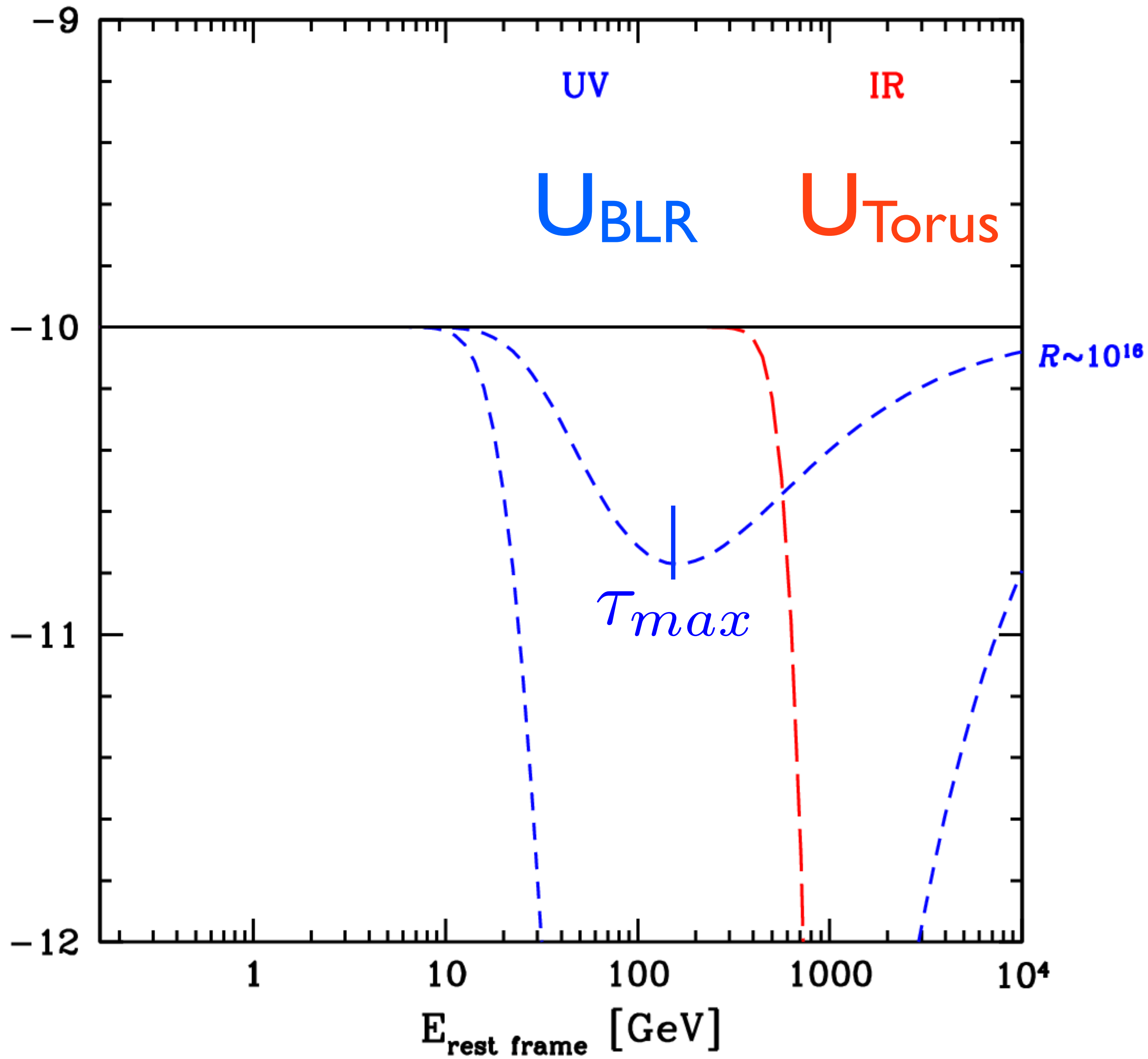
$$R_{HD} \simeq 2.5 \times L_{46}{}^{1/2}\ \mathrm{pc}$$

(Cleary et al. 2007 ; Nenkova et al. 2008)

$$\mathbf{U_{rad} \propto L/R^2 \sim const.}$$

BLR opacity: optical depths >>1

$\gamma\gamma \rightarrow e^+e^-$ $$x_1 x_2 \geq \frac{2}{1-\cos\theta}$$ $x \equiv h\nu/m_e c^2$

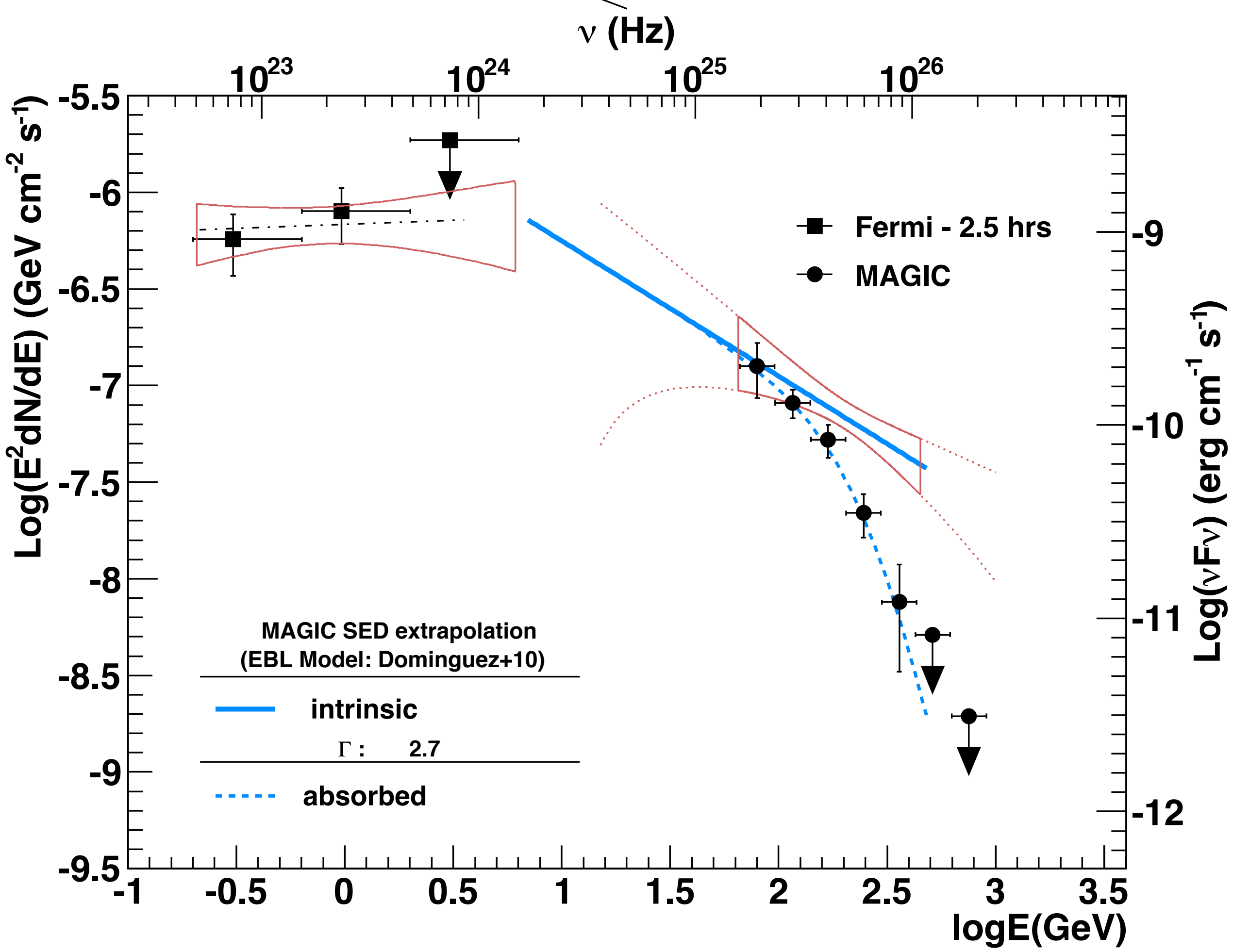


e.g. on BlackBody target field (good approximation to BLR attenuation)

Expected in FSRQ: no VHE detections, cutoff ~10-20 GeV

Sometimes gamma-rays beyond the BLR:

a) FSRQ detected at VHE

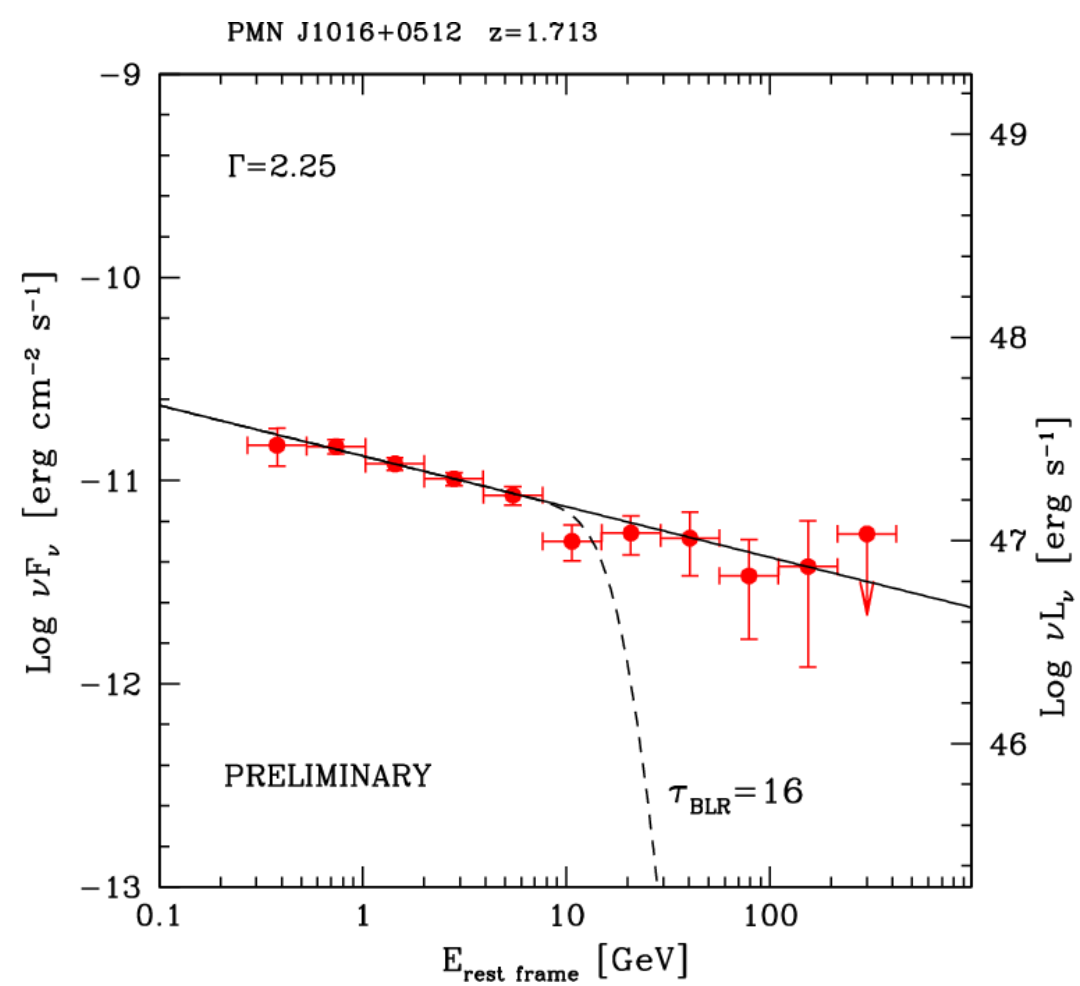


Aleksic et al. (MAGIC Coll) 2011

Detections 4C 21.35 (Magic)

PKS 1510-089 (HESS, Magic)

b) >10 GeV in LAT



PMN J1016+0512:

$L_{disk} \sim 9\times10^{45}$ erg/s , $R_{blr} \sim 3\times10^{17}$ cm

if $R_{diss} \sim 2.5\times10^{17} \Rightarrow \tau_{BLR} > 16$!

e.g. Costamante et al. 2009, 2010

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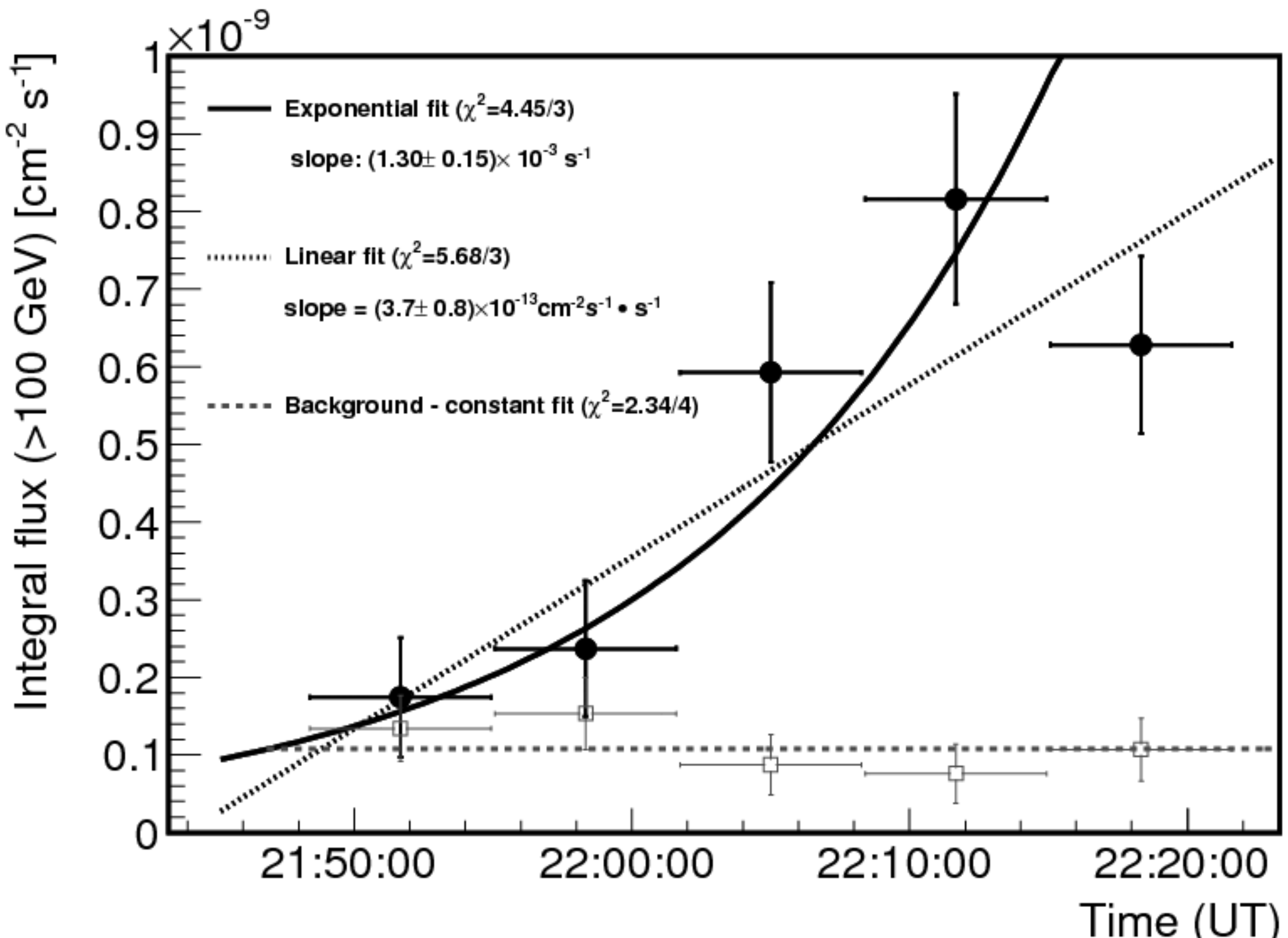

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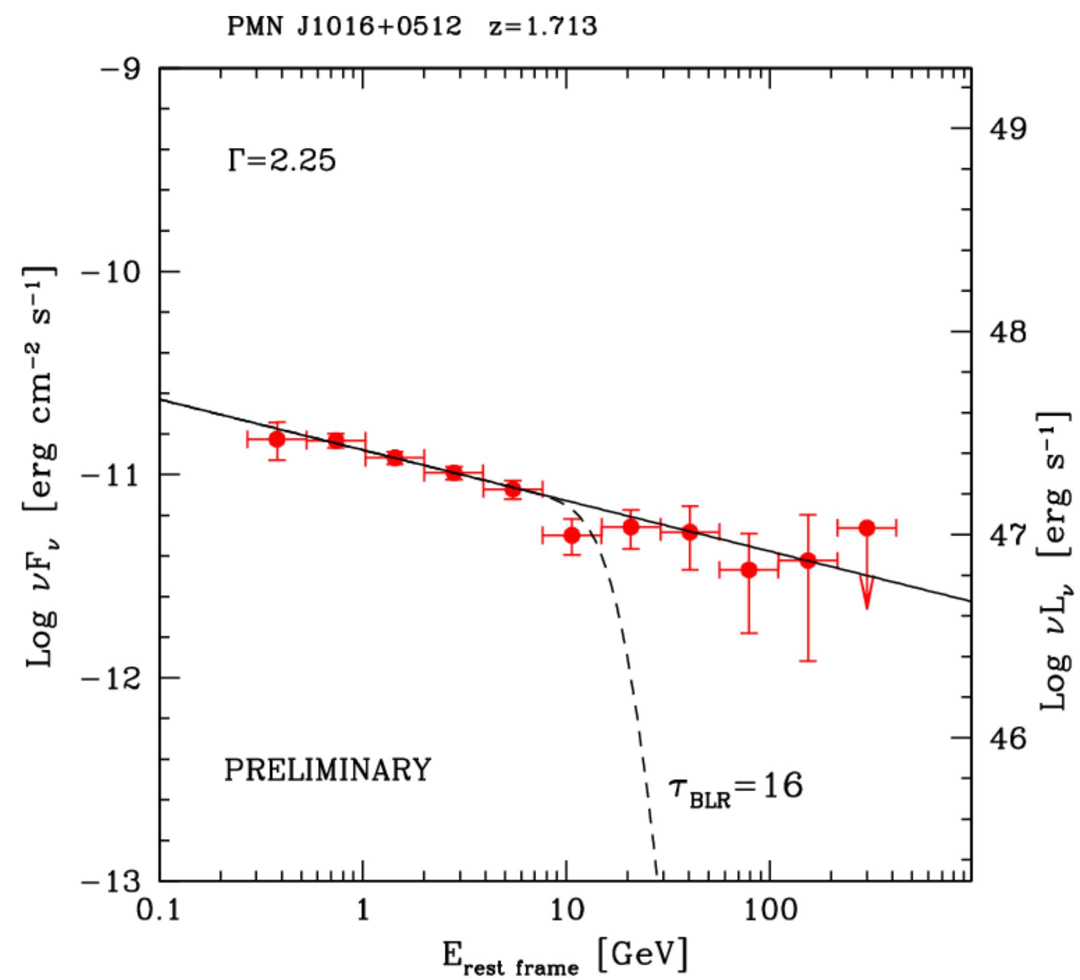

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L_{disk} ~ 9×10^{45} erg/s , R_{blr} ~3×10^{17} cm

if R_{diss} ~2.5×10^{17} ⇒ **τ_{BLR} > 16** !

e.g. Costamante et al. 2009, 2010

For population studies
EC(BLR) still most common SED model in FSRQs

1) is BLR absorption a common phenomenon ?
2) is it consistent with EC modeling ?
3) different location in high-flaring vs steady state ?

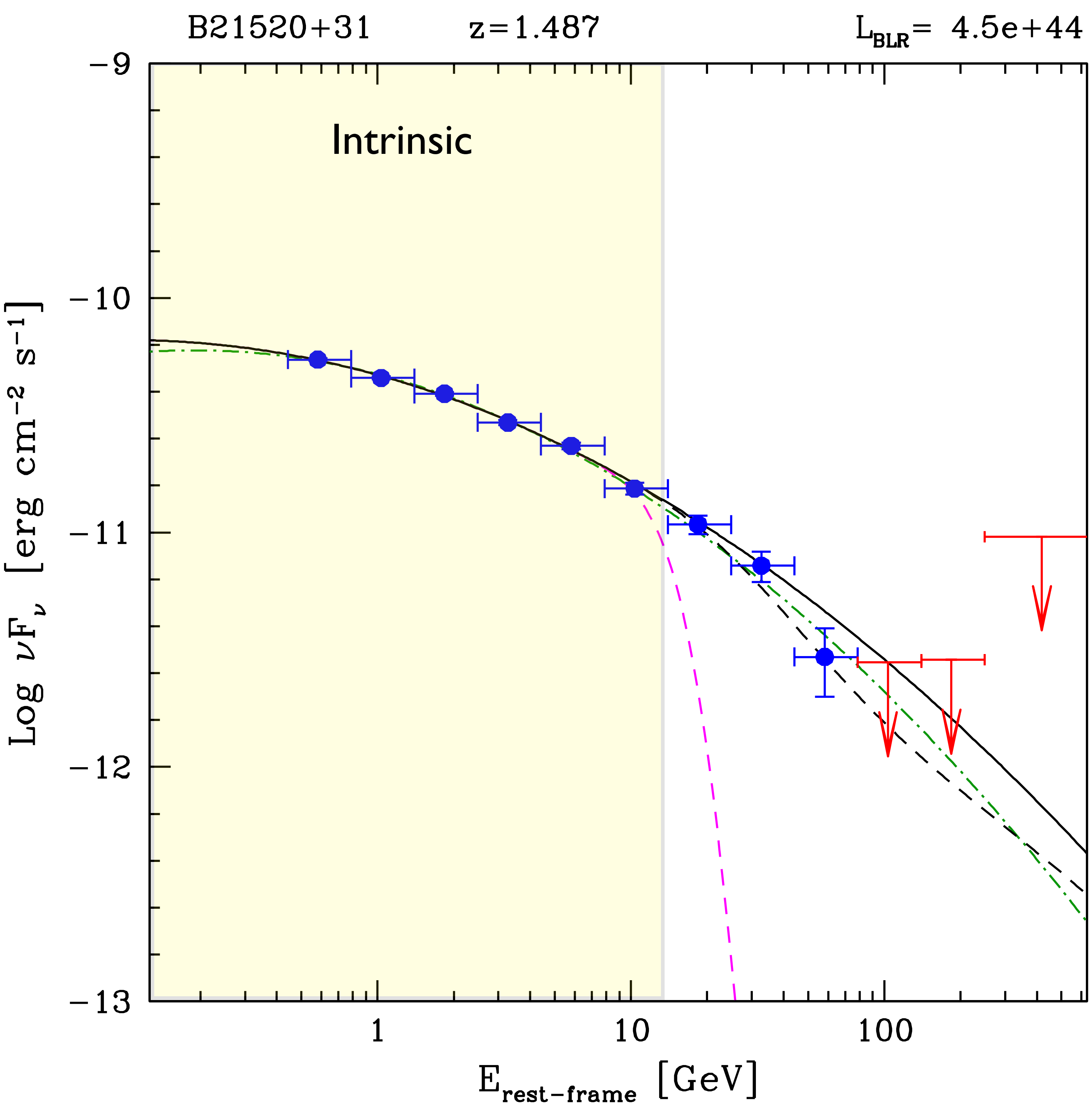
100 highest-significance Gamma-ray FSRQs in the 3LAC
+ 6 large-BLR cases

Fermi-LAT Data, PASS8, 7.3-years exposure

106 in total, 83 with L_{BLR} estimates

Costamante, Cutini, Tosti, Antolini, Tramacere 2018, MNRAS, in press (arXiv 1804.06282)

Methodology



Intrinsic band model:
Power-law or Log-parabolic

— Intrinsic extrapolated

--- Fitted free tau_BLR

--- Expected tau_BLR (deep in BLR, ~R_{BLR}/2)

-.- Log-parabolic Full band (no BLR)

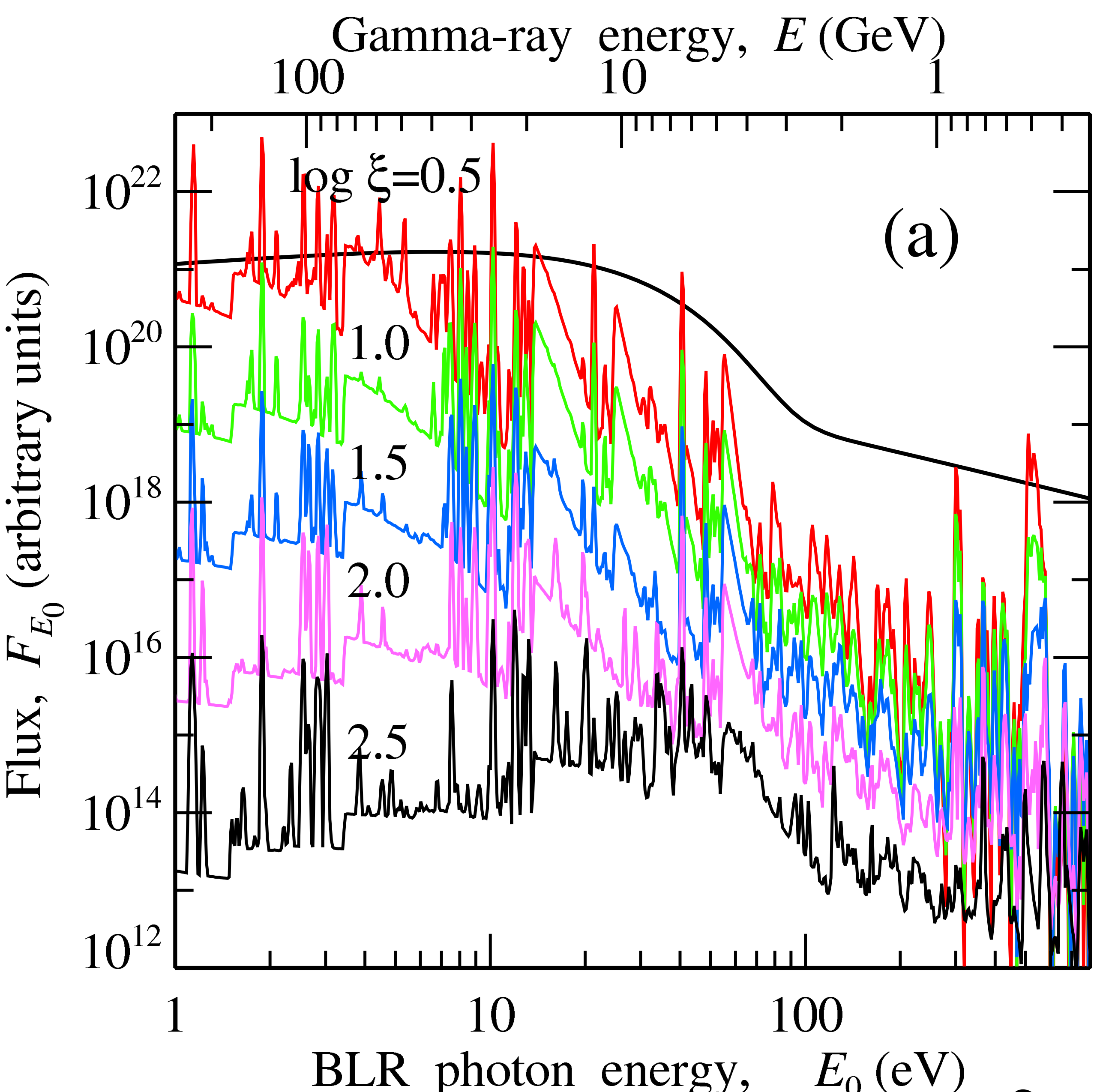
Upper limit if:
TS <4 or
Npred <3 or
Err >50%

NB: Rest-Frame Energies ! E*(1+z)

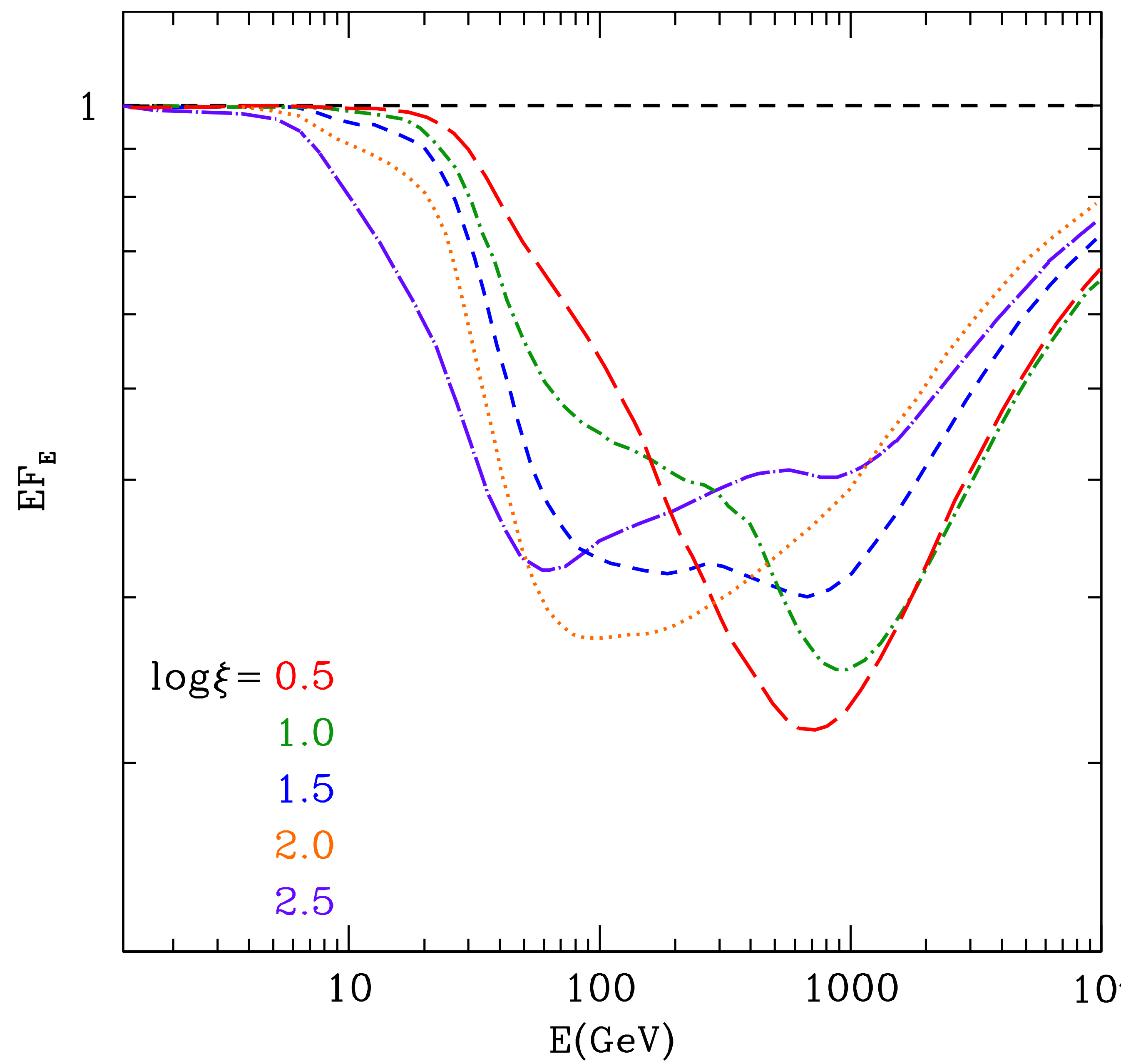
BLR spectrum

BBody (same as for EC) is a good approximation for attenuation shoulder

BLR at different ionization parameter



BLR absorption feature



Stern & Poutanen 2014

BLR spectrum

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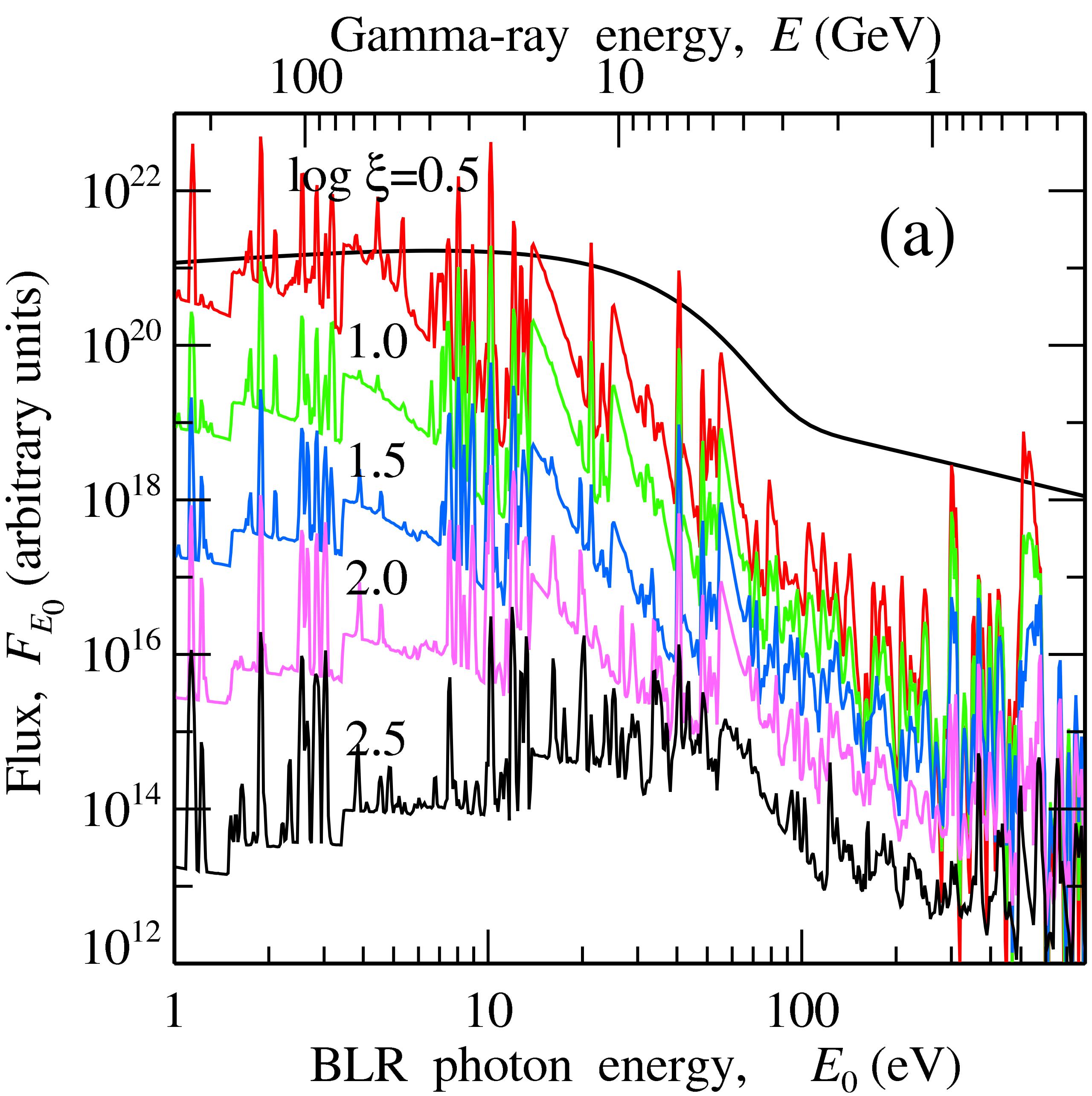
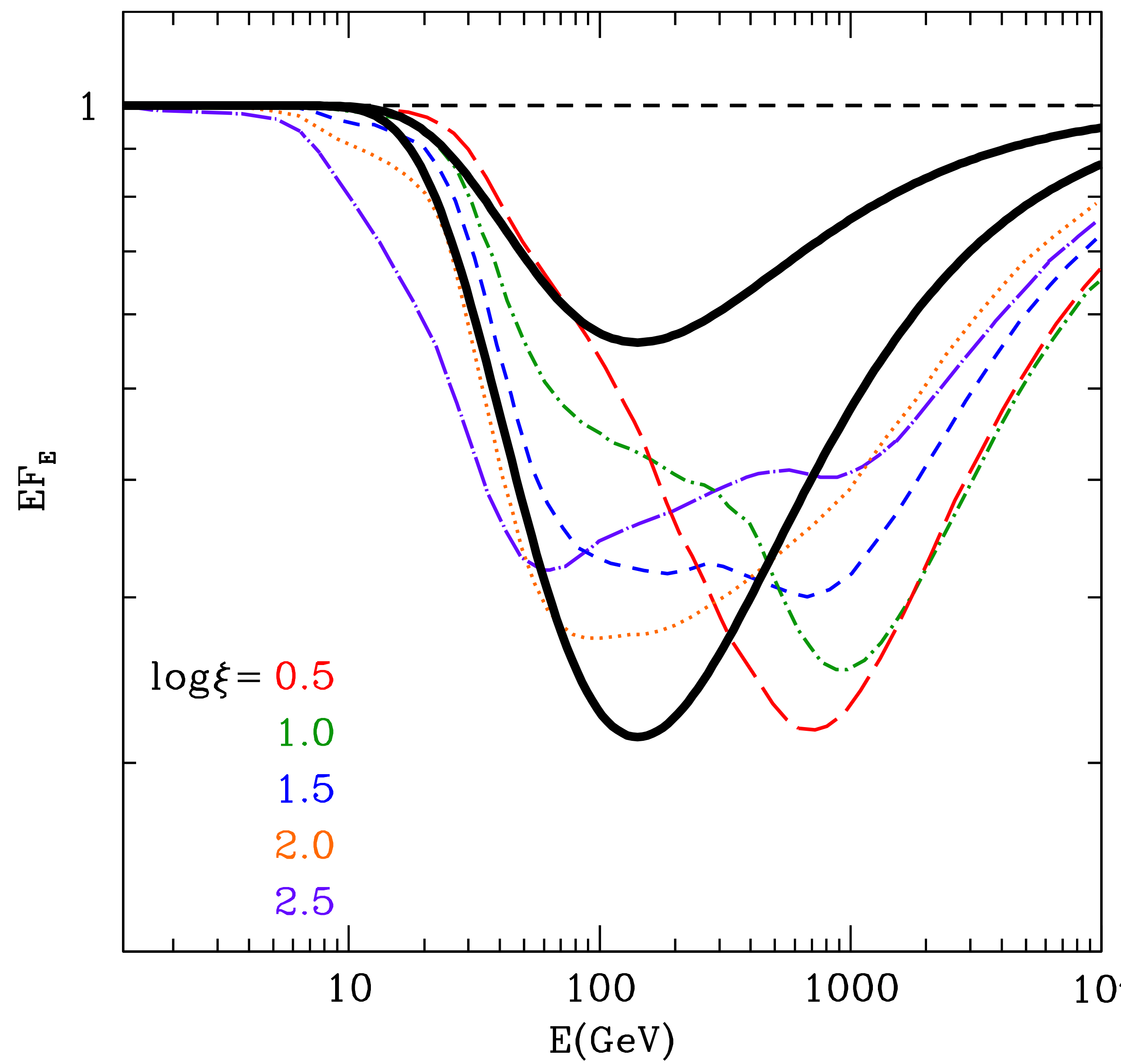
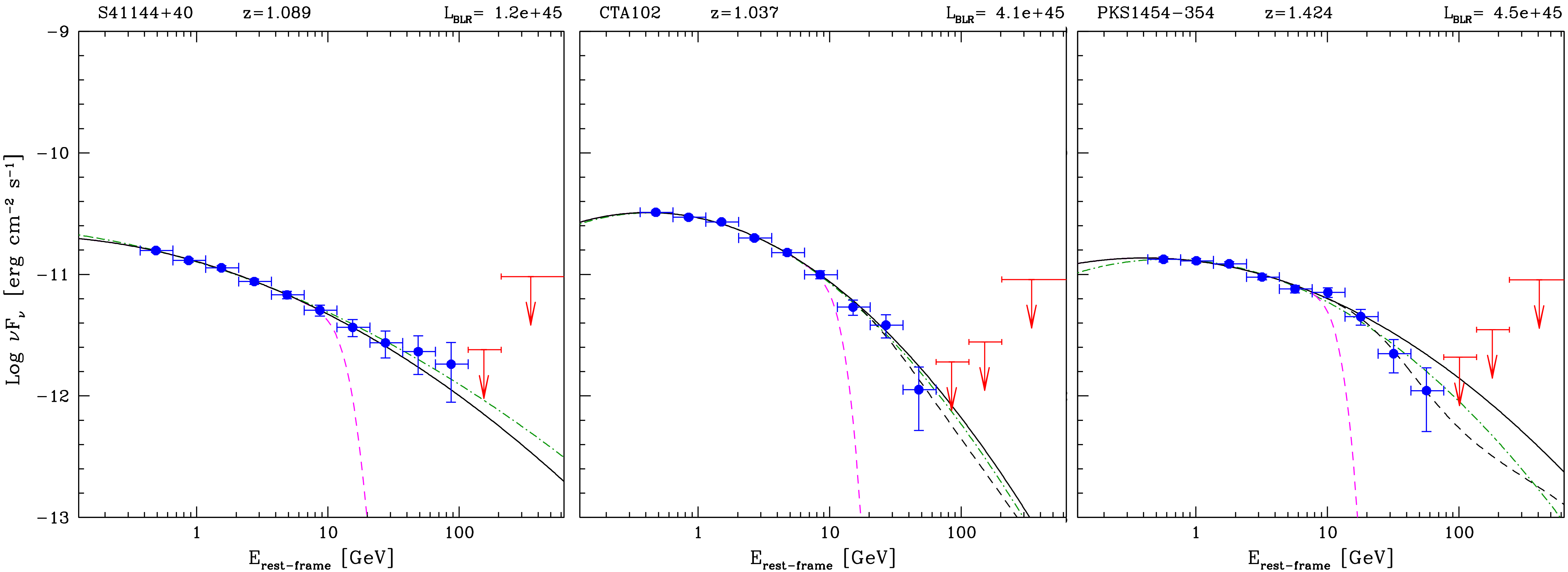


BLR absorption feature



NO evidence of BLR cut-offs !

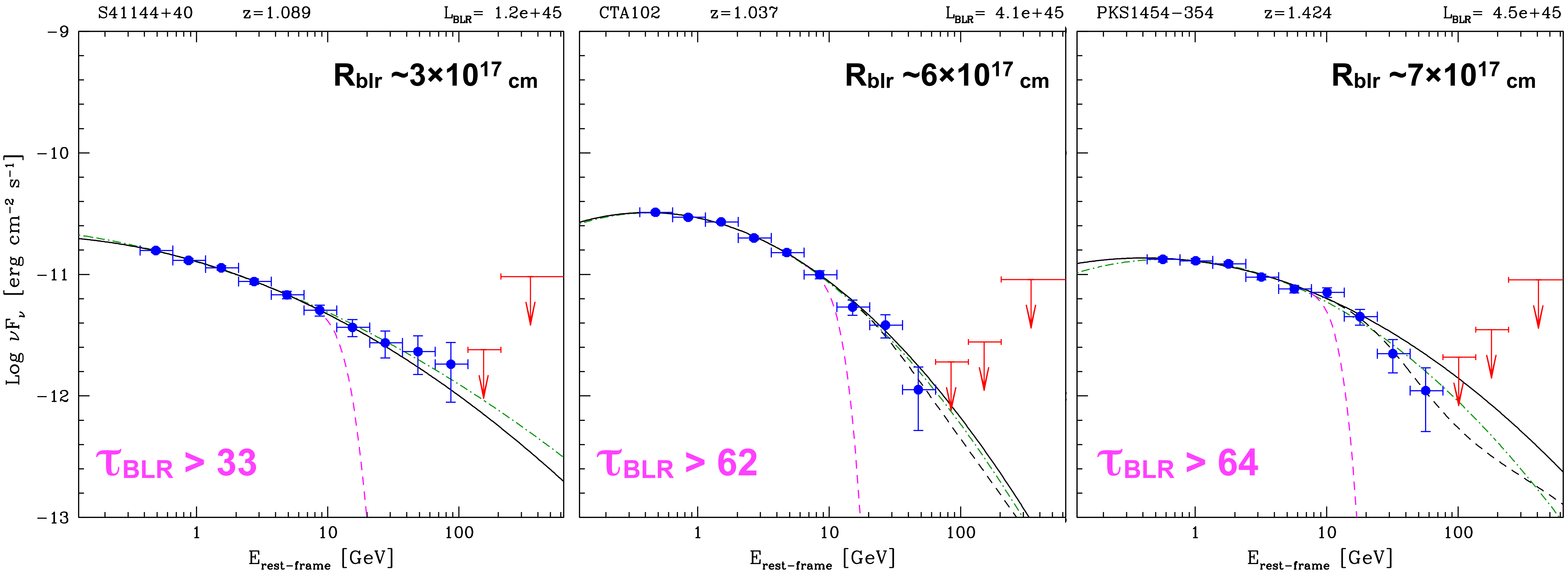


2/3 of the sample: $\tau_{max} < 1$

9/10 objects: $\tau_{max} < 3$

Only 1 out of 10 FSRQ compatible with significant BLR absorption

NO evidence of BLR cut-offs !



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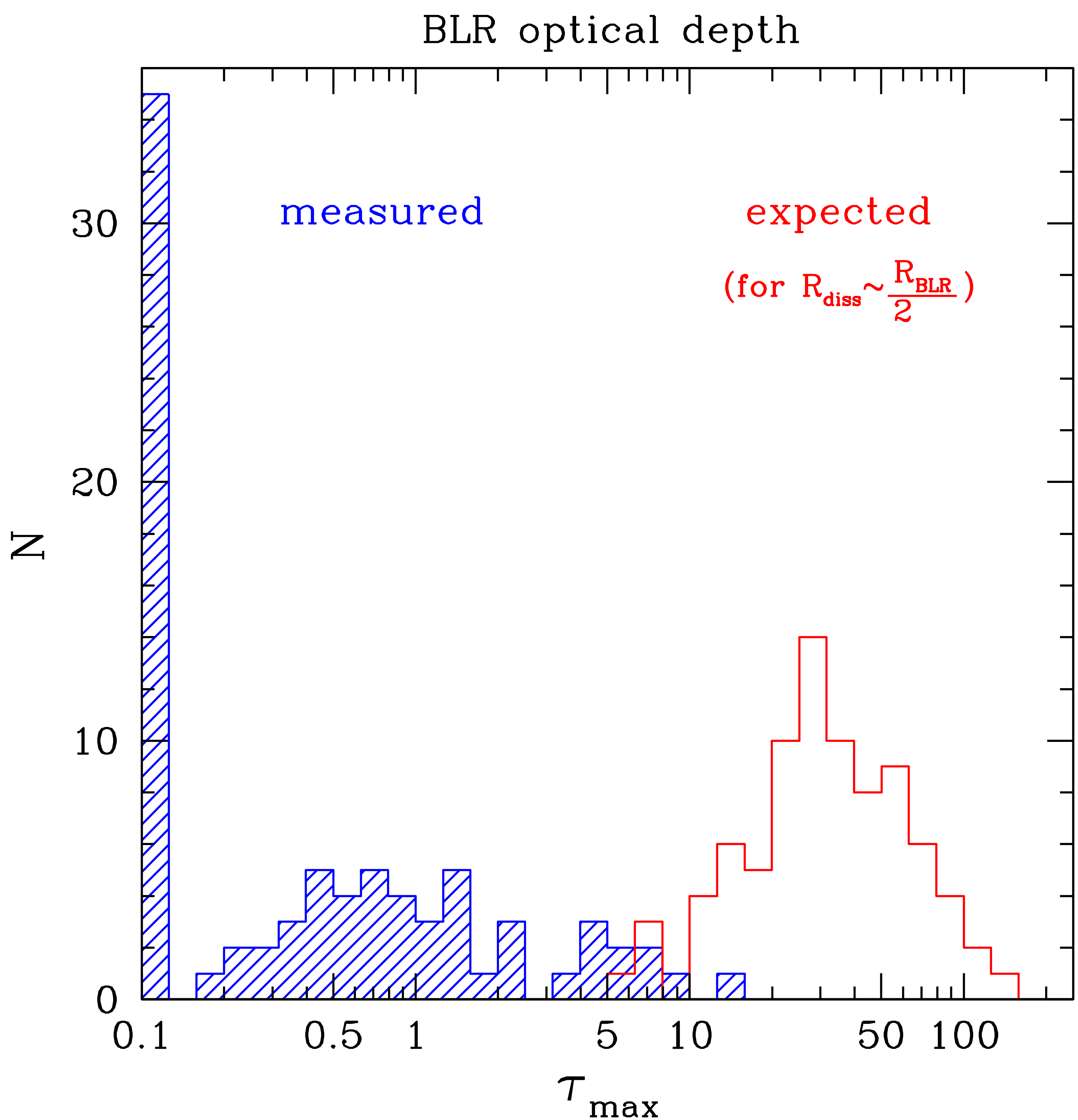
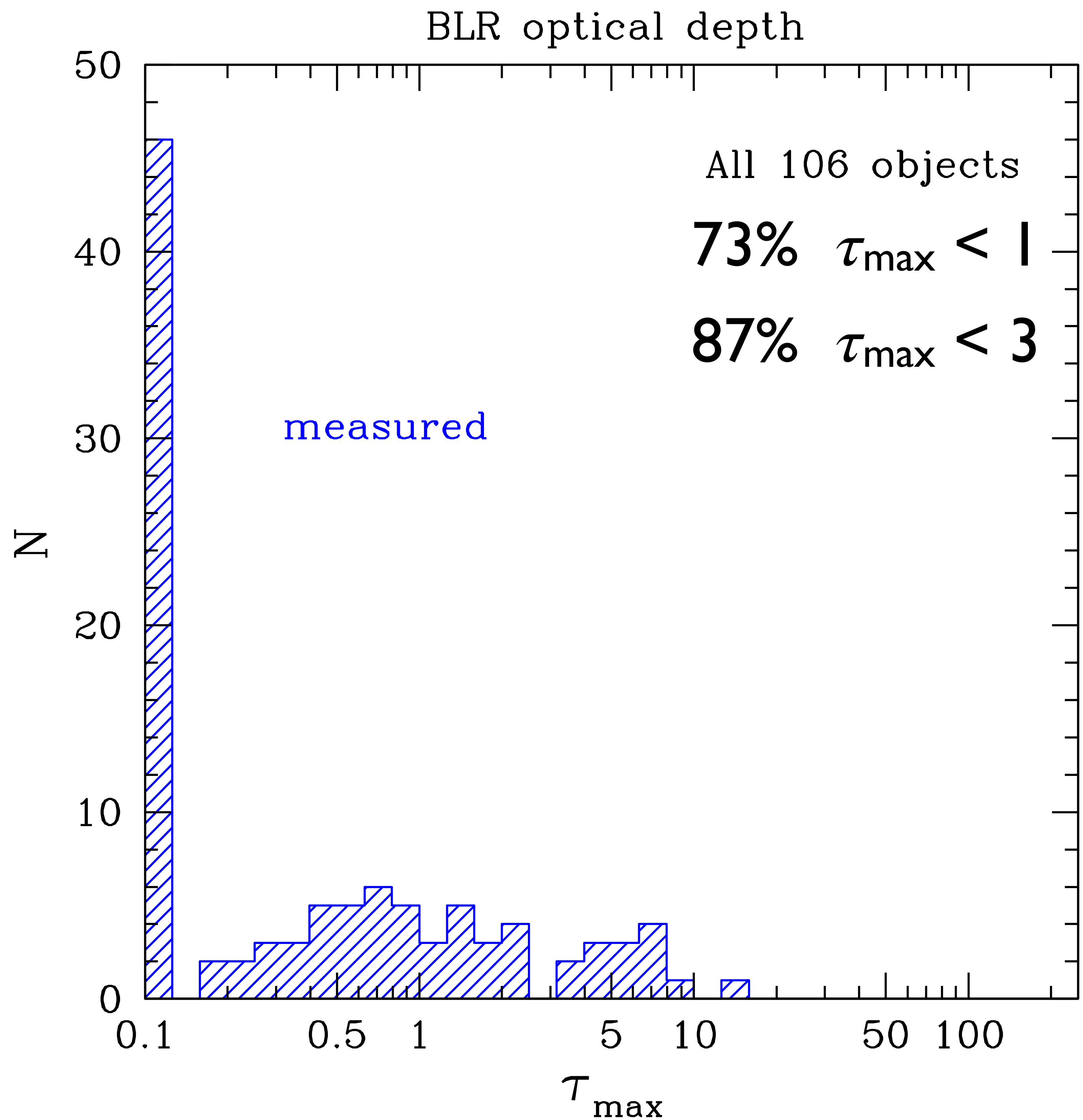


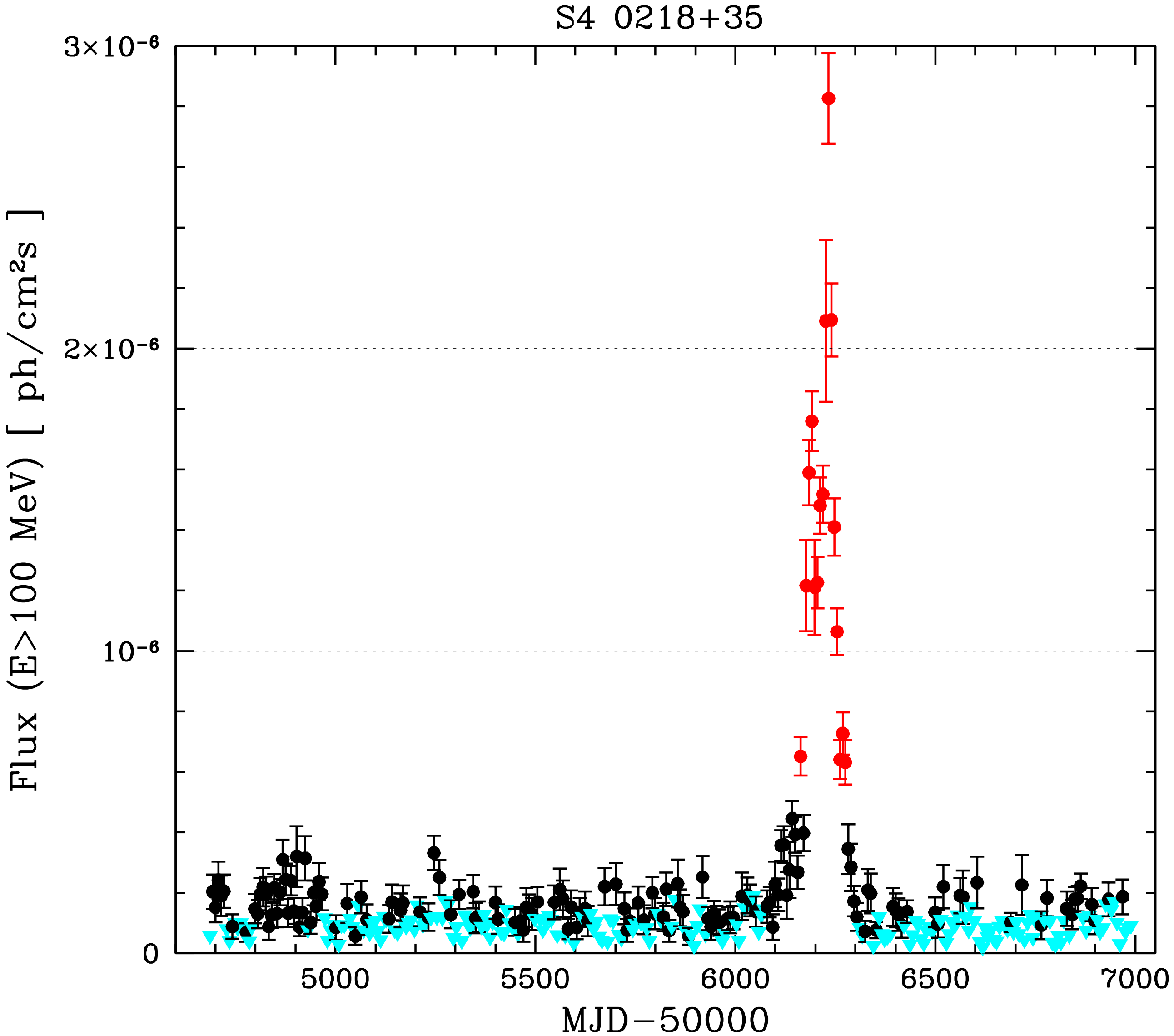
for EC(BLR)

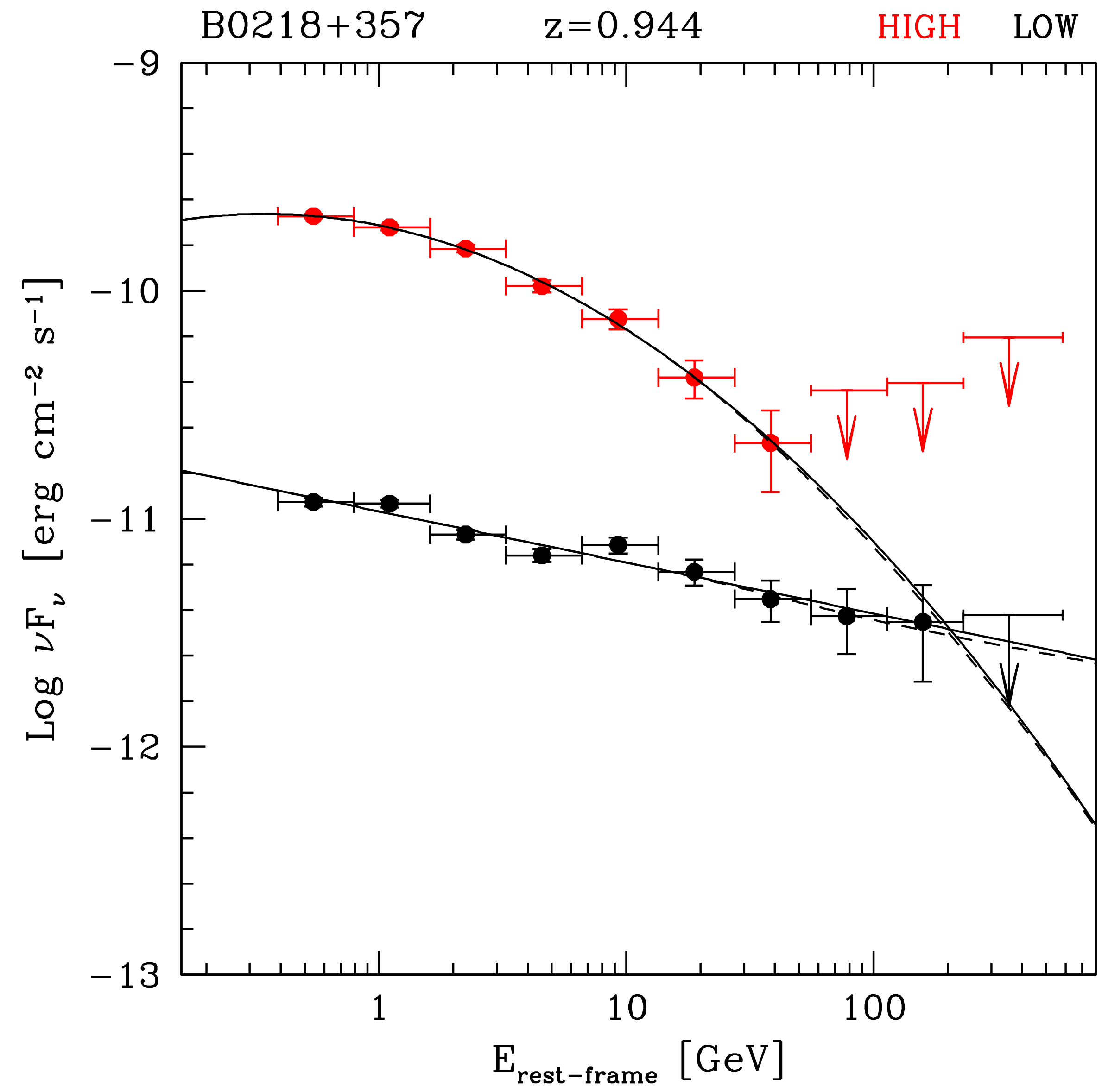
Sample 83 objects with L_{BLR} estimate



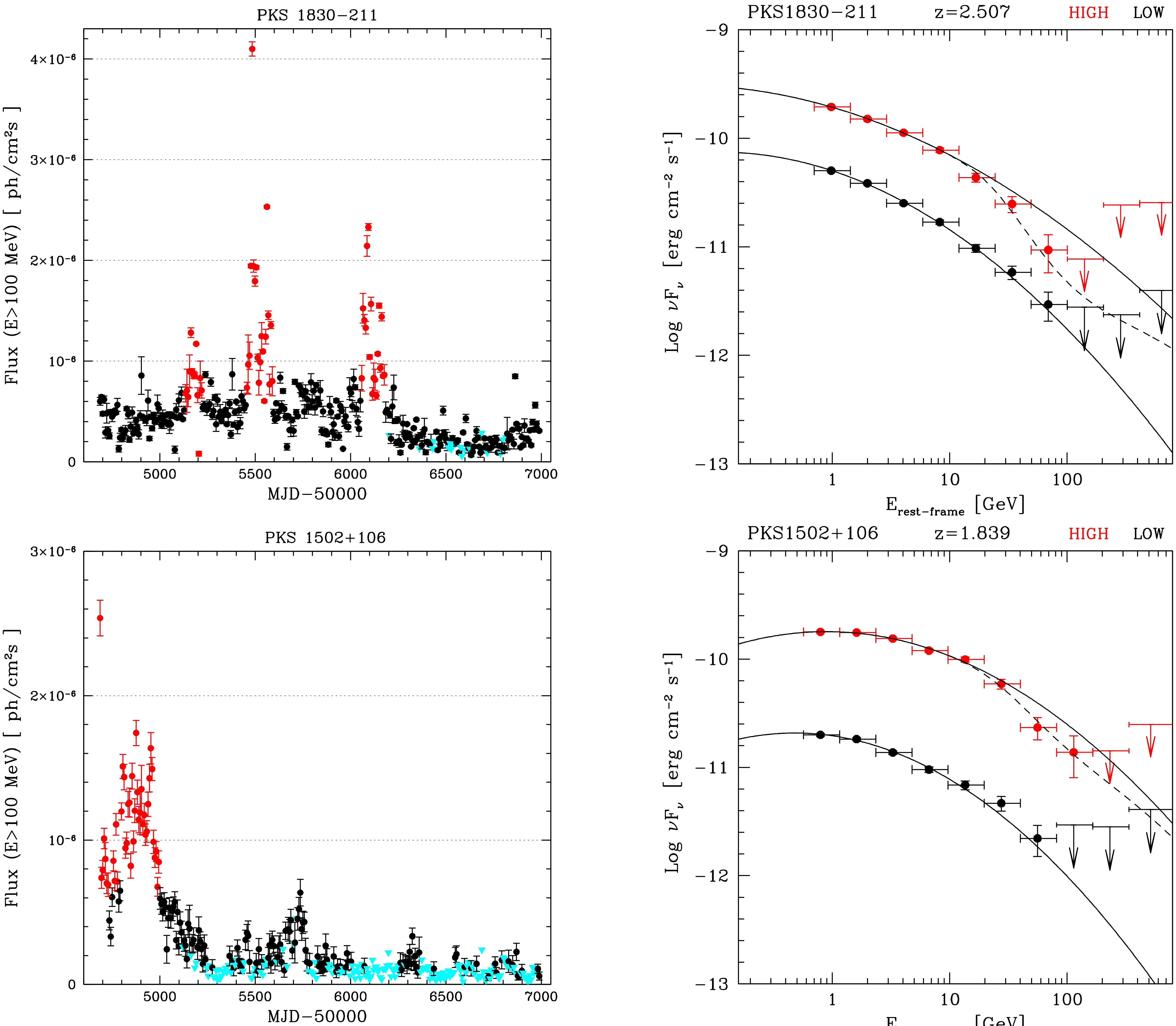
Total Sample of 106 objects

For the brightest 20:   difference High/Low state ?



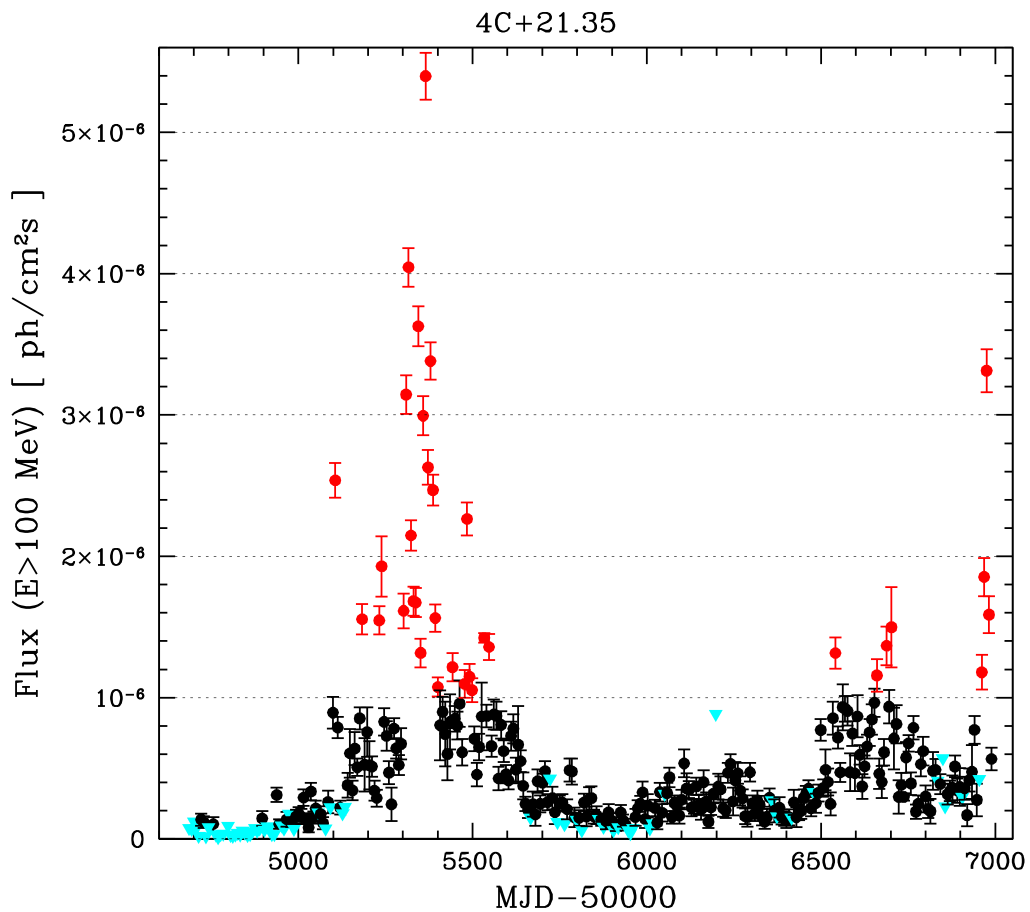


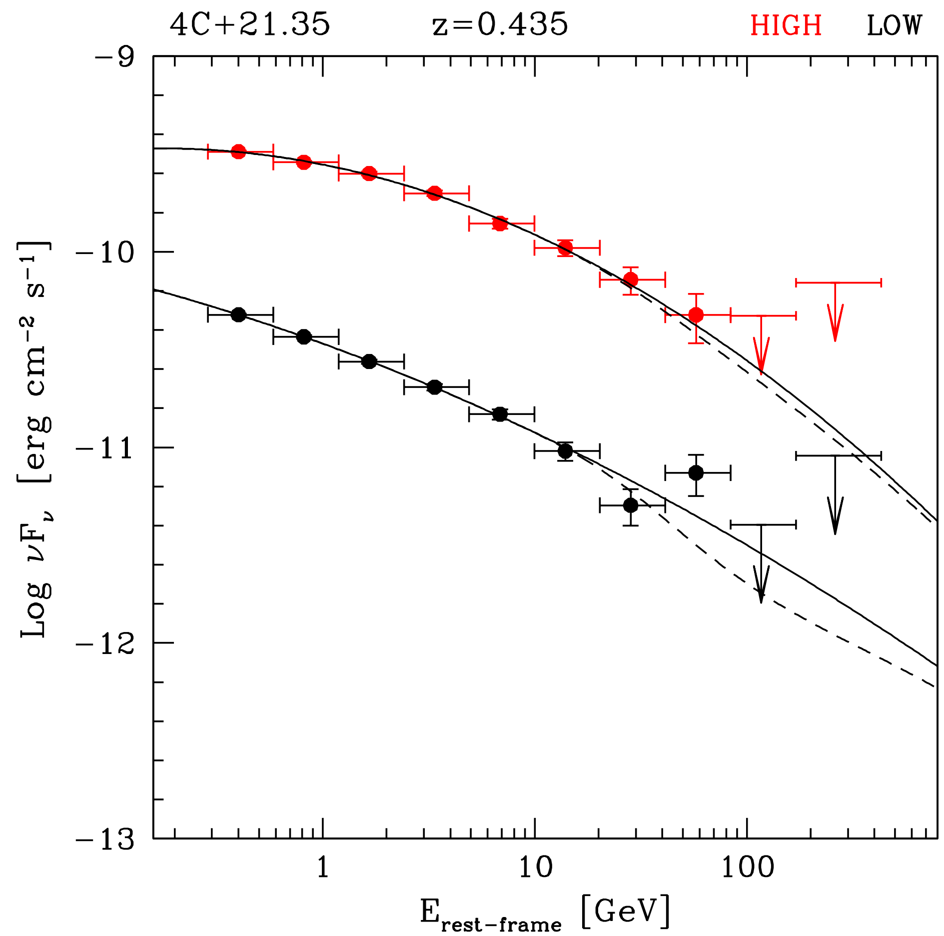
No evidence of strong interaction with BLR photons

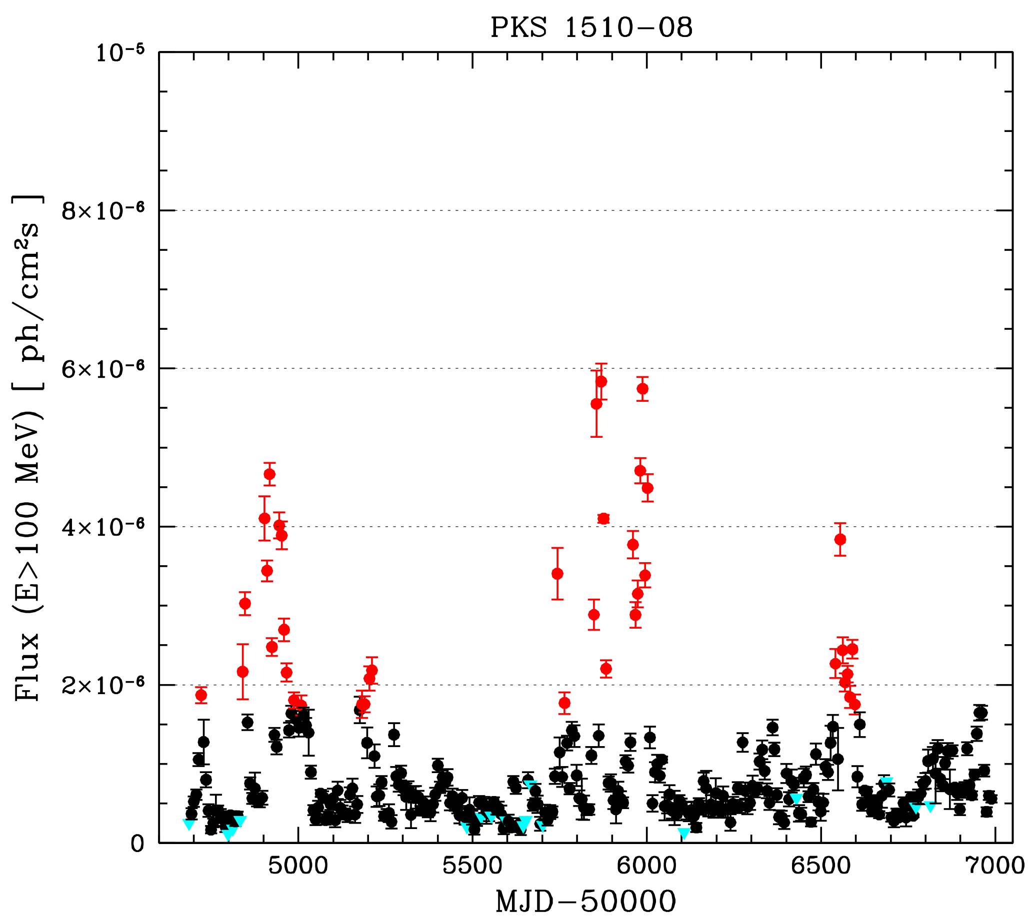


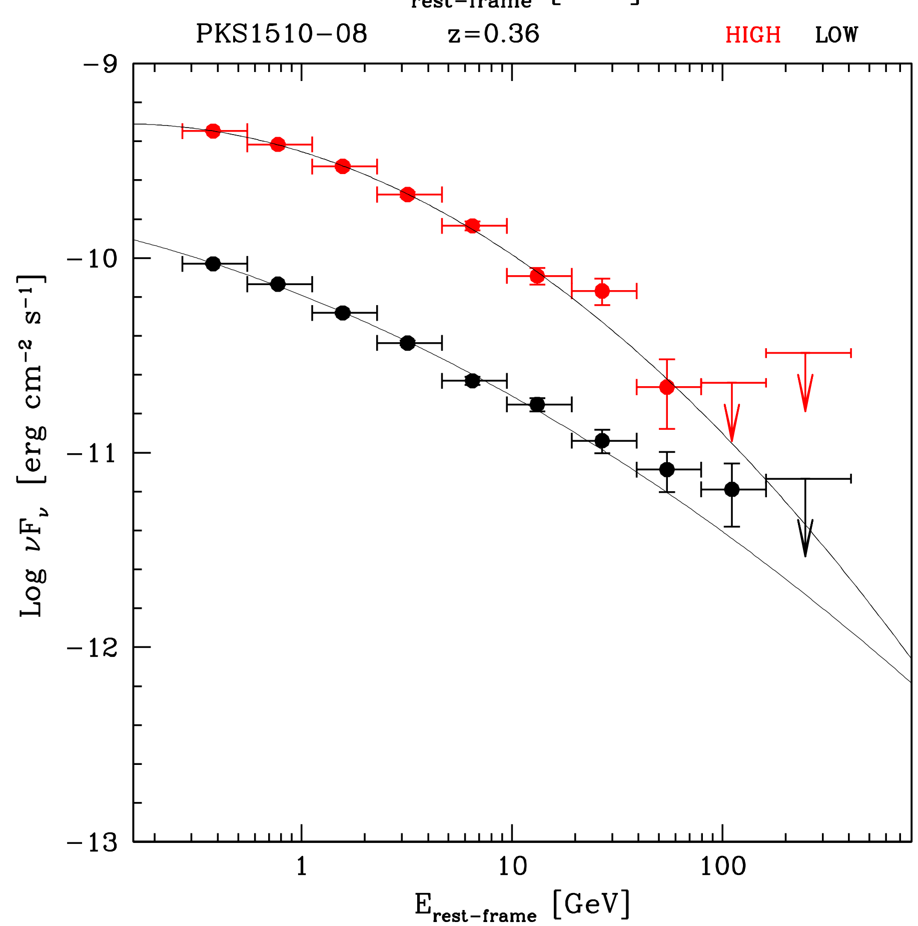
PKS 1830−211
Flux (E>100 MeV) [ph/cm²s]
4×10⁻⁶
3×10⁻⁶
2×10⁻⁶
10⁻⁶
0
5000
5500
6000
6500
7000
MJD−50000
PKS1830−211
z=2.507
HIGH
LOW
Log νF_ν [erg cm⁻² s⁻¹]
−9
−10
−11
−12
−13
1
10
100
E_rest-frame [GeV]
PKS 1502+106
Flux (E>100 MeV) [ph/cm²s]
3×10⁻⁶
2×10⁻⁶
10⁻⁶
0
5000
5500
6000
6500
7000
MJD−50000
PKS1502+106
z=1.839
HIGH
LOW
Log νF_ν [erg cm⁻² s⁻¹]
−9
−10
−11
−12
−13
1
10
100

VHE-detected FSRQs: also in Low state

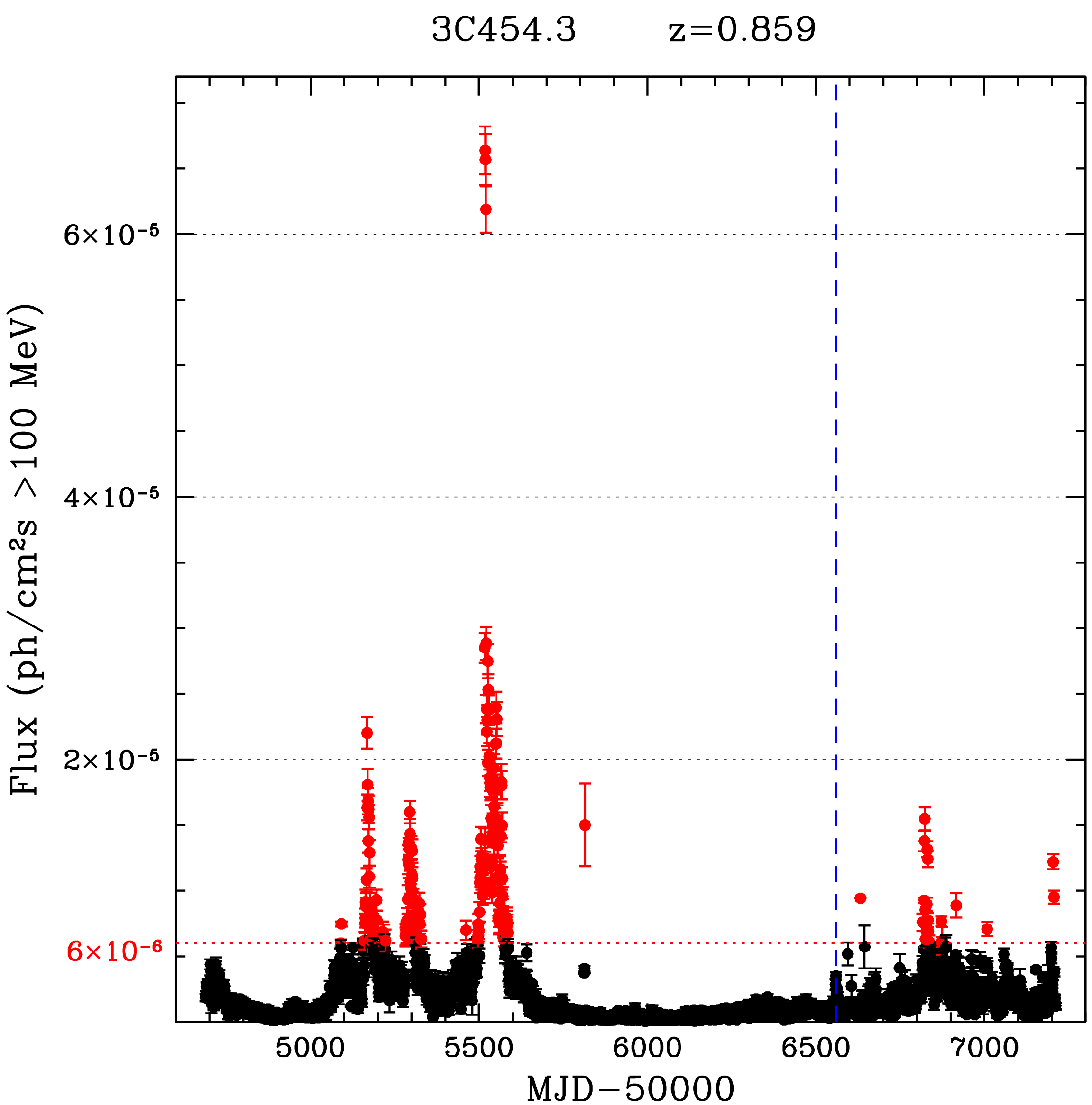


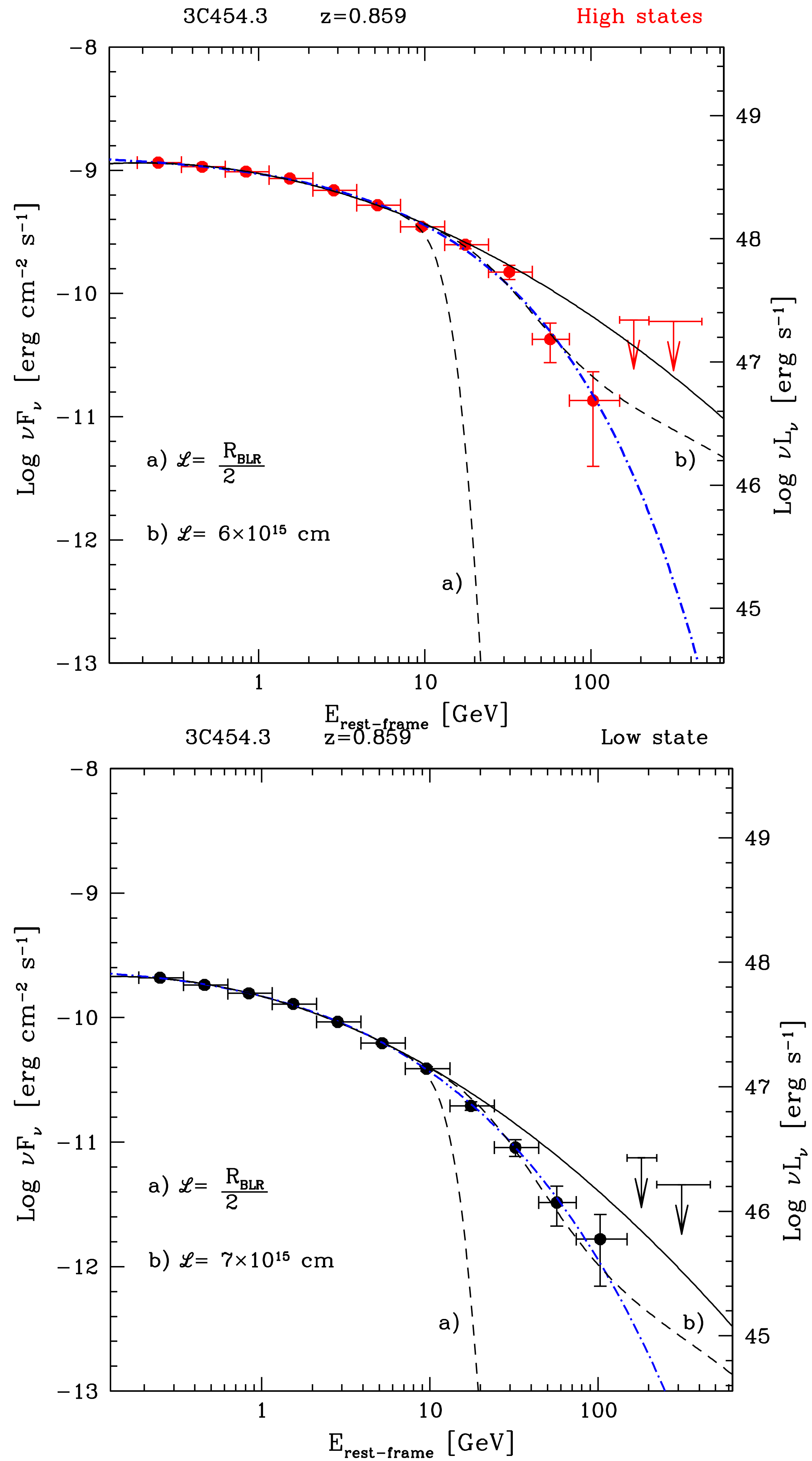






Even 3C 454.3 !





Better fitted with intrinsic electron cutoff !

Conclusion:

NO evidence of jet interaction with BLR photons !

EC(BLR) seems the exception, not the normality,
of the gamma-ray emission in Fermi Blazars

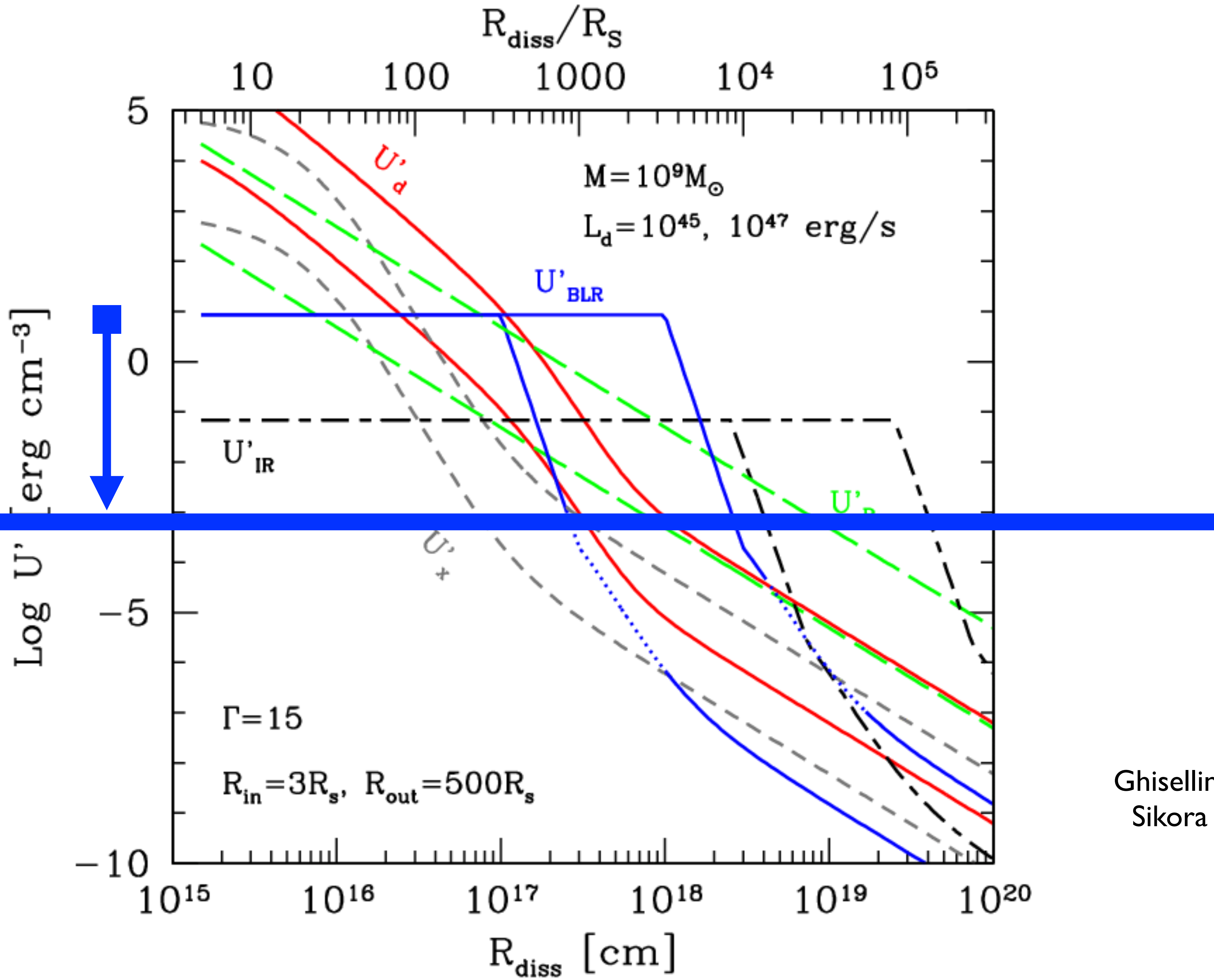
Alternatives?

to reduce absorption but staying within the BLR ?

1. *Much larger BLR (~100x)* $\tau \propto 1/R_{\mathrm{BLR}}$

2. *Shift $\gamma\gamma$ threshold by selecting angles ("Flattened BLR")*

1. Energy density U_{BLR} goes down 10^{-4}

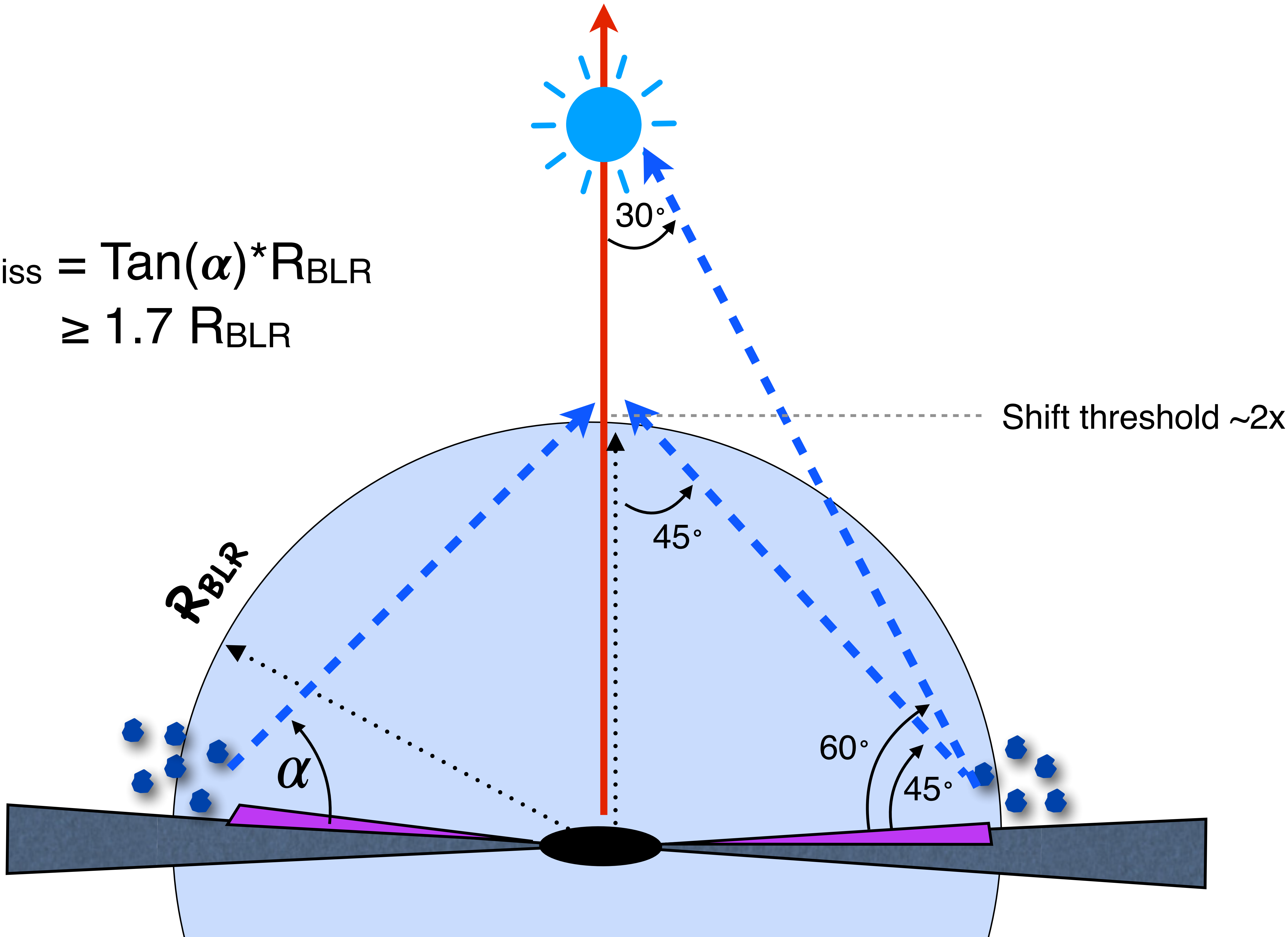


Ghisellini et al. 2009
Sikora et al. 2009

U_{BLR} *becomes lower than any other radiation field —> EC(BLR) disfavoured*

2. Shift threshold 5x (to ~100 GeV) —> $\vartheta \leq$ 30 deg

$R_{diss} = \mathrm{Tan}(\alpha)^{*}R_{BLR}$
$\geq 1.7\ R_{BLR}$



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2. ~~*Shift $\gamma\gamma$ threshold by selecting angles ("Flattened BLR")*~~

Both do NOT keep EC(BLR) viable

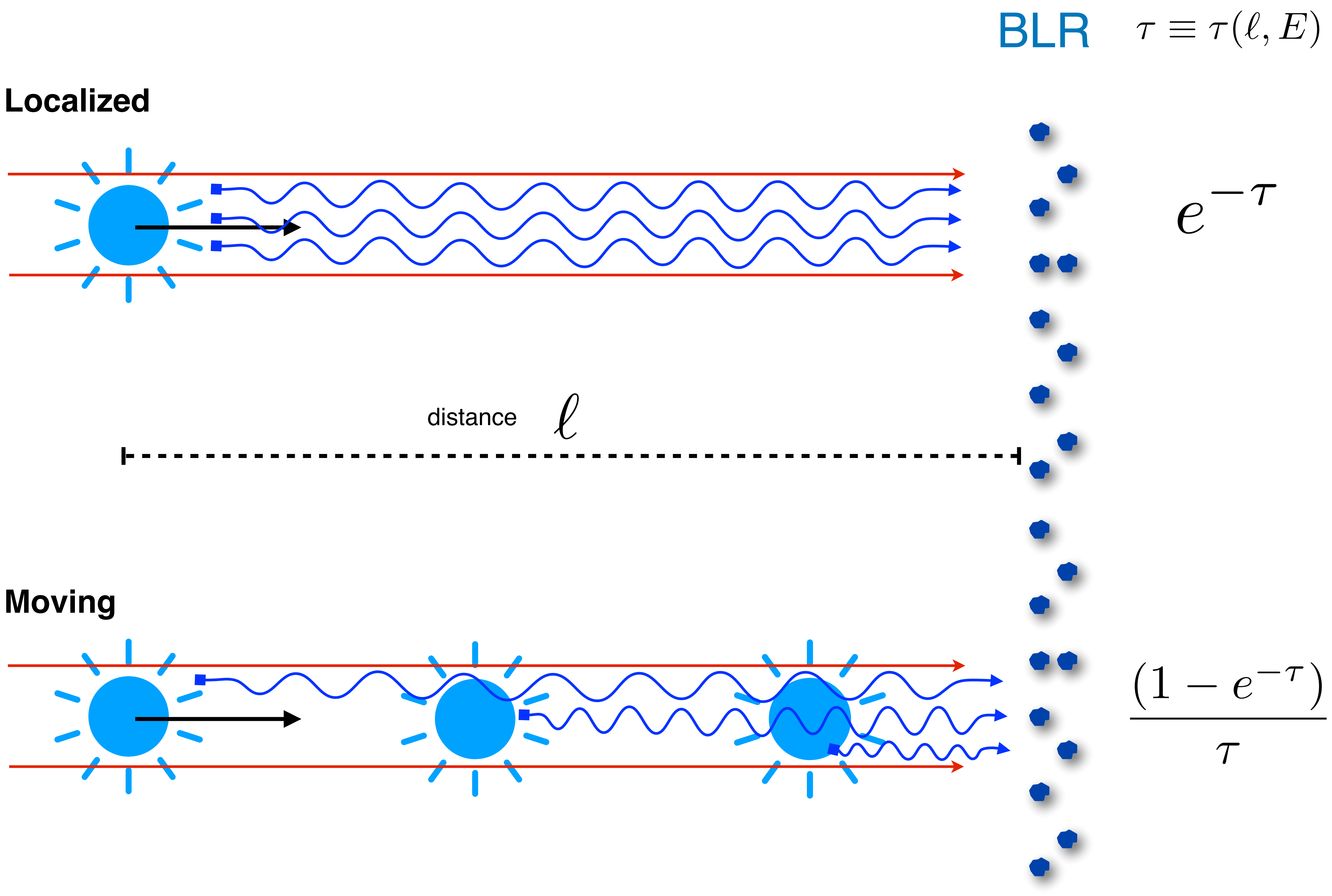
Two Caveats:

1) Long integration time (years)

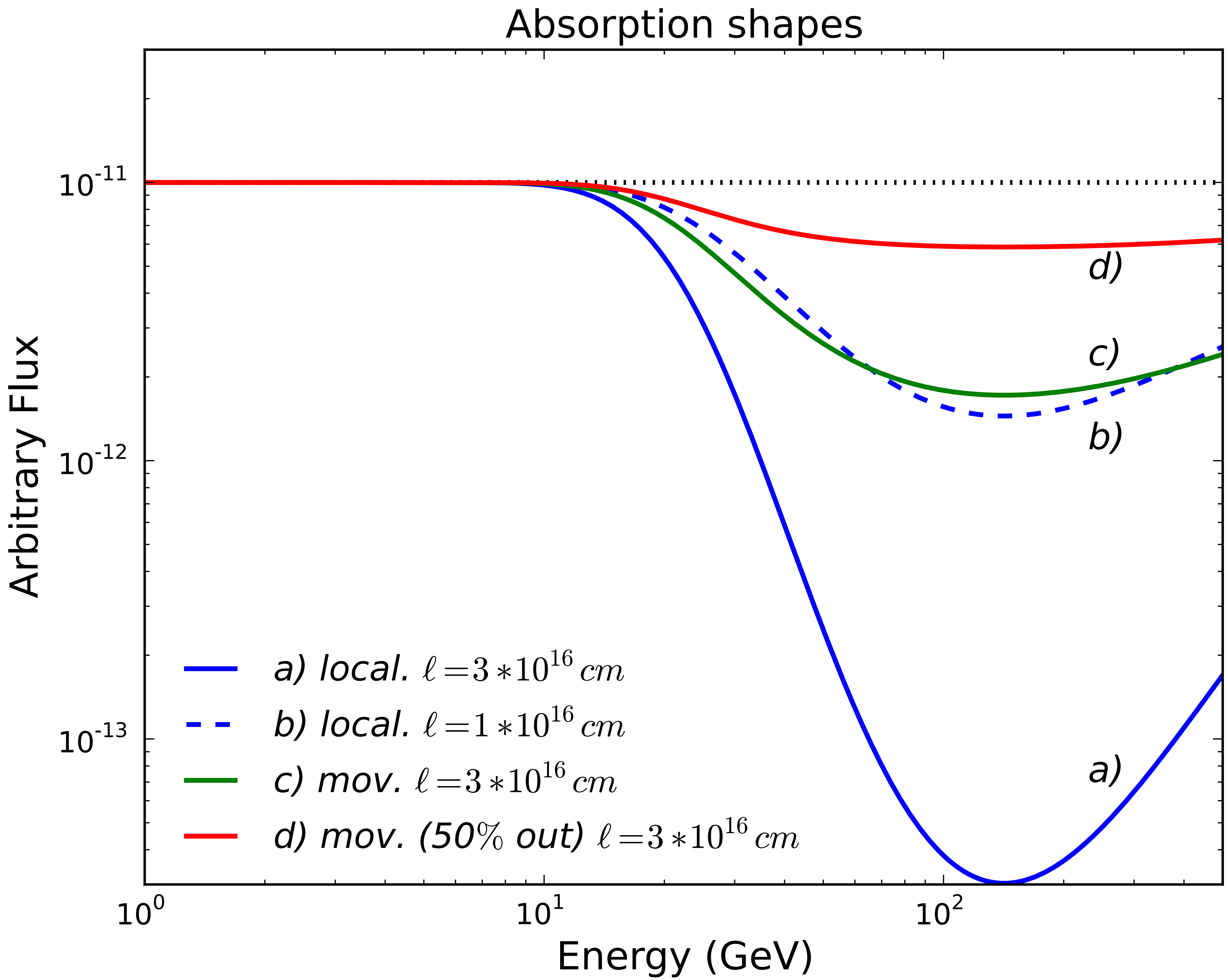
2) Kinematics of the emission
(localized dissipation vs moving blob)

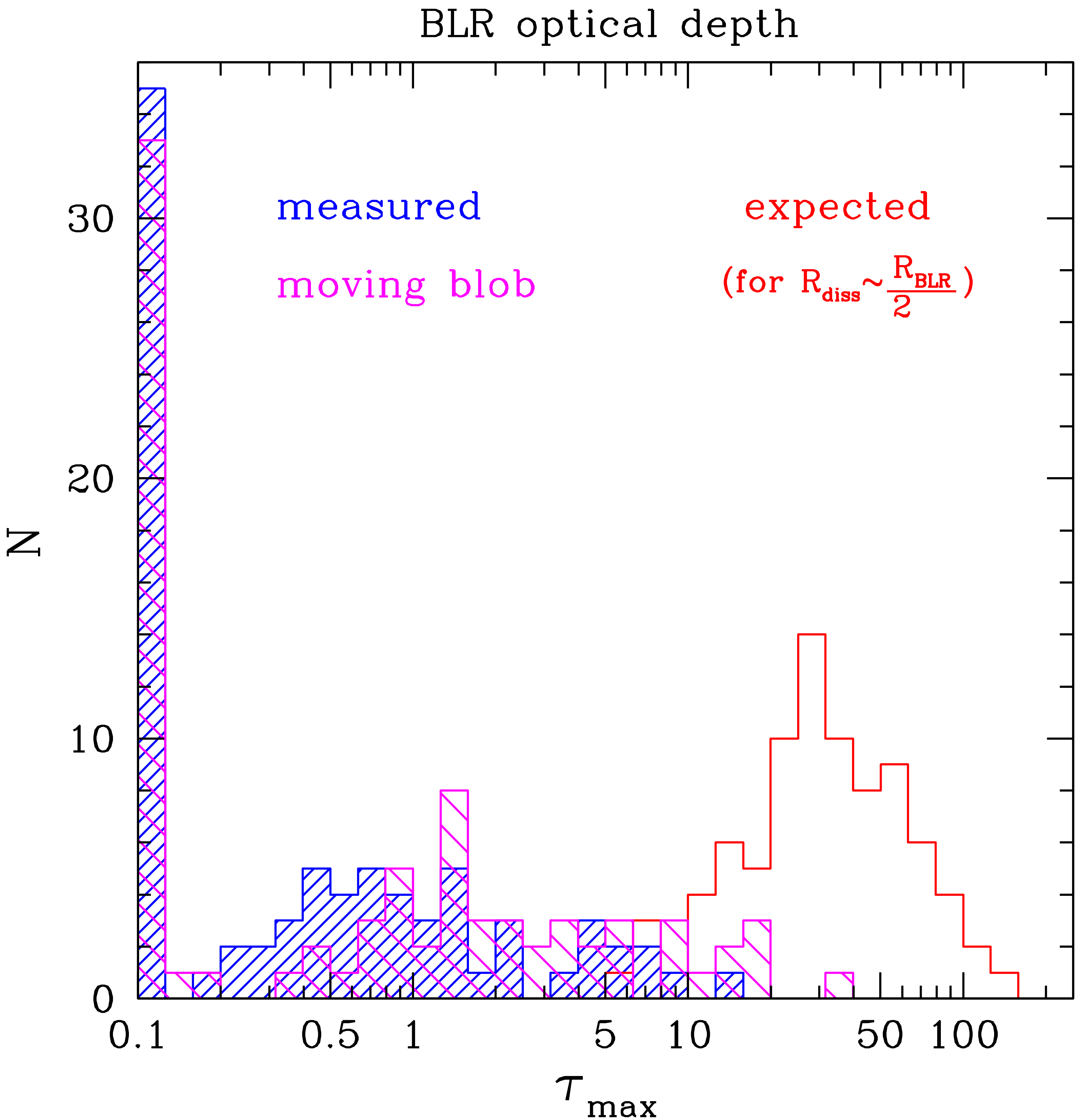
Doppler effect: $\Delta R \simeq \Delta t_{obs} * \beta * \Gamma^2$

$$\begin{array}{c} \Gamma = 10 \\ \Delta t_{obs} \geq 10^5 s \end{array} \Longrightarrow \Delta R \geq 10^{17} cm$$


BLR
$\tau \equiv \tau(\ell, E)$
Localized
$e^{-\tau}$
distance ℓ
Moving
$\dfrac{(1-e^{-\tau})}{\tau}$

We can gain a factor ~3 in path length





It does **NOT** *change the main result*

Conclusion & Consequences

1) EC(BLR) is disfavoured as gamma-ray emission mechanism in Broad-line Blazars *(~9/10 , EC-IR or SSC or EC-ambient)*

   ⇒ *re-model SED for jet parameters*

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   ⇒ *re-model SED for jet parameters*

2) Gamma-ray spectrum is mostly intrinsic (particle distribution)
   ⇒ *new diagnostic possibilities*

The Astrophysical Journal, 753:176 (14pp), 2012 July 10 doi:10.1088/0004-637X/753/2/176

ON THE SPECTRAL SHAPE OF RADIATION DUE TO INVERSE COMPTON SCATTERING CLOSE TO THE MAXIMUM CUTOFF

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Received 2012 March 10; accepted 2012 May 11; published 2012 June 26

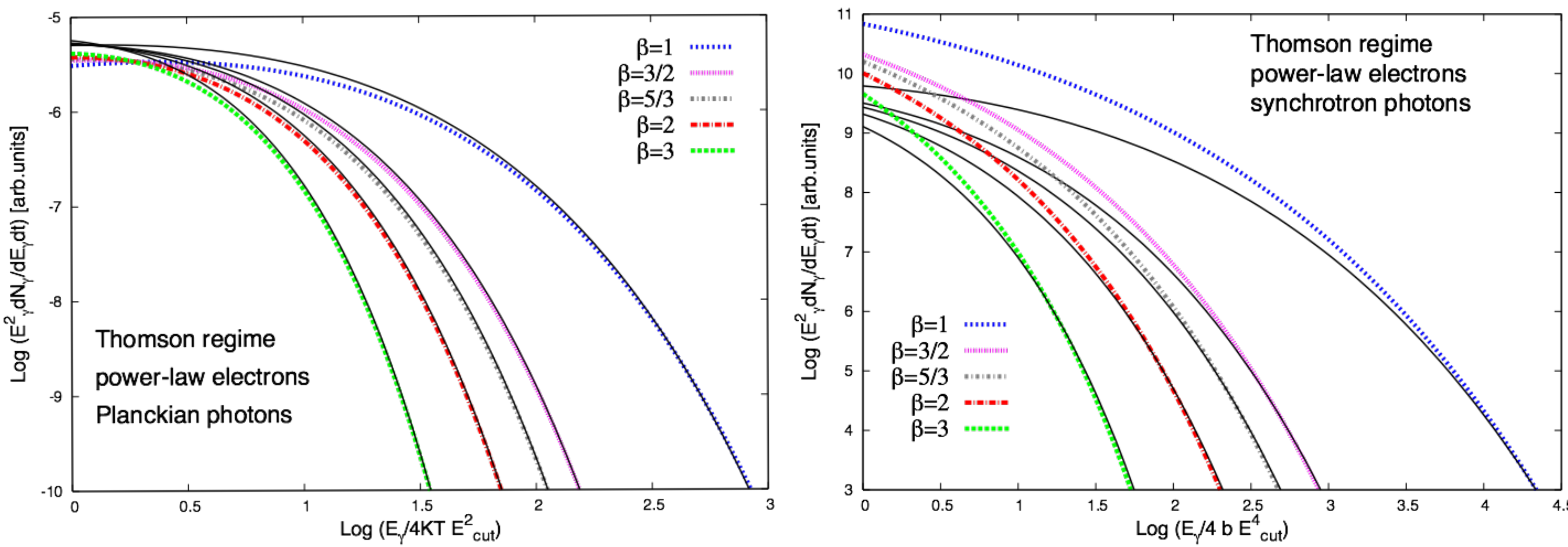

Table 1
The Index of the Exponential Cutoff in the Energy Spectrum of IC Radiation β_C Calculated for Three Different Target Photon Fields, in the Thomson and Klein-Nishina Regimes

Scattering regime	Thomson	Klein-Nishina	Thomson	Klein-Nishina
Radiation field electrons	β	β	abrupt cutoff	abrupt cutoff
Monochromatic photons	$\beta/2$	β	∞	∞
Planckian photons	$\beta/(\beta+2)$	β	1	∞
Synchrotron photons	$\beta/(\beta+4)$	β	1	∞

Note. The index β characterizes the exponential cutoff in the electron energy distribution given by Equation 1.

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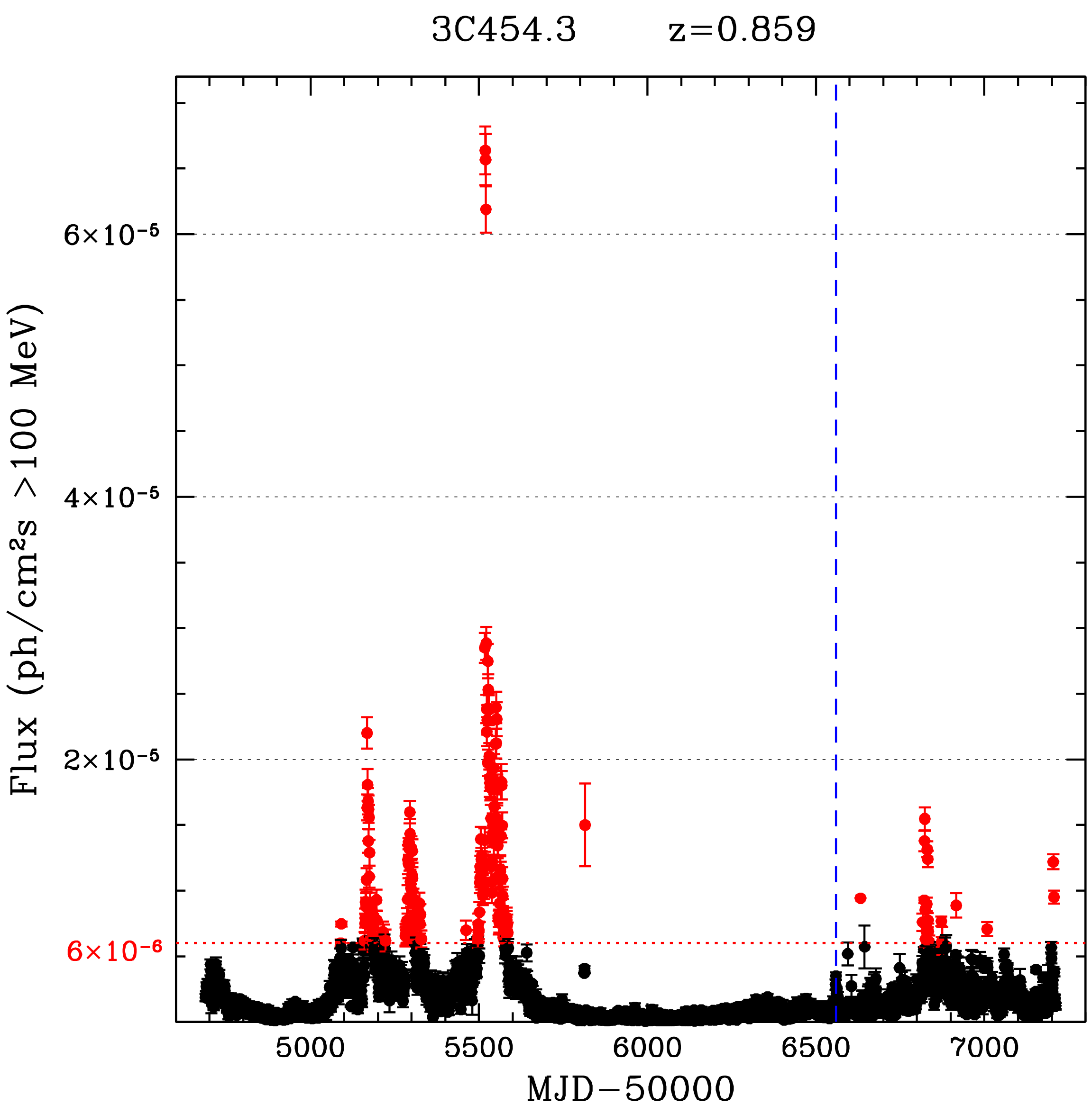
   ⇒ *re-model SED for jet parameters*

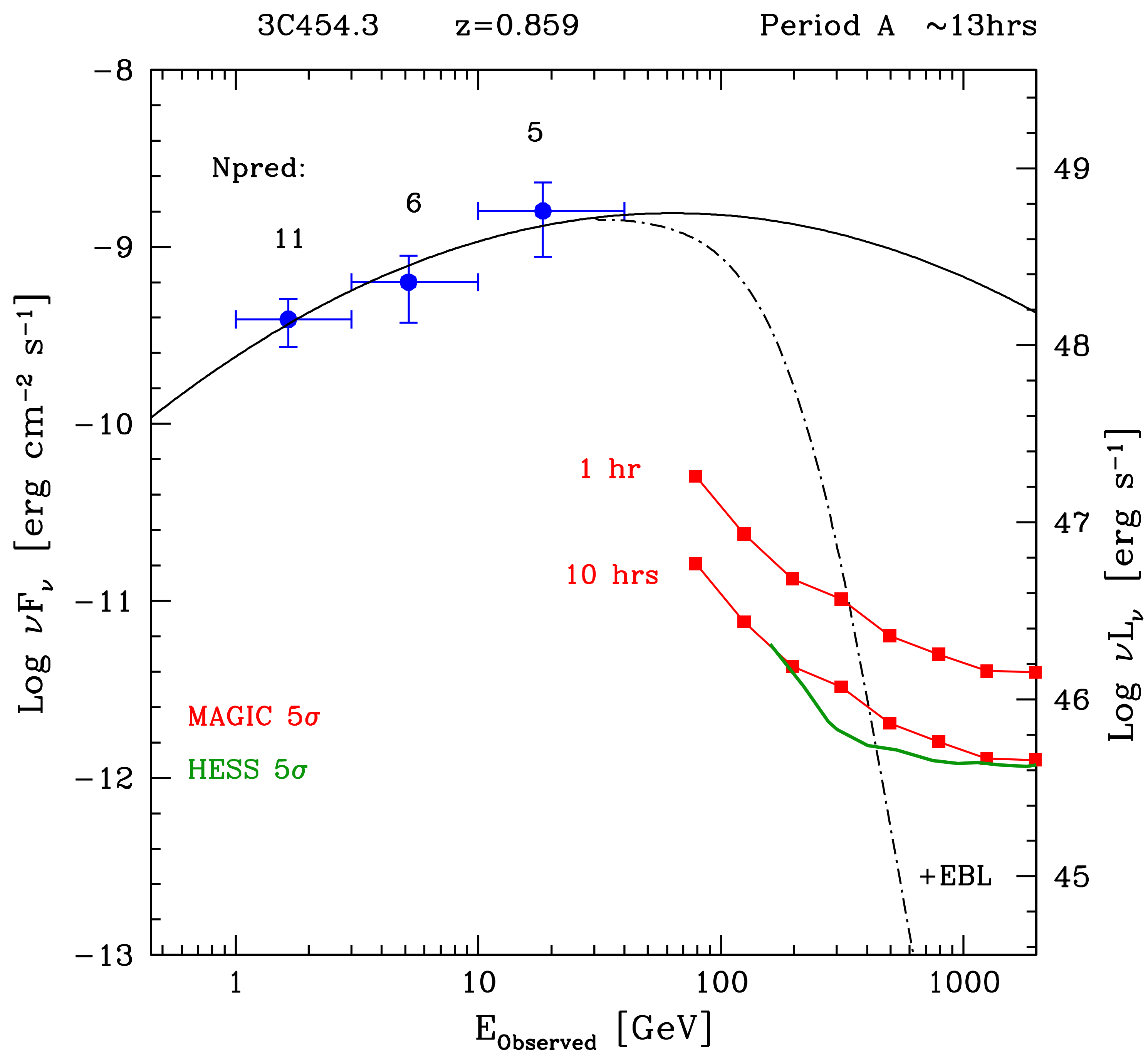
2) Gamma-ray spectrum is mostly intrinsic (particle distribution)
   ⇒ *new diagnostic possibilities* (e.g. *Lefa et al 2014*)

3) Without BLR suppression, FSRQs luminous at VHE
   ⇒ *CTA sky much richer of FSRQs*

3C 454.3 can be easily detectable at VHE !



Pacciani et al. 2014 - flare



HBL-like flare !

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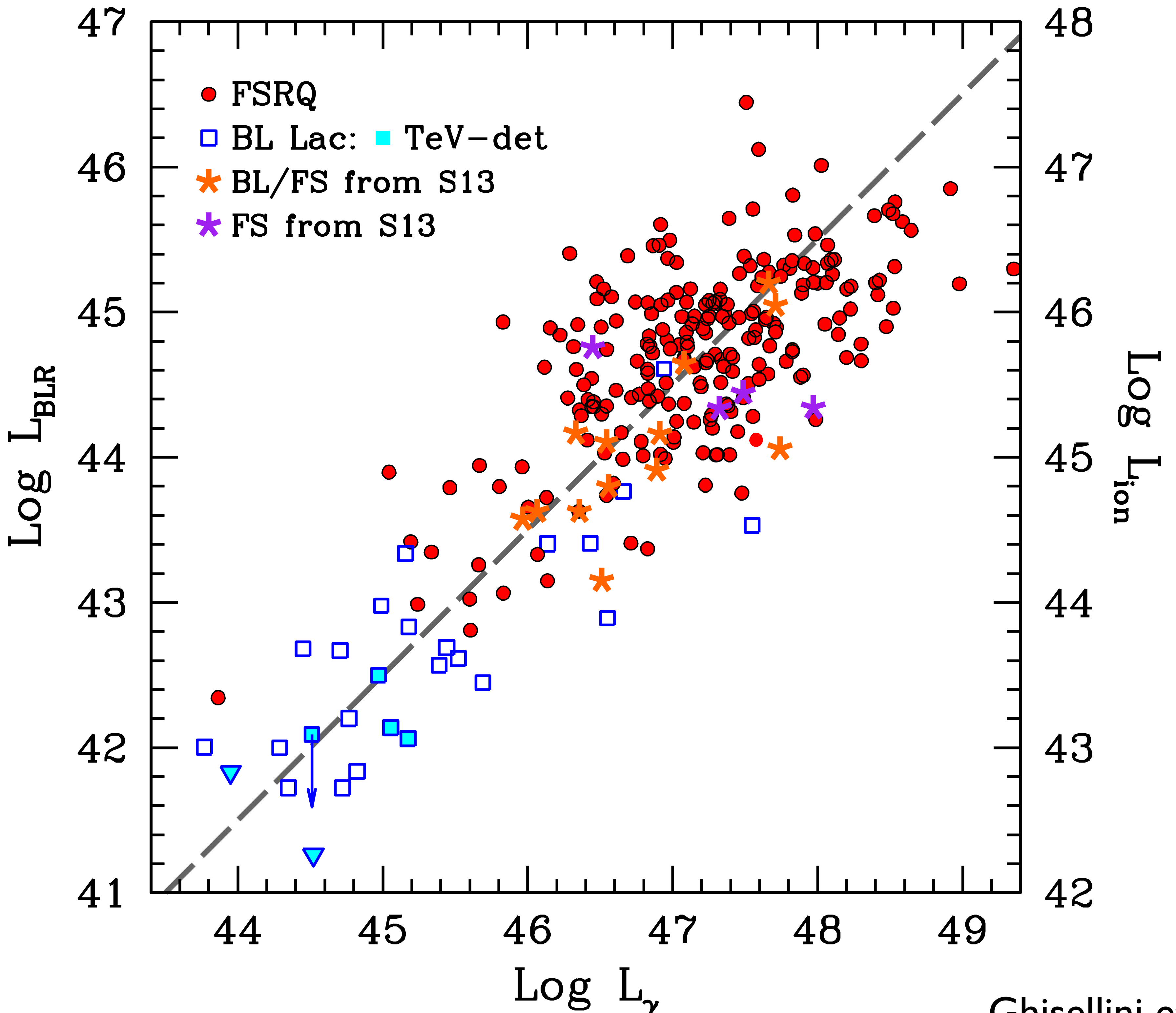
4) Differences FSRQ/BLLac ?

LC et al. 2018, MNRAS, in press (arXiv 1804.06282)

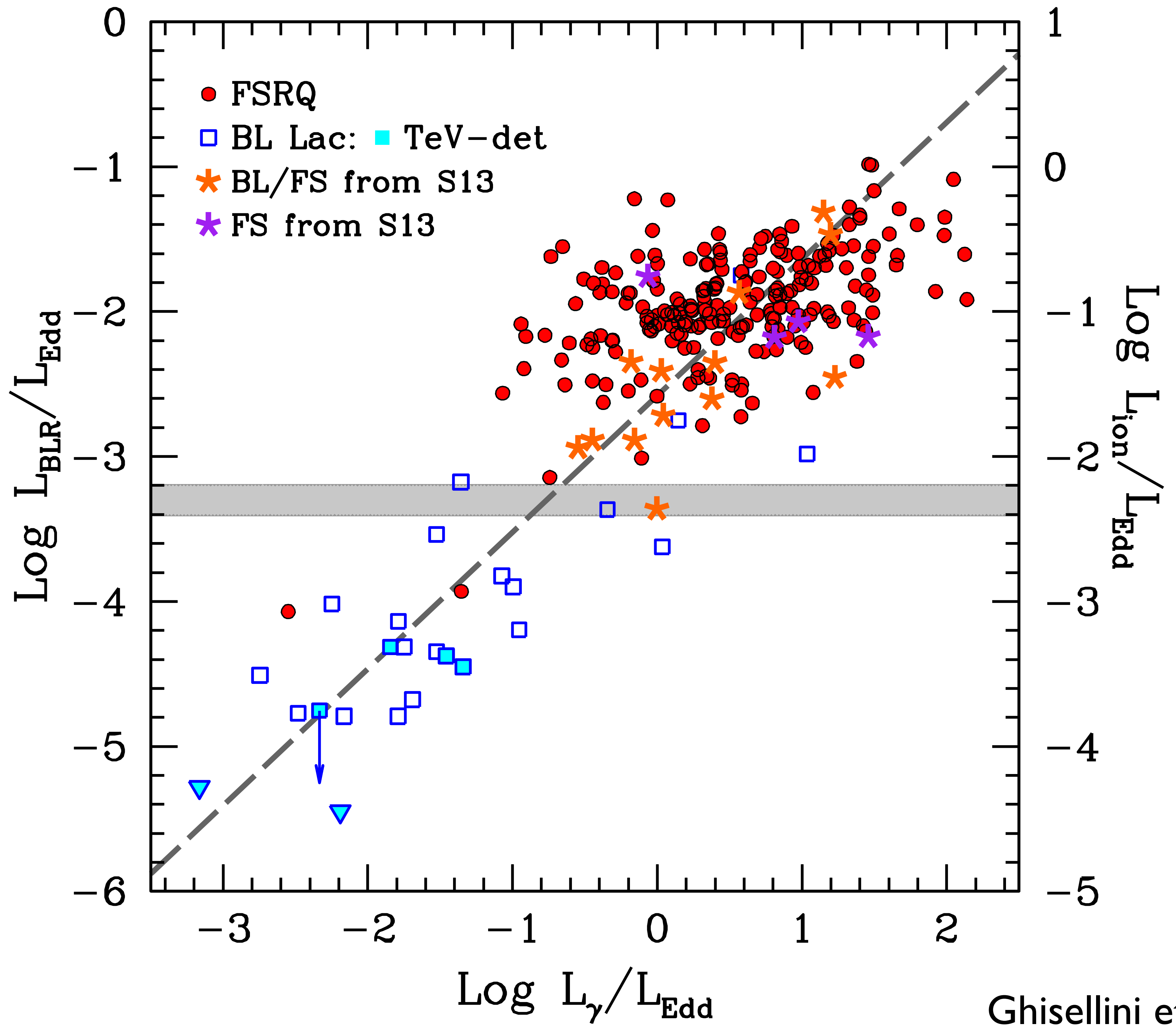
What about the Gamma-BLR connection then ?



Ghisellini et al 2013
Sbarrato et al 2011, 2014

What about the Jet-Accretion connection then ?

BLR acts as proxy of the disk, does not affect Jet radiation



radiatively efficient

radiatively inefficient

Ghisellini et al 2013
Sbarrato et al 2011, 2014

Conclusion & Consequences

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2) Gamma-ray spectrum is mostly intrinsic (particle distribution)
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3) Without BLR suppression, FSRQs should be luminous at VHE
   ⇒ *CTA sky much richer of FSRQs*

4) Differences FSRQ/BLLac are intrinsic to how the jet is born: accretion and jet power

LC et al. 2018, MNRAS, in press (arXiv 1804.06282)