Synchrotron Emission from VHE Gamma-Ray Induced Pair Cascades in AGN Environments

Parisa Roustazadeh

Advisor: Markus Boettcher

Ohio University
Athens, OH

Motivation

Sequence of Blazars:

FSRQ → LBL → IBL → HBL

Some non-HBL VHE gamma-ray blazars have been detected:

S5 0716+714, BL Lacertae, PKS 1424+240, 3C 66A, W Comae, 3C 279.

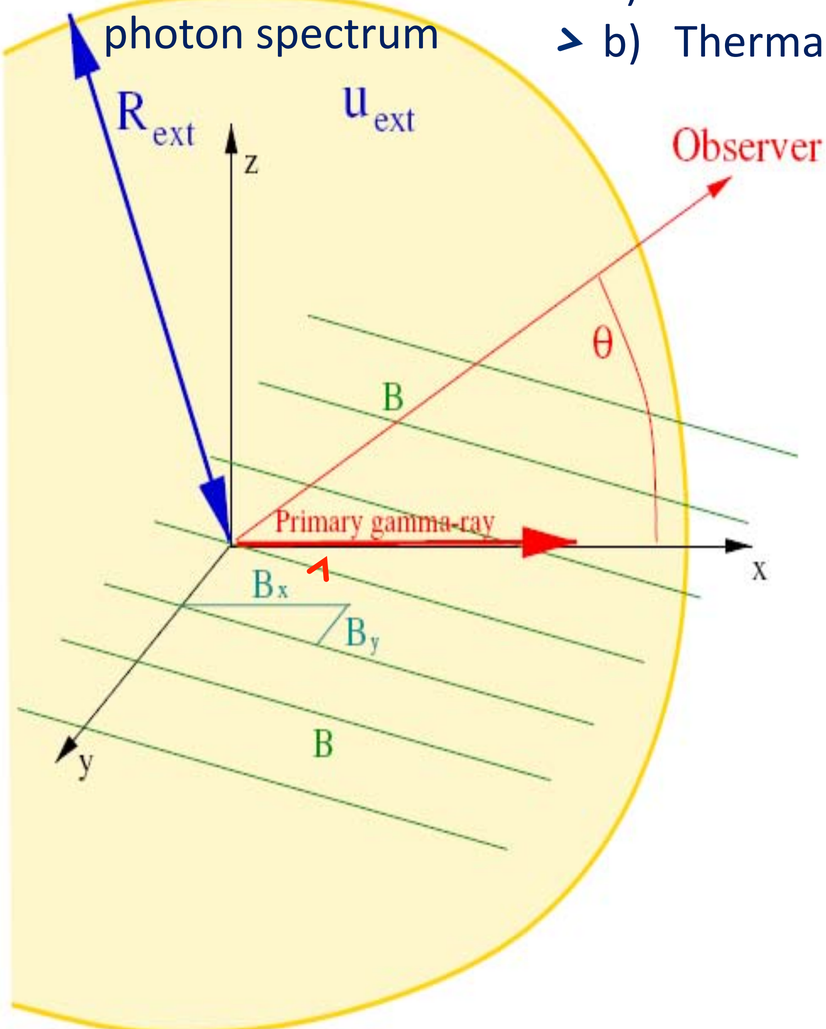
Spectral modeling requires EC component
-> external radiation fields
-> How do photons get out through those radiation fields?

VHE γ-ray production within dense external radiation fields

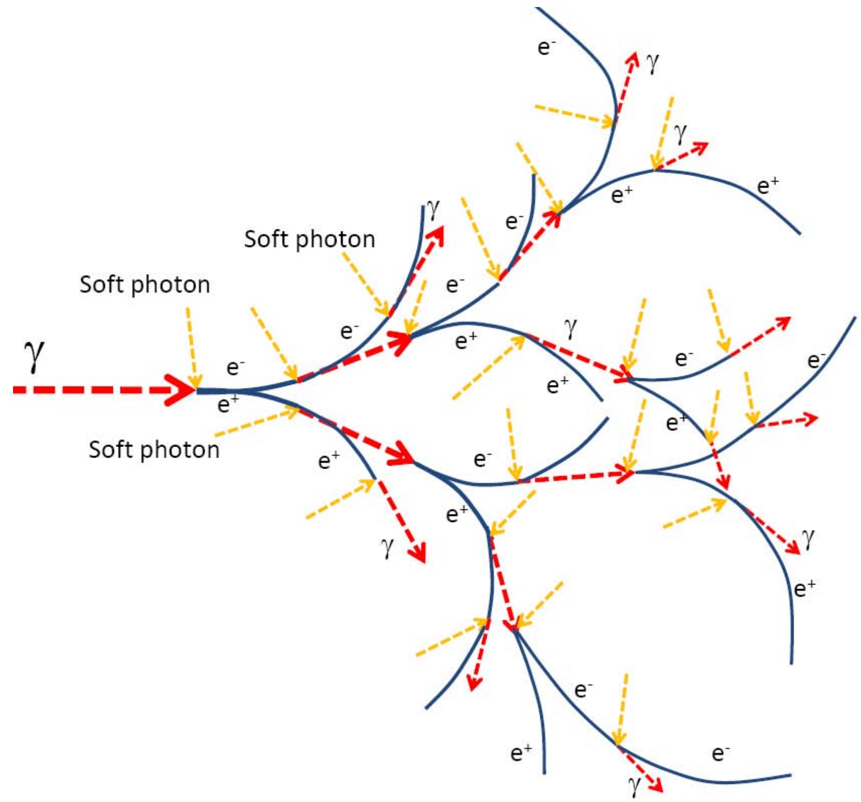
- $\gamma\gamma$ absorption
- Pair cascades
- Deflection by B-fields

→ HE (EGRET, Fermi) γ-ray Detections of Radio Galaxies

Model Setup



- a) Monoenergetic optical/UV (BLR)
- b) Thermal IR (torus)



The trajectories of the particles are followed in full **three-dimensional geometry**.

Compton vs. Synchrotron

$$\frac{P_{synch}}{P_{compt}} = \frac{U_B}{U_{ph}},$$ In AGN env.: $\frac{U_B}{U_{ph}} \ll 1$ → Inverse Compton Scattering dominates

→ Compton supported cascades

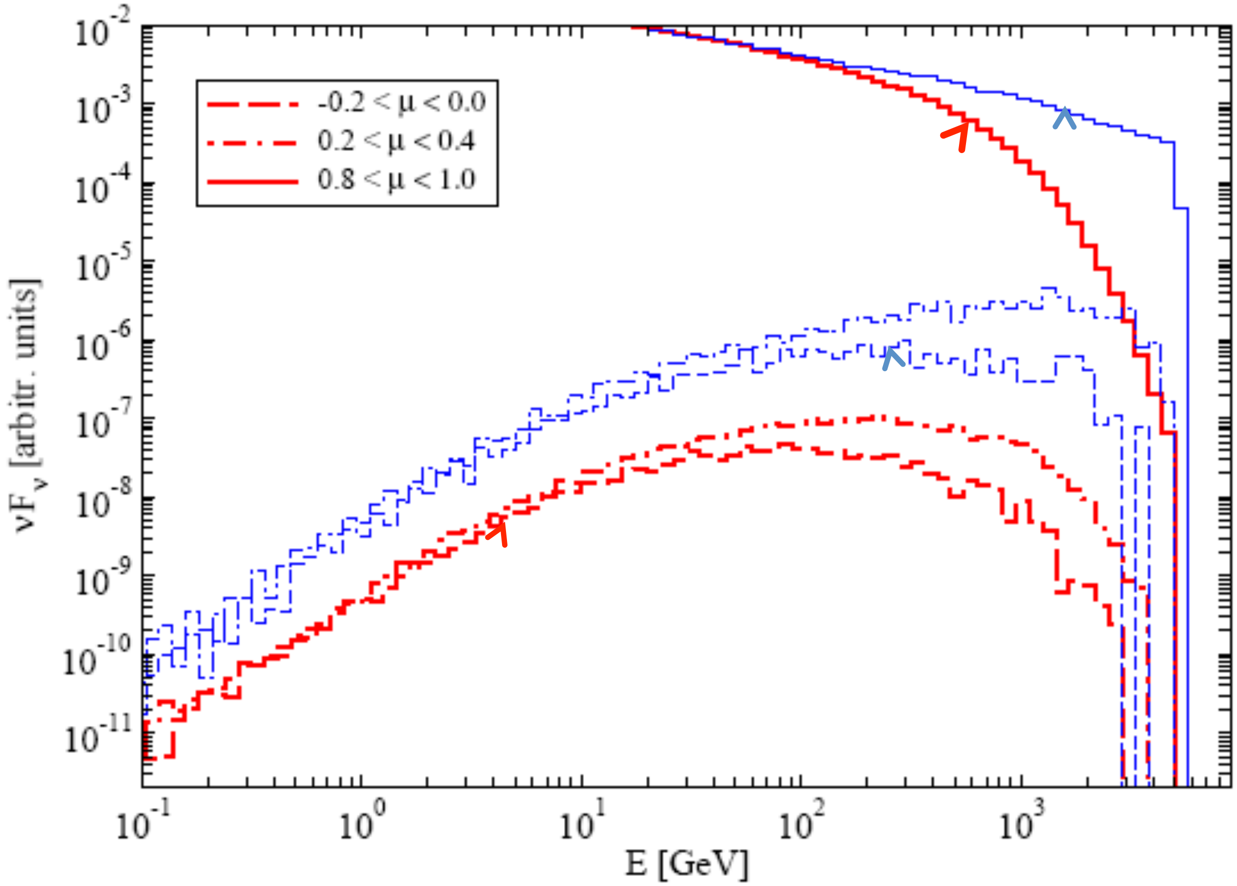
$$\lambda_{synch} = \frac{6 m_e c^2 \pi}{\sigma_T \beta^2 \gamma B^2} \sim 3.8 E_{TeV}^{-1} B_{-3}^{-2} pc$$

$$\lambda_{Compt} = \frac{3 m_e c^2}{4 \sigma_T \beta^2 \gamma U_{BLR}} \sim 5 \times 10^{-6} E_{TeV}^{-1} L_{46}^{-1} \tau_{-1}^{-1} R_{-1}^2 pc.$$

$$r_g = \frac{\gamma m c^2}{qB} \sim 10^{-6} E_{TeV} B_{-3}^{-1} pc$$

> Deflection, isotropization

Dependence on Primary Gamma-Ray Spectrum



$B = 1\ \mu G$
$\theta_B = 45^o$
$R_{ext} = 10^{18}$ cm
$T_{BB} = 1000$ K

PL + EXP Cut Off

Pure PL

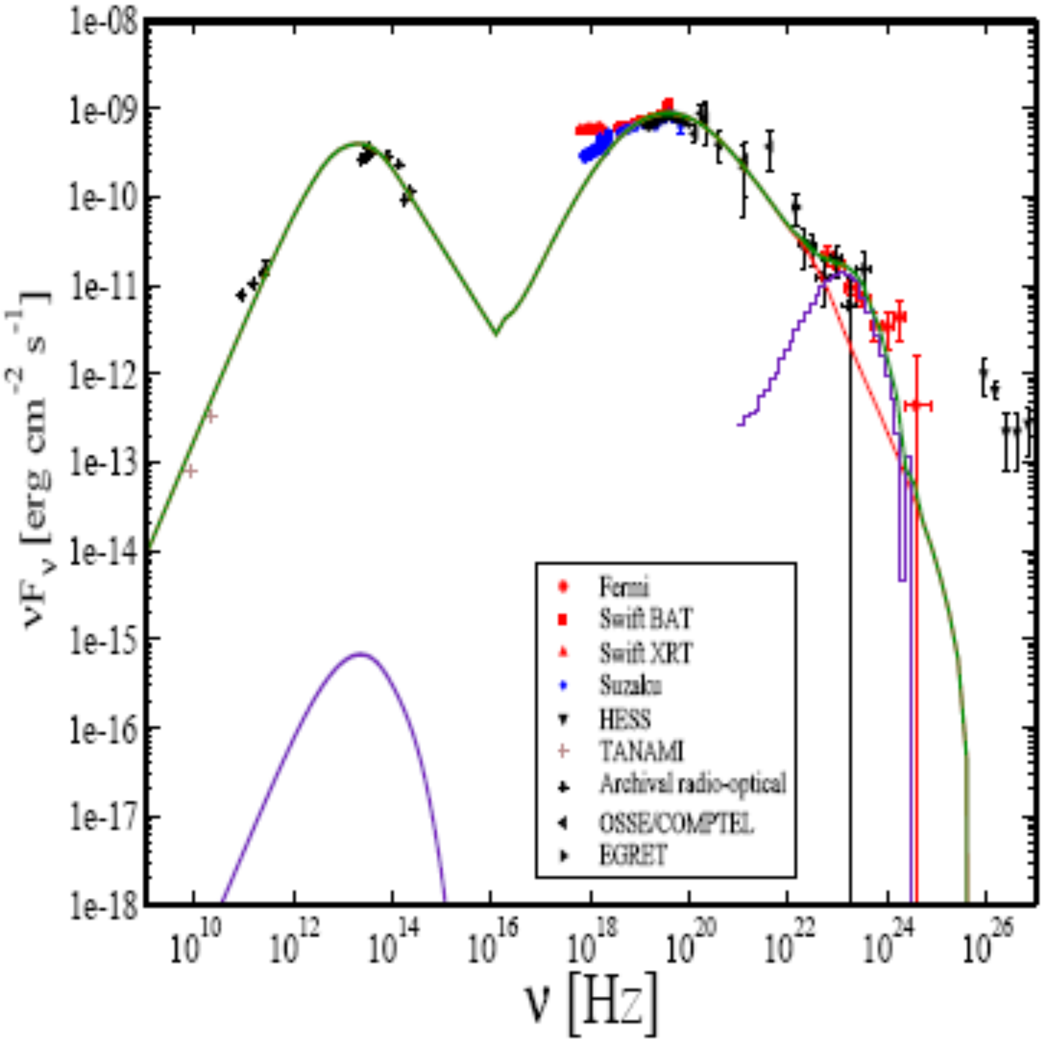
Application to Cen A

D = 3.7 Mpc

Viewing angle ~ $50^o - 80^o$

$\nu L_\nu \sim 6X10^{41}$ erg/s

R ~ $6x10^{17}$ cm



T = 2300 K

→ peak frequency at K-band

$U_{ext} = 1.5 * 10^{-3}$ erg/cm^{-3}

$R_{ext} = 3 * 10^{16}$ cm

$\mathbf{L_{BLR} = 4 \pi R^2_{ext}\, c\, u_{ext}}$

$\mathbf{= 5 * 10^{41}}$ **ergs^{-1}**

B= 1 mG, $\theta_B = 4^0$

$67^0 < \theta < 73^0$

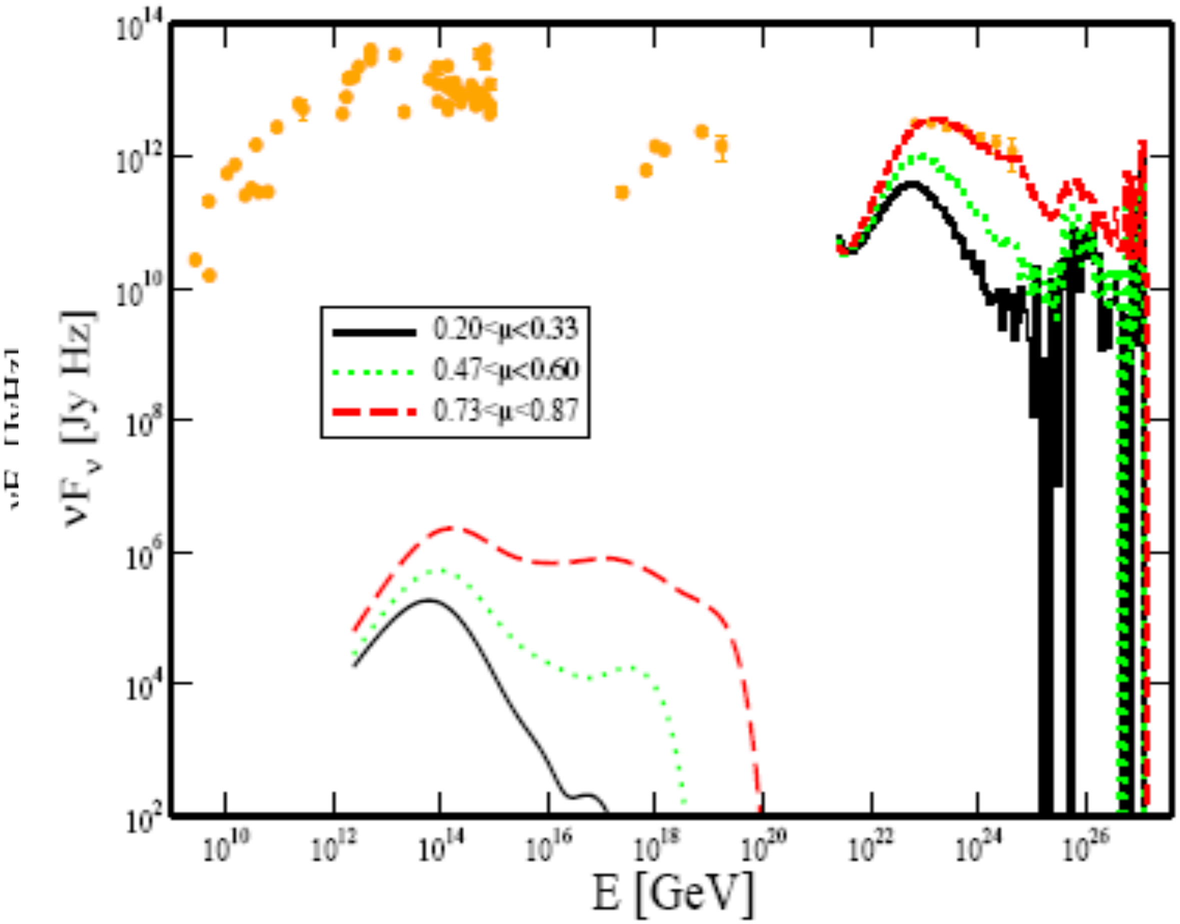
h & Böttcher 2011)

(Boettcher & Chiang 2002)

Application to NGC 1275

D = 74 Mpc $L_{BLR} = 1.6\mathrm{x}10^{42}$ erg/s

$\theta \approx 30^o - 55^o$ $R \lesssim$ a few parsecs.



(Roustazadeh & Böttcher 2010)

Incident (forward) γ-ray spectrum normalized to a moderately bright Fermi blazar

$U_{ext} = 5*10^{-2}$ erg/cm $^{-3}$

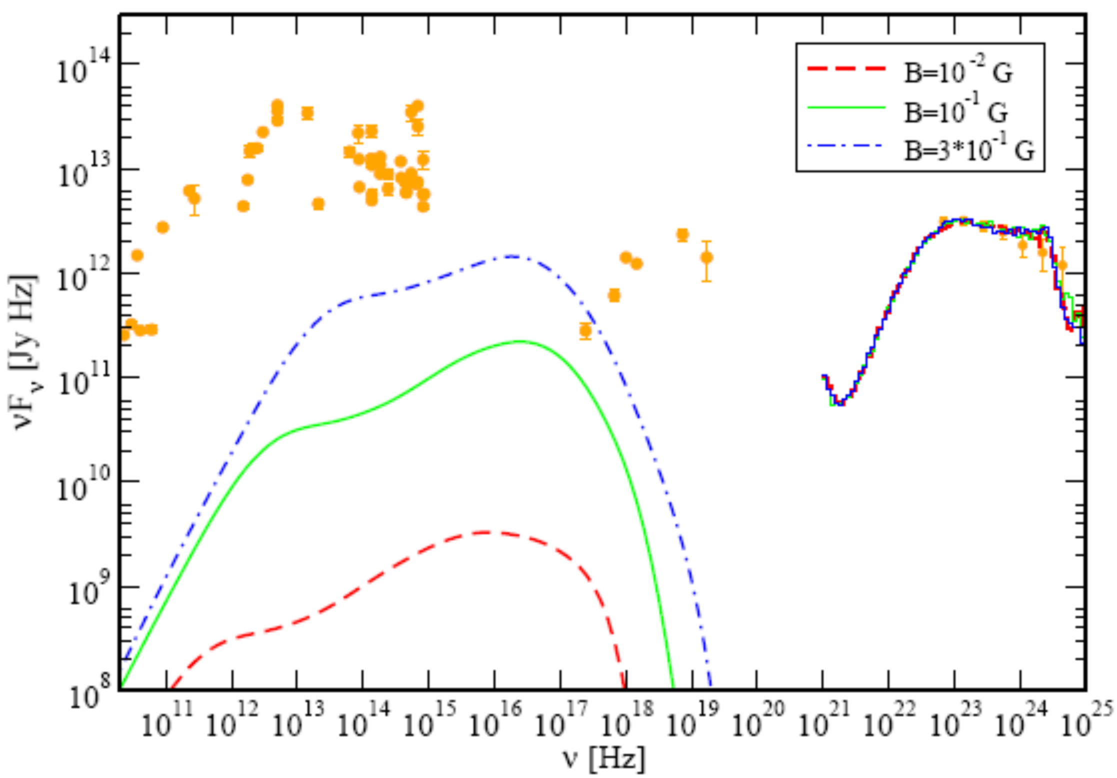
$R_{ext} = 10^{16}$ cm

$$L_{BLR} = 4\pi R^2_{ext}\, c\, u_{ext}$$

B= 1 mG, $\theta_B = 8^0$

$30^0 < \theta < 43^0$

Degeneracy of Magnetic Field for NGC 1275



$U_{ext} = 5 * 10^{-2}$ erg/cm $^{-3}$

$R_{ext} = 10^{16}$ cm

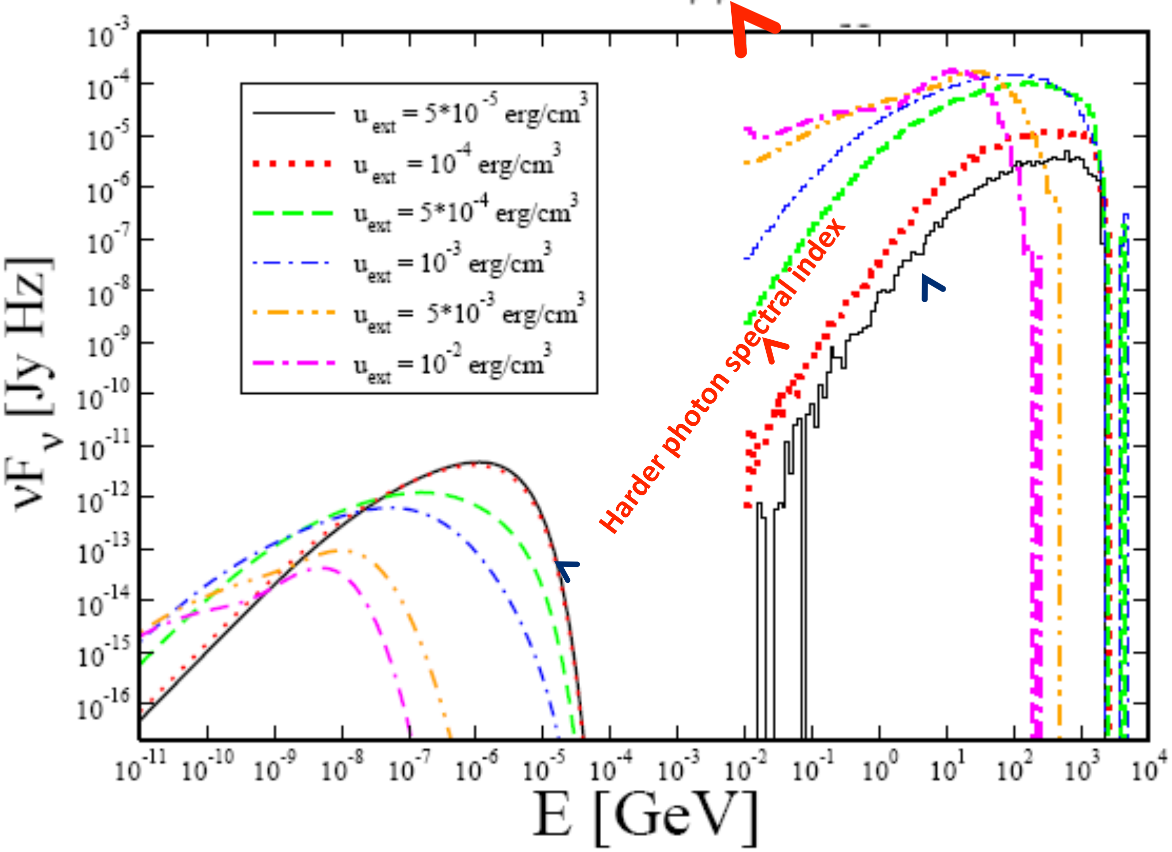
$$\mathbf{L_{BLR} = 4 \pi R^2_{ext}\, c\, u_{ext}}$$

$\theta_B = 11^0$

$67^0 < \theta < 73^0$

External Radiation Field, u_{ext}

$\tau_{\gamma\gamma} \gg 1$:



Particle escape:

$$\epsilon_{\rm esc} = \frac{9 \times 2.8\, kT\, m_e c^2\, \cos^2\theta_B}{16\, \sigma_T^2\, u_{\rm ext}^2\, R_{\rm ext}^2}$$

B = 1 μG

$\theta_B = 45^o$

$R_{ext} = 10^{16}$ cm

$T_{BB} = 1000$ K

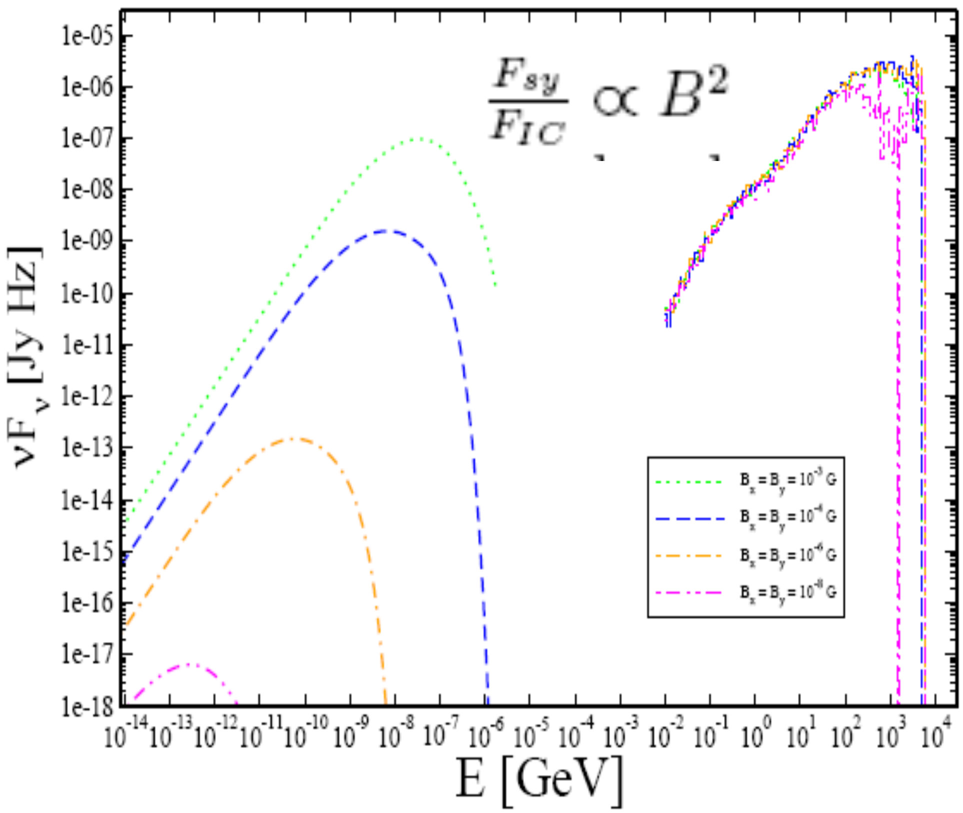
$$0.2 \leq \mu \leq 0.4$$

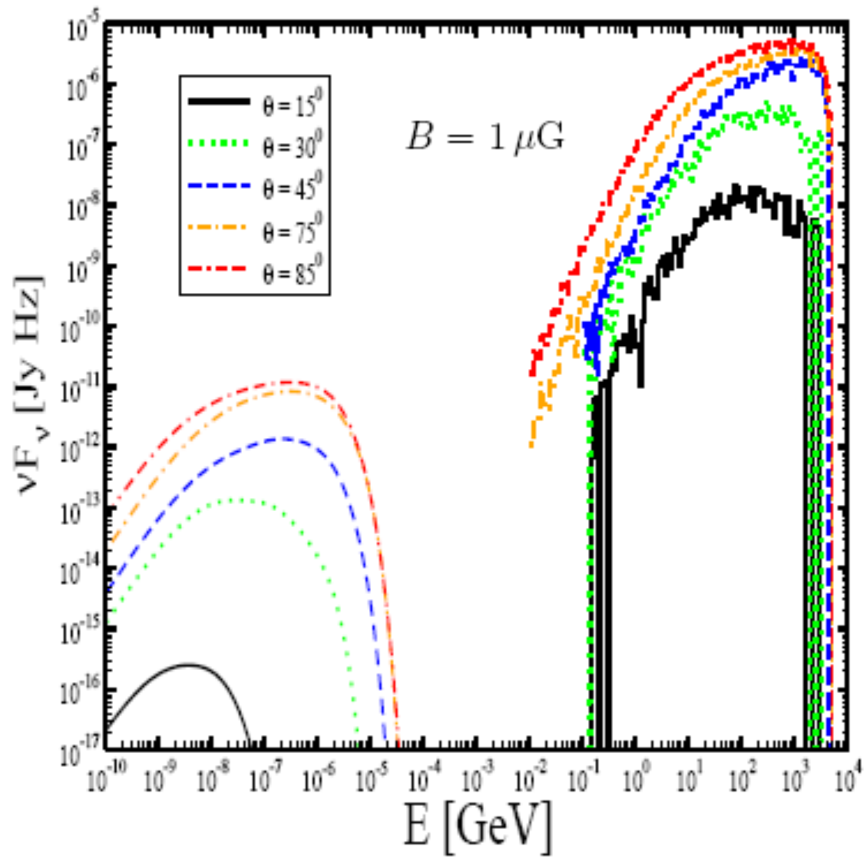
$$E_{sy,br} \cong \gamma_c^2 B m_e c^2 / B_{cr} = \frac{3 m_e c^2 e B^2}{4 \sigma_T u_{ext}\, \theta\; B_{cr}} \sim 6.15 B_{-6}^2 u_{-3}^{-1} \theta^{-1} \mathrm{meV}$$

$$E_{\rm IC,br} = \frac{3\, e\, B}{4\, \sigma_T\, u_{\rm ext}\, \theta} E_s \;\sim\; 1.3\; B_{-3}\, u_{-5}^{-1}\, T_3\, \theta^{-1}\; {\rm GeV}.$$

$$\frac{F_{sy}}{F_{IC}} \propto u_{\rm ext}^{-1}:$$

Effect of Magnetic Field B



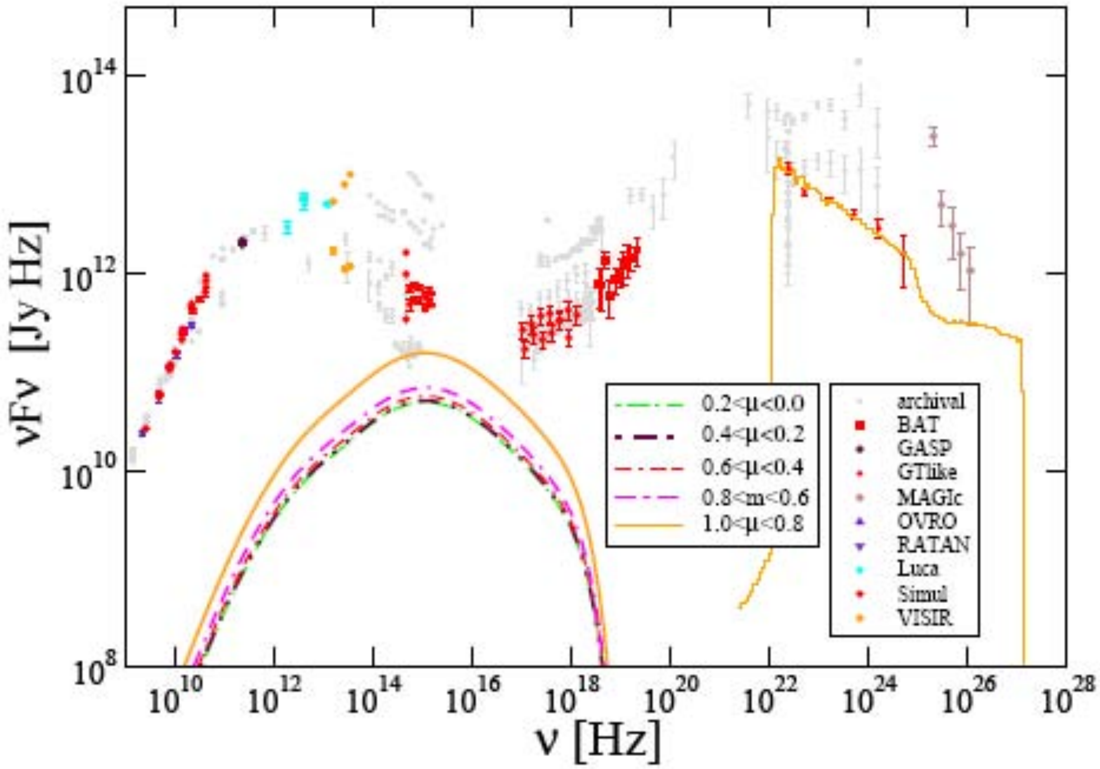


Perpendicular magnetic field component is responsible for the isotropization and for synchrotron output.

Big Blue Bump In 3C 279

Z= 0.536

$\theta < 0.5^0$



$U_{ext} = 10^{-4}$ erg/cm $^{-3}$

$R_{ext} = 5*10^{17}$ cm

$B = 10^{-2}$ G

$\theta_B = 85^0$

T= 2000 K

Alternative explanation for BBB?

(Roustazadeh & Böttcher, submitted)

Summary

1- Leptonic models prefer external-Compton over SSC in non-HBL blazars -> VHE γ-ray emission in intense external radiation fields -> $\gamma\gamma$ absorption (detectable by Fermi+CTA)-> Compton supported pair cascades.

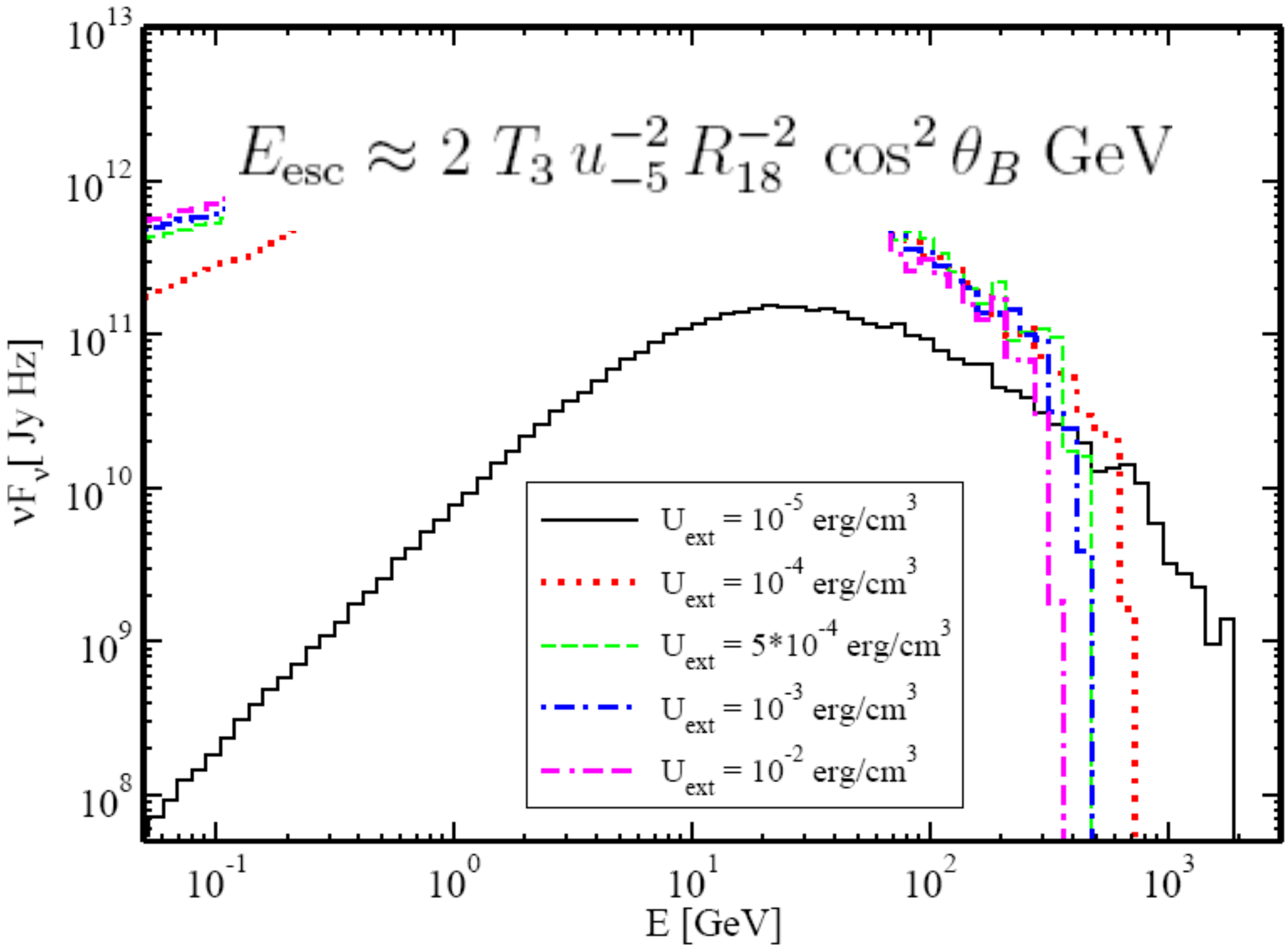
2 - VHE gamma-ray induced cascades are effectively isotropized even in weak perpendicular (B_y) magnetic fields ($B_y \sim \mu G$) -> MeV- GeV gamma-ray flux in directions misaligned with respect to the jet axis.

3 - Fermi detections of radio galaxies (NGC 1275, Cen A) can be modeled as off-axis VHE gamma-ray induced pair cascade emission.

4- Magnetic field can only be determined if synchrotron emission observed as well.

5- Cascade synchrotron emission could mimic BBB.

External Radiation Field, u_{ext}



Viewing Angle

B = 1 mG
$\theta_B = 5^o$
$u_{ext} = 10^{-5}$ erg cm^{-3}
$R_{ext} = 10^{18}$ cm
$T_{BB} = 1000$ K