Are BL Lac jets weakly magnetised?

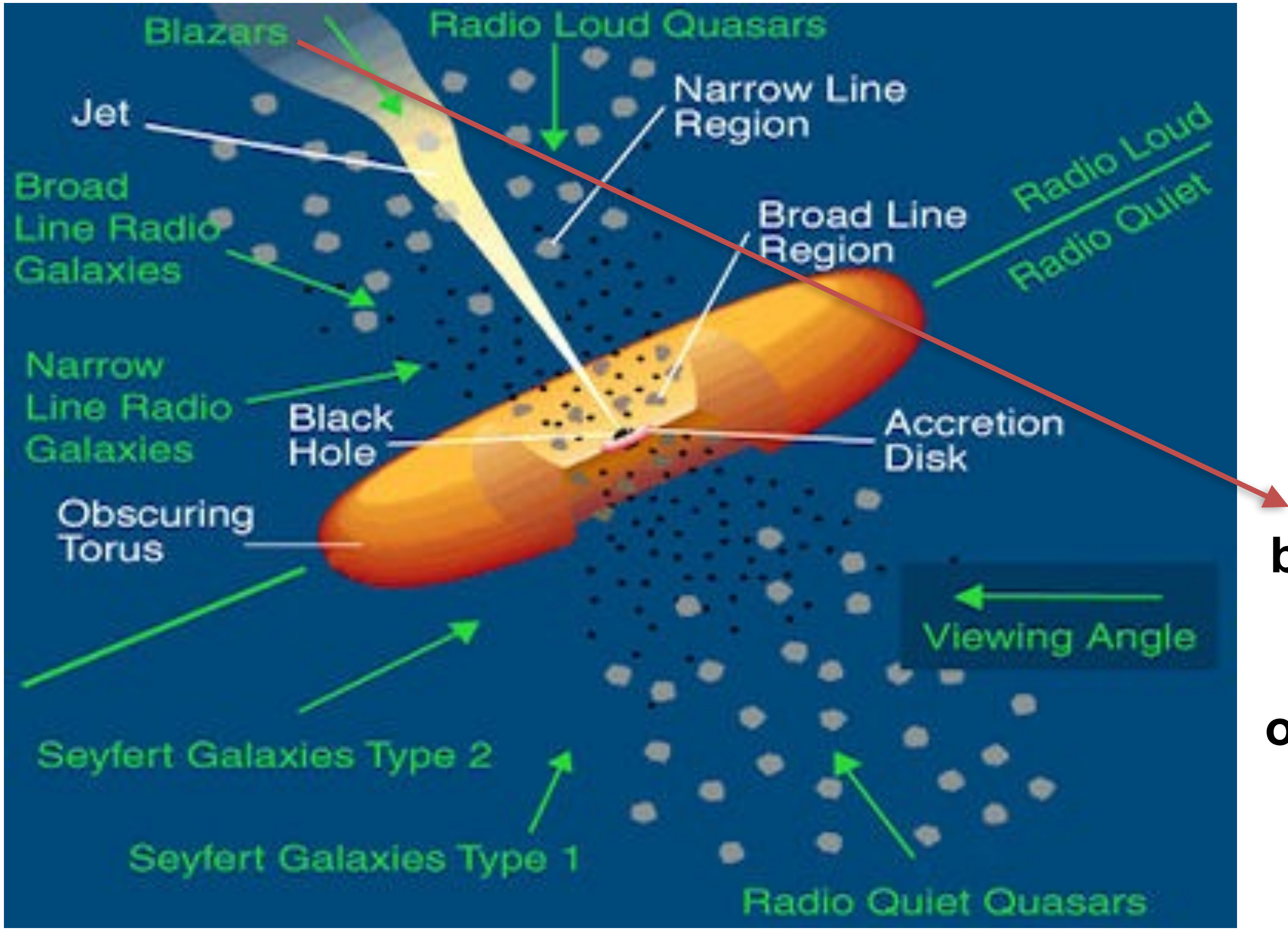
E. Sobacchi
Y. E. Lyubarsky

(2019, MNRAS, 484, 1192)

THE OPEN UNIVERSITY OF ISRAEL

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

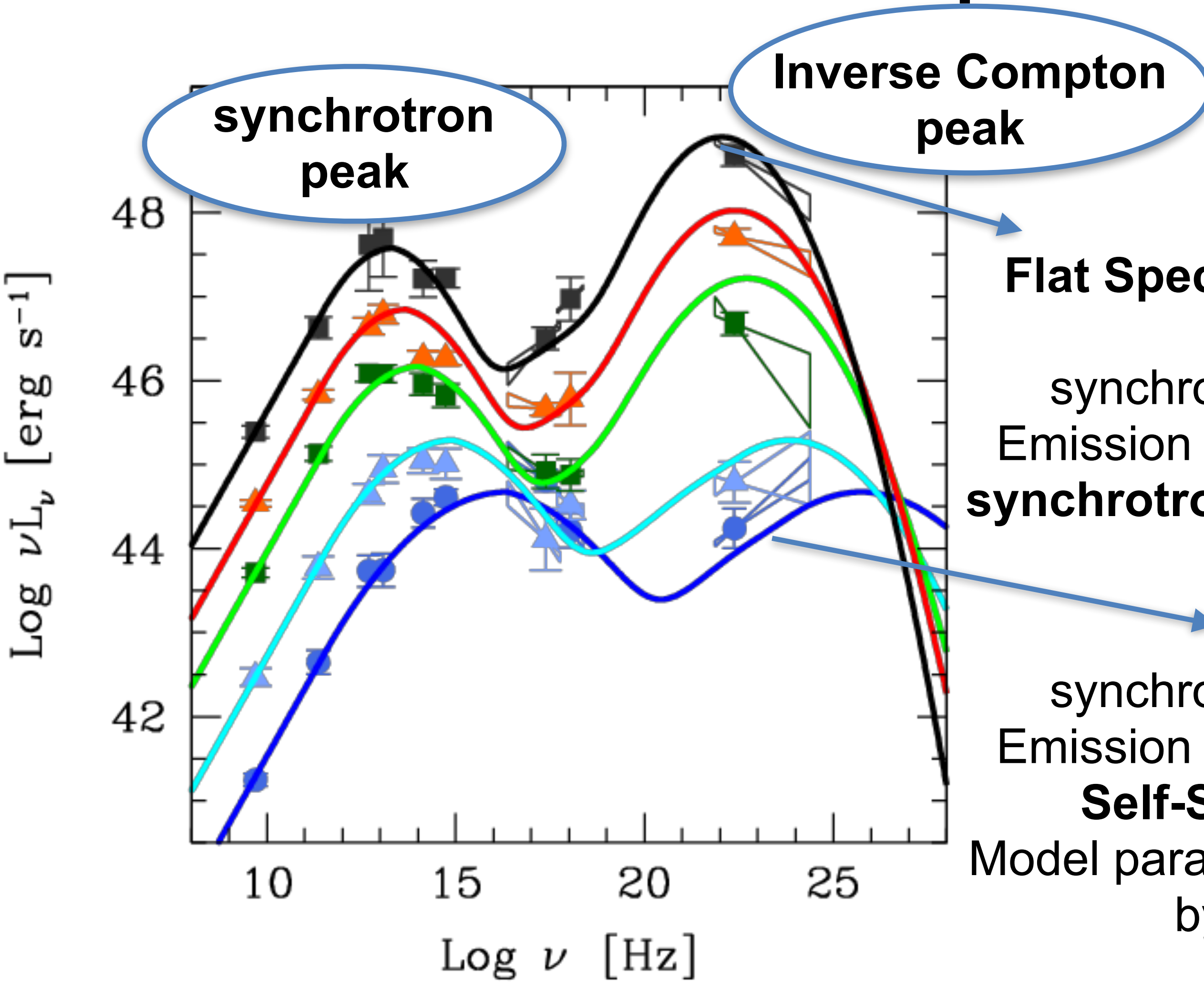
BL Lacs are a sub-class of blazars



unification scheme for Active Galactic Nuclei
(Urry & Padovani 1995)

blazars are AGN with a jet that points in the direction of the observer (radiation is strongly beamed)

The blazar sequence

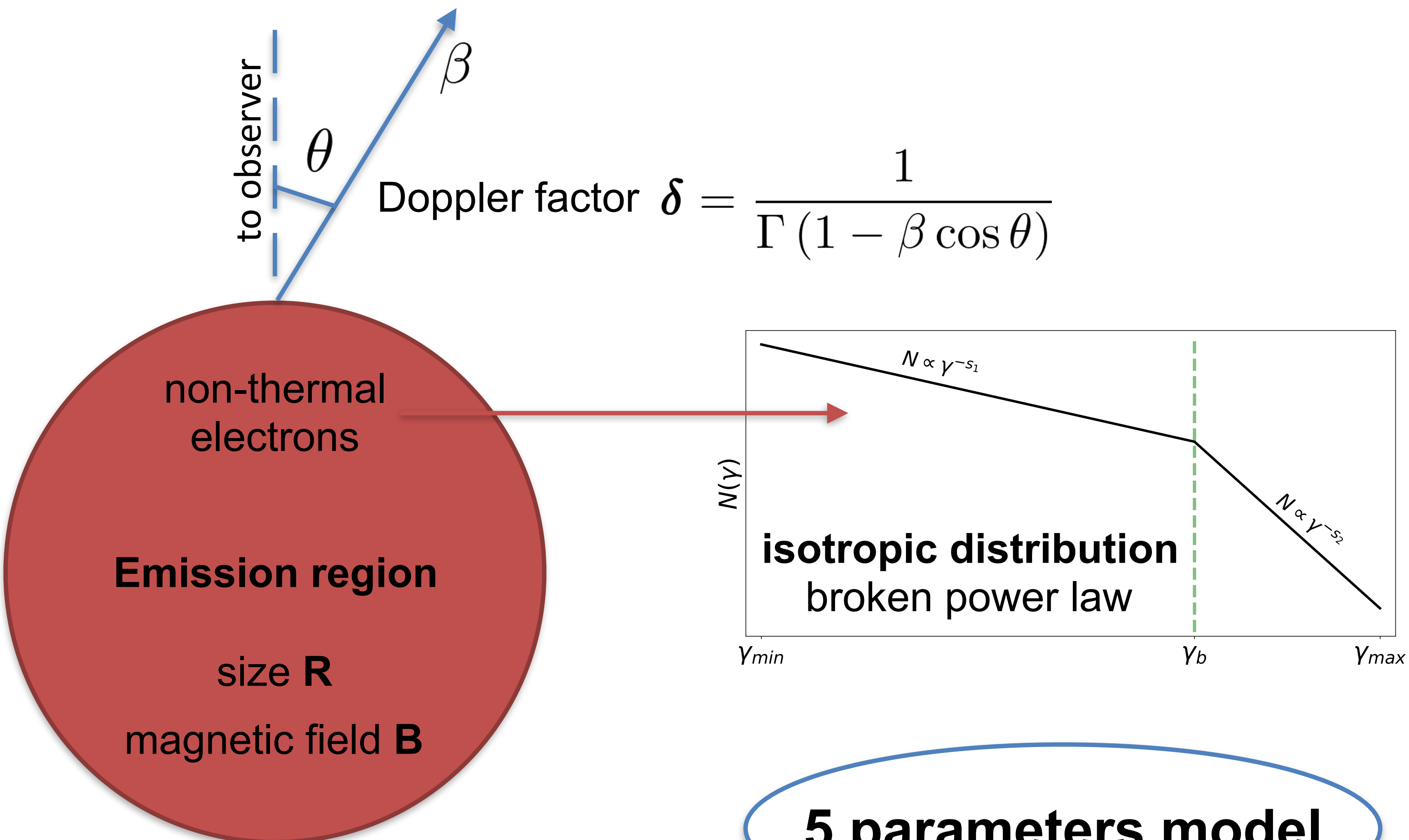


Flat Spectrum Radio Quasars (FSRQ):
synchrotron < IC luminosity
Emission mechanism most likely
synchrotron + External Compton

BL Lacs:
synchrotron ~ IC luminosity
Emission mechanism most likely
Self-Synchro-Compton
Model parameters well constrained by observations

(Fossati et al. 1998; Ghisellini et al. 2017)

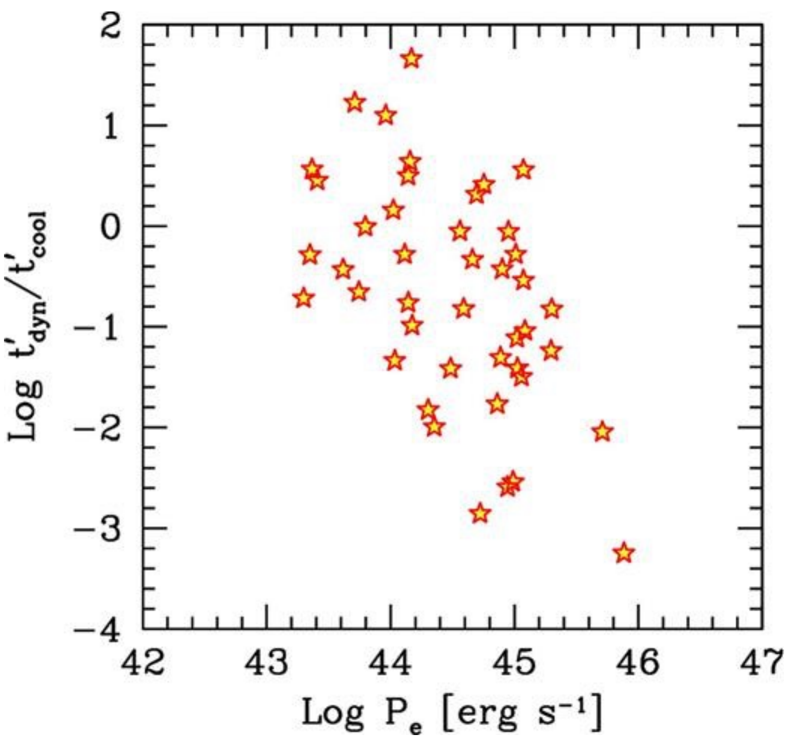
A closer look to the Self-Synchro-Compton model

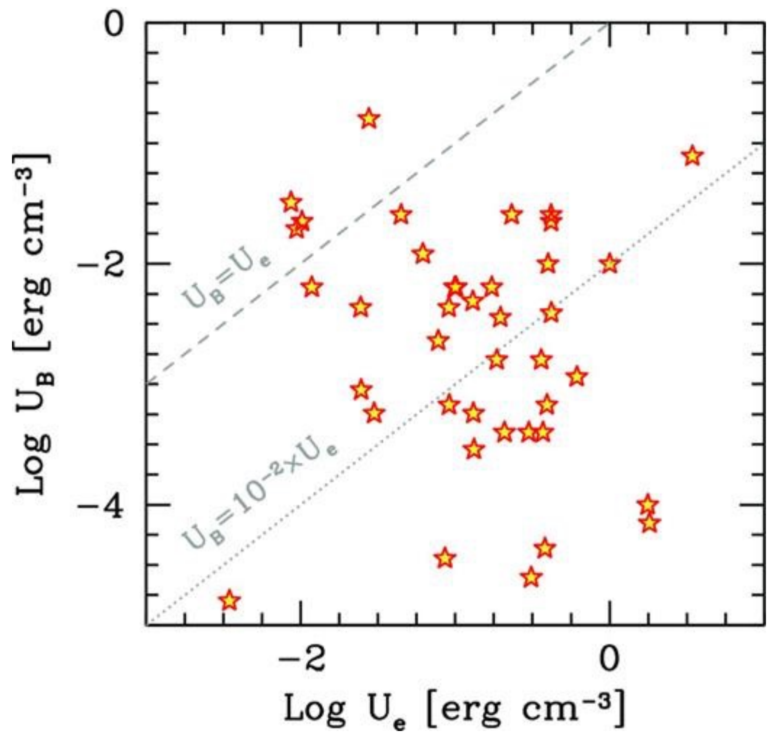


5 parameters model

Two problems with BL Lacs

Fit of the spectrum with a one-zone Self-Synchro-Compton model
(Tavecchio & Ghisellini 2016)

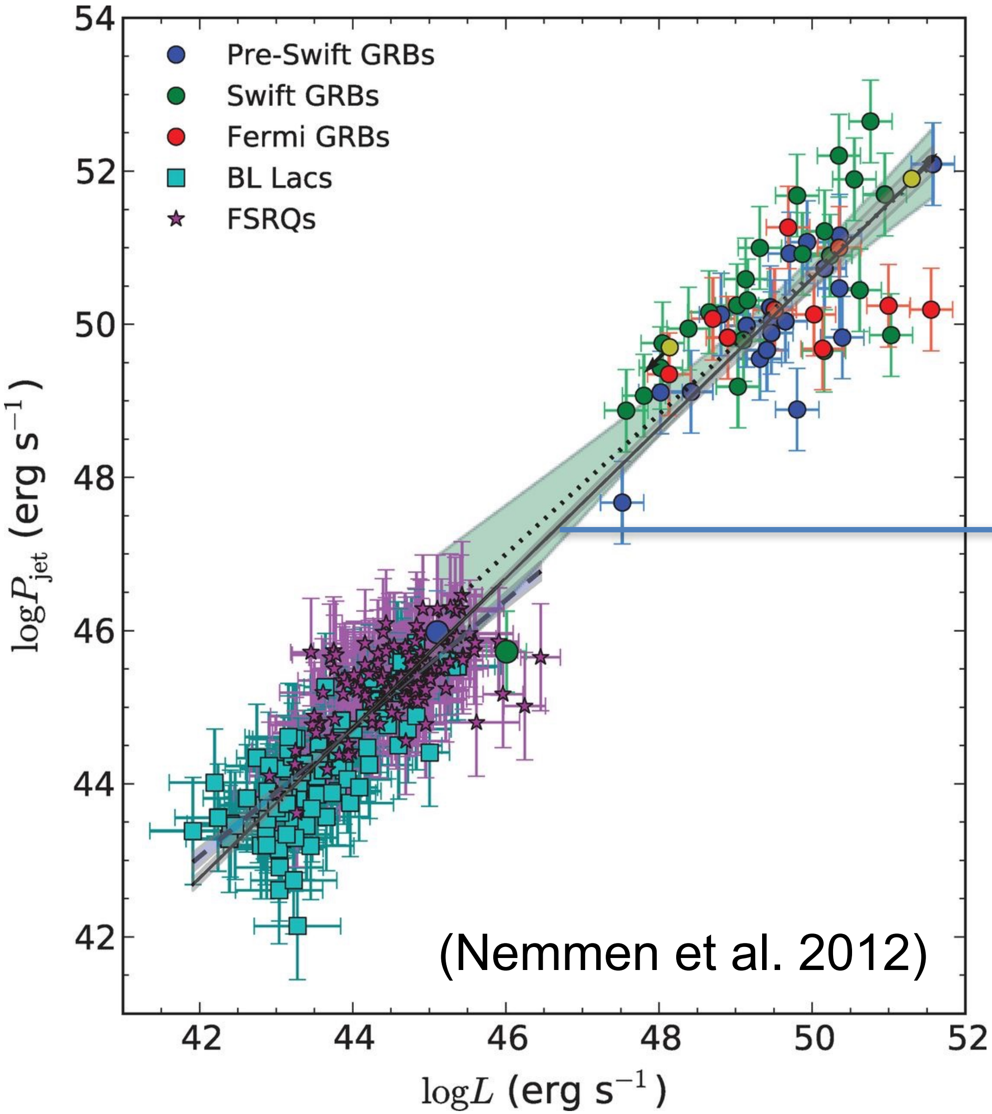




low radiative efficiency

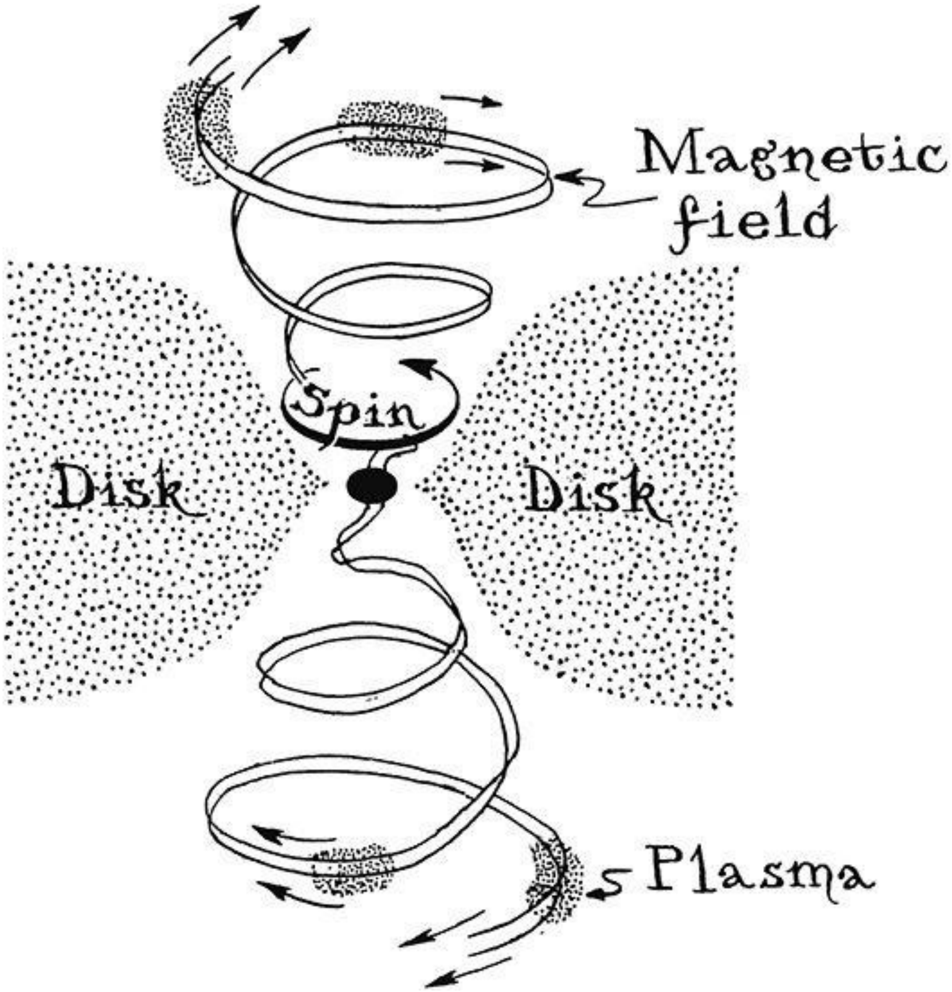
low magnetisation

Radiative efficiency of relativistic jets



Best fit suggests
high radiative efficiency
Radiative efficiency is universal

Magnetisation of the emission region



(Blandford & Znajek 1977)

Extraction of rotational energy
from the black hole
via electromagnetic stresses

At the launching point the jet is
Poynting dominated

The jet remains
Poynting dominated
at the dissipation distance
(e.g. Lyubarsky 2010)

Problem with SSC model may be assuming isotropic momentum distribution of the non-thermal electrons

Problem with SSC model may be assuming isotropic momentum distribution of the non-thermal electrons

Since the particle Larmor radius is much smaller than the size of the system,
the energy may be brought down to the dissipation scale
by a **turbulent MHD cascade**

Problem with SSC model may be assuming isotropic momentum distribution of the non-thermal electrons

Since the particle Larmor radius is much smaller than the size of the system, the energy may be brought down to the dissipation scale by a **turbulent MHD cascade**

MHD turbulence dissipated through **reconnection with a strong guide field,** which leads to **longitudinal particle heating**. The initial **momentum distribution** might be **strongly elongated** in the direction of the background magnetic field (e.g. Thompson 2006)

Problem with SSC model may be assuming isotropic momentum distribution of the non-thermal electrons

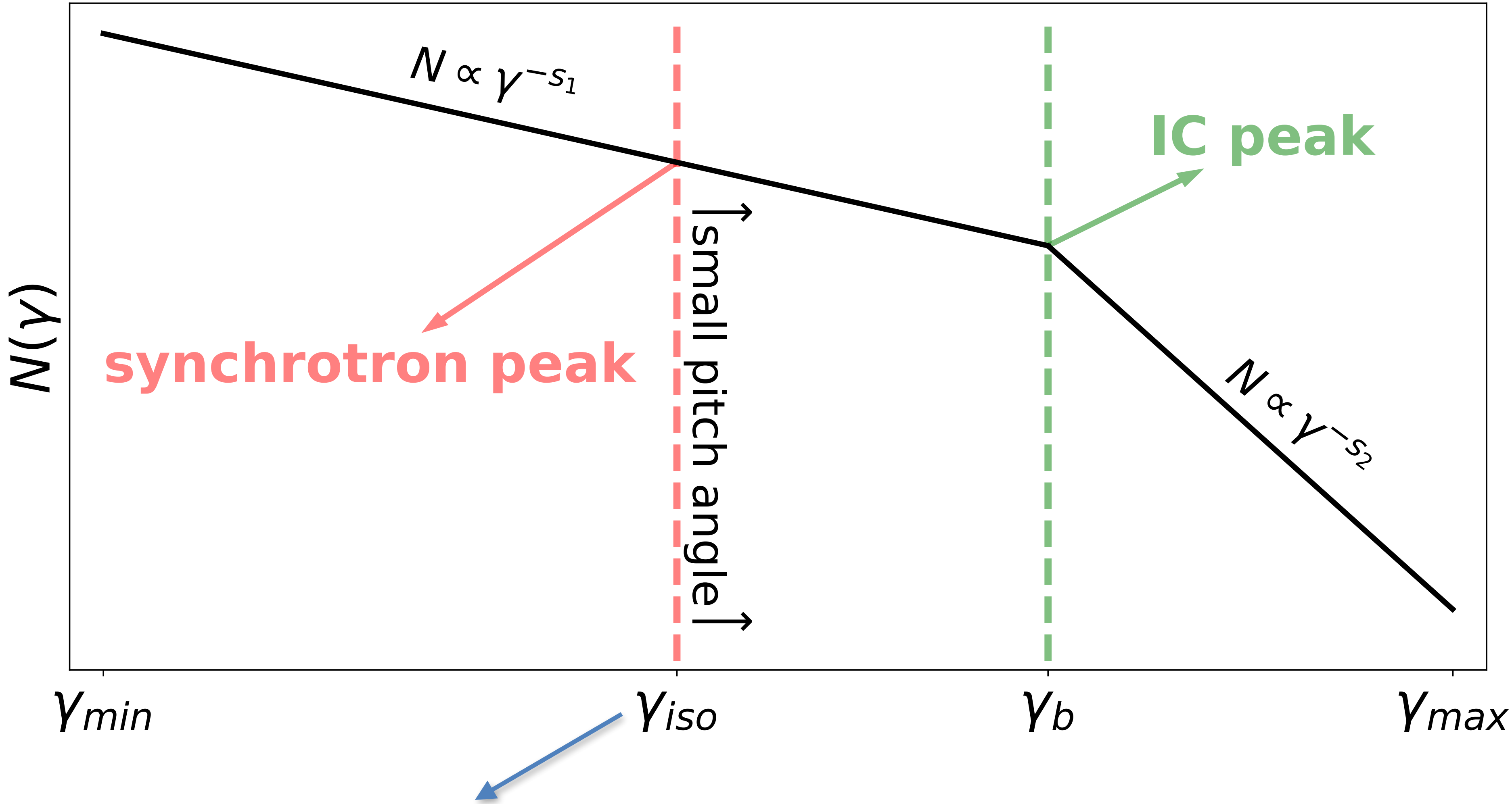
Since the particle Larmor radius is much smaller than the size of the system, the energy may be brought down to the dissipation scale by a **turbulent MHD cascade**

MHD turbulence dissipated through **reconnection with a strong guide field,** which leads to **longitudinal particle heating**. The initial **momentum distribution** might be **strongly elongated** in the direction of the background magnetic field (e.g. Thompson 2006)

Gyro-resonant scattering by Alfvén waves in **electron-positron-ion** plasma:

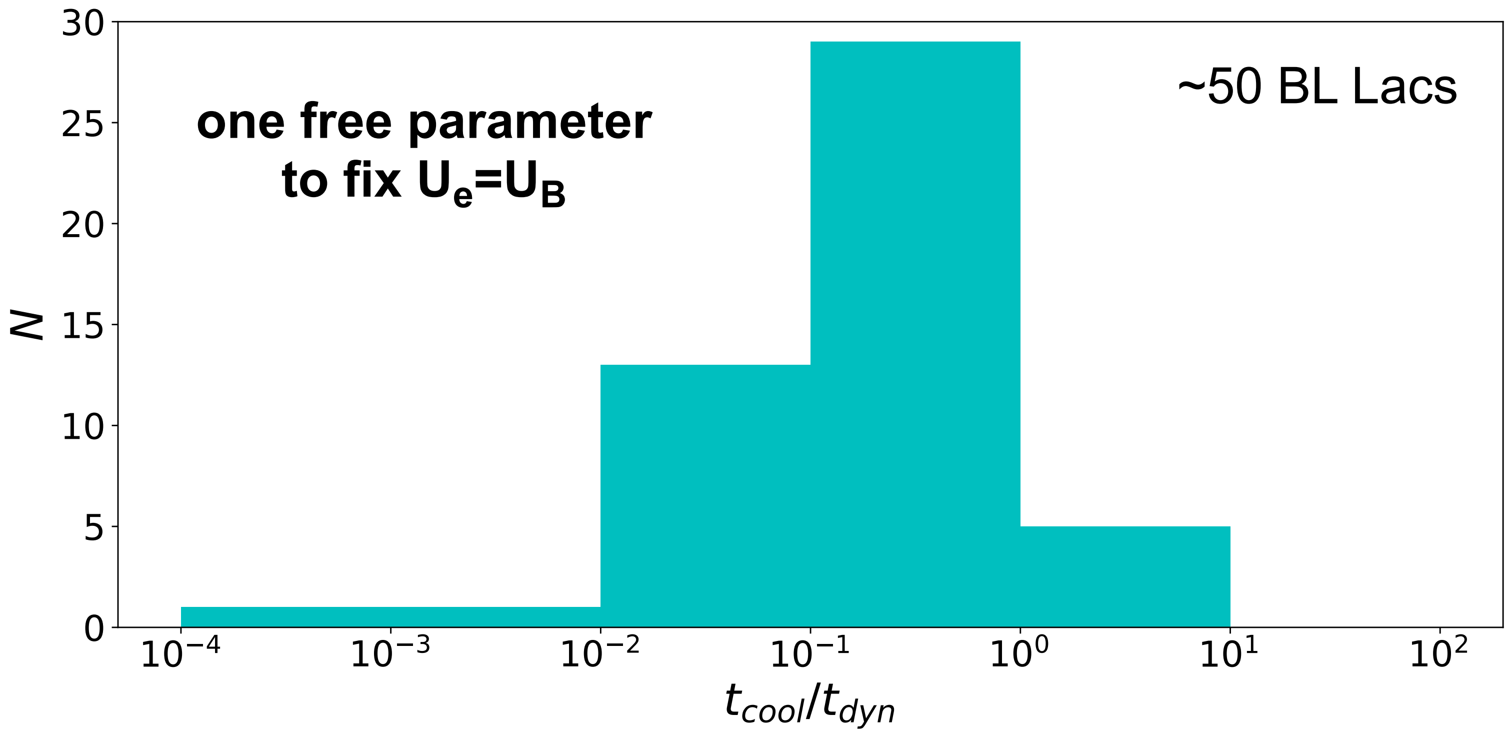
momentum of low energy electrons is isotropised, **while high energy electrons remain anisotropic**

An anisotropic model for the electron momentum distribution



one more free parameter than the usual isotropic model; we expect $\gamma_{\rm iso} \gtrsim m_p/m_e$

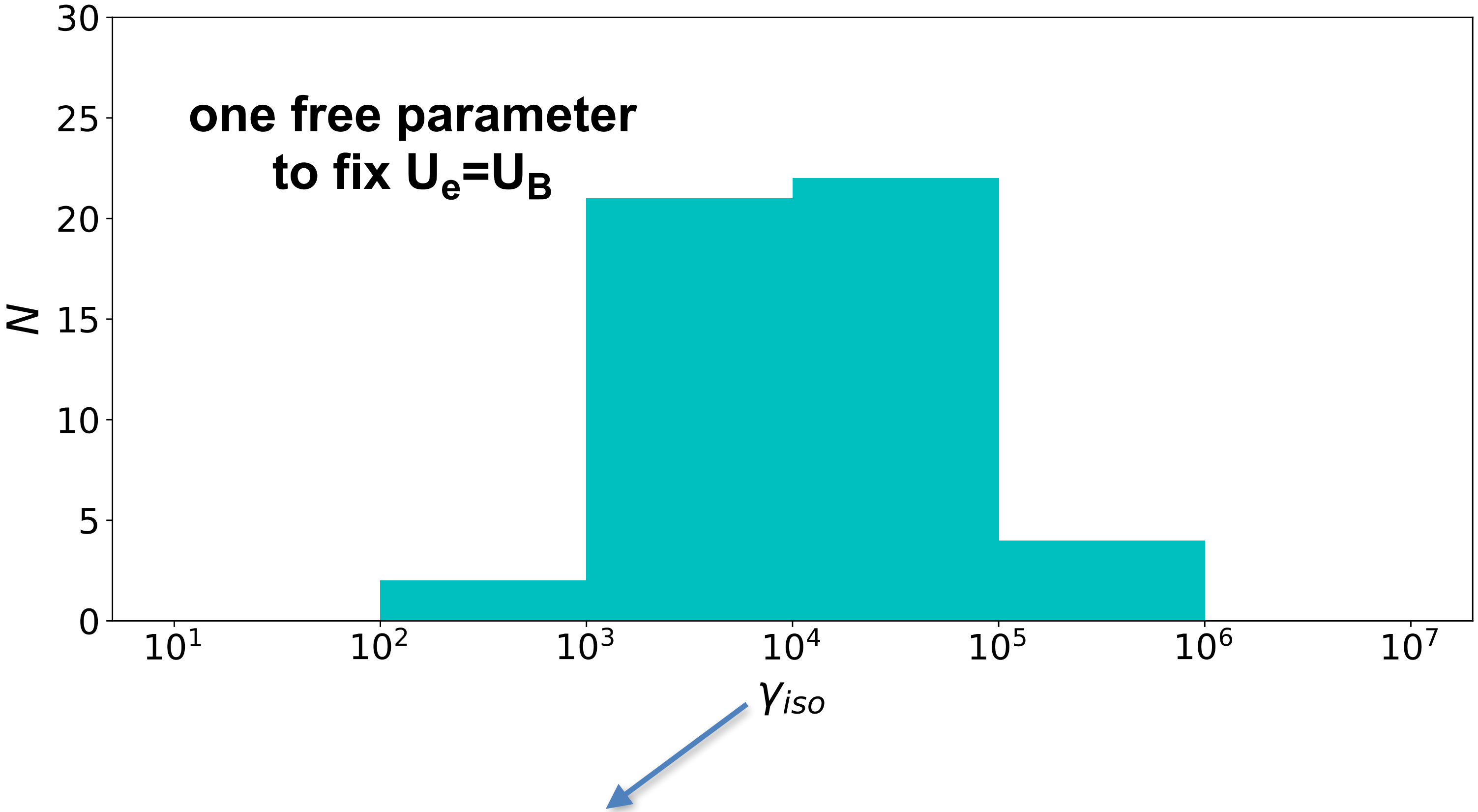
An anisotropic model with energy equipartition



Assuming that $U_e=U_B$ guarantees a **high radiative efficiency**

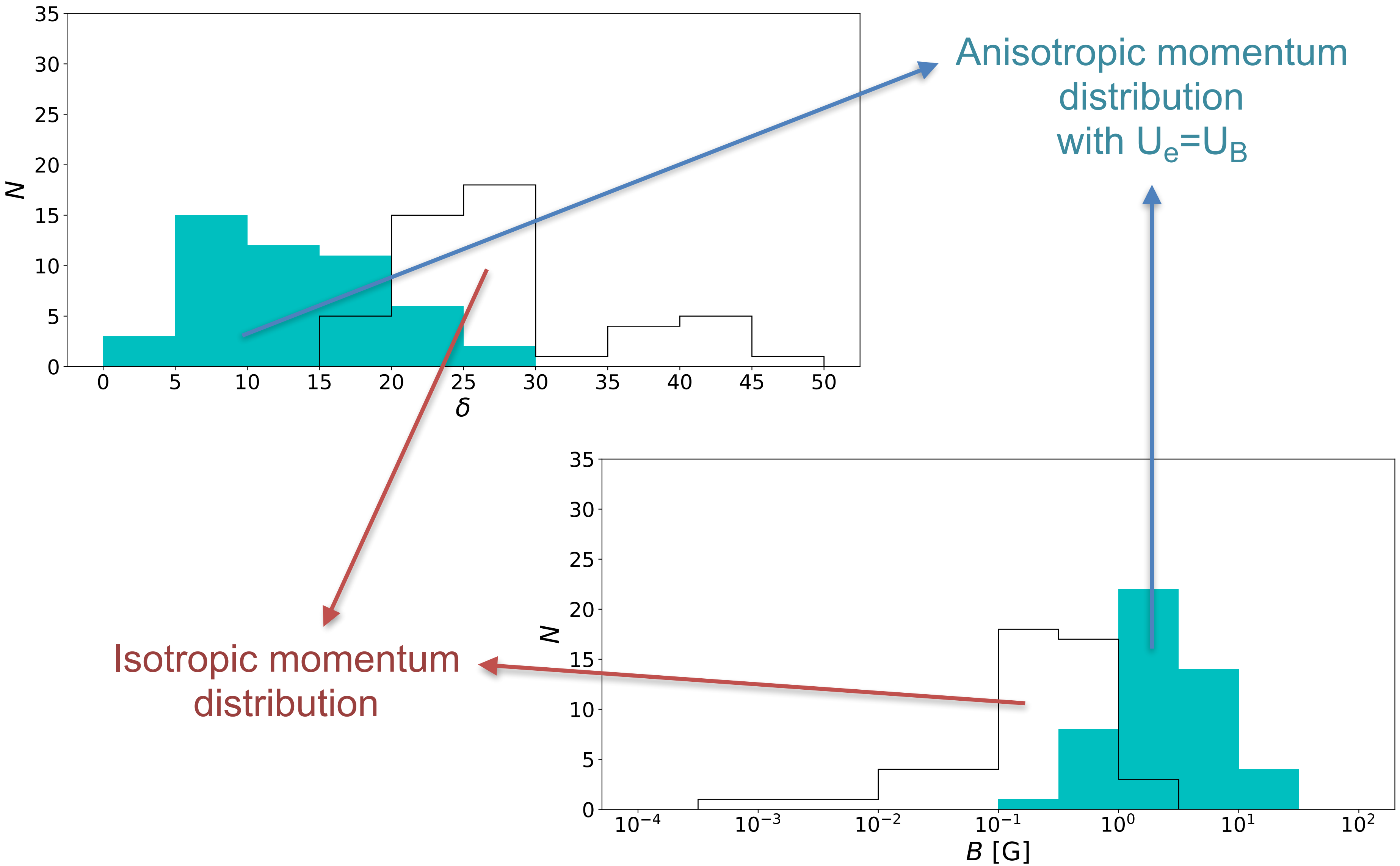
Natural interpretation of the **energy spectral break due to cooling**

An anisotropic model with energy equipartition

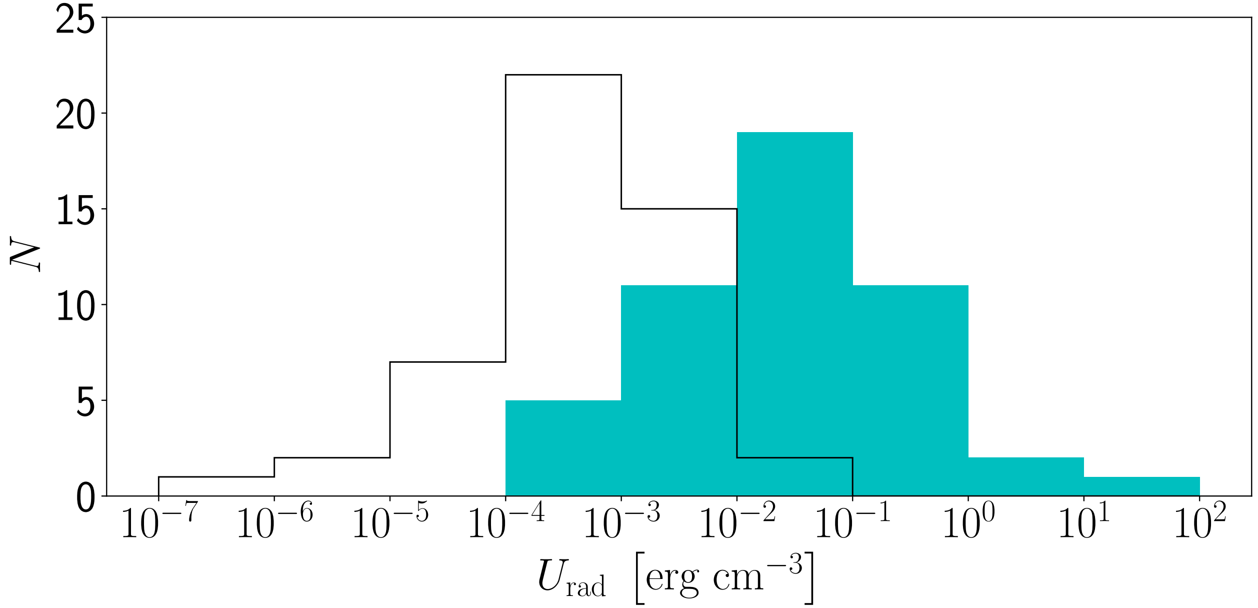


Free parameter in good agreement with the prediction that $\gamma_{\rm iso} \gtrsim m_p/m_e$

Comparison between the physical parameters



Connection with the production of neutrinos?



$$U_{\rm rad} = \frac{L_{\rm s}}{4\pi R^2 c \delta^4}$$

The radiation energy density in the emitting region is a factor ~100 higher
Production of neutrinos by BL Lacs more efficient than expected?

Conclusions

Momentum distribution of non-thermal electrons in BL Lacs may be anisotropic.
If the magnetic energy is dissipated via a turbulent MHD cascade,
the most energetic electrons may retain small pitch angles

Possible to construct an anisotropic model for the electron momentum distribution such that:

1. **energy equipartition** between the non-thermal electrons and the magnetic fields
2. bulk of the electrons cool in a dynamical time (**high radiative efficiency**)

Higher radiation energy density in the emitting region.
Possible implications for the production of neutrinos by BL Lacs?

Extra

Momentum isotropisation in a highly magnetised plasma

Wave-particle interaction at the resonances

$$\omega - \mathbf{k}\cdot\mathbf{v} \sim n\Omega_{\mathrm{L}}$$

Scattering + wave emission at the anomalous cyclotron resonance $n = -1$

The resonant particles and the wave are moving in the same direction
Pitch angle diffusion due to scattering
decreases the linear momentum of the particles,
and increases the linear momentum of the wave

Instability

Momentum isotropisation in a highly magnetised plasma

Wave-particle interaction at the resonances

$$\omega - \mathbf{k} \cdot \mathbf{v} \sim n\Omega_{\mathrm{L}}$$

Scattering + wave emission at the anomalous cyclotron resonance $n = -1$

Scattering + wave absorption at the cyclotron resonance $n = 1$

The resonant particles and the wave are moving in opposite directions
Pitch angle diffusion due to scattering
increases the linear momentum of the particles,
and decreases the linear momentum of the wave

Damping

Momentum isotropisation in a highly magnetised plasma

Wave-particle interaction at the resonances

$$\omega - \mathbf{k} \cdot \mathbf{v} \sim n\Omega_{\mathrm{L}}$$

Scattering + wave emission at the anomalous cyclotron resonance $n = -1$

Scattering + wave absorption at the cyclotron resonance $n = 1$

Instability or damping
depends on the number of particles at the resonances

In electron-positron plasma waves are absorbed: elongated distribution is stable

In **electron-positron-ion** plasma short waves may be unstable:
momentum of low energy electrons is isotropised,
while the high energy electrons remain anisotropic

Is the momentum distribution of the non-thermal electrons isotropic?

The answer is probably not

The most energetic electrons may retain small pitch angles

$$\gamma_{\rm iso} \sim \left(\frac{n_p m_p}{n_e m_e}\right)^{\frac{1}{s-2}} \frac{m_p}{m_e}$$

jet composition

proton energy spectral index ($s > 2$)