Systematic Study of TeV detected BL Lacs: Jet Energetics and Particle Acceleration Efficiency in the Blazar Zone

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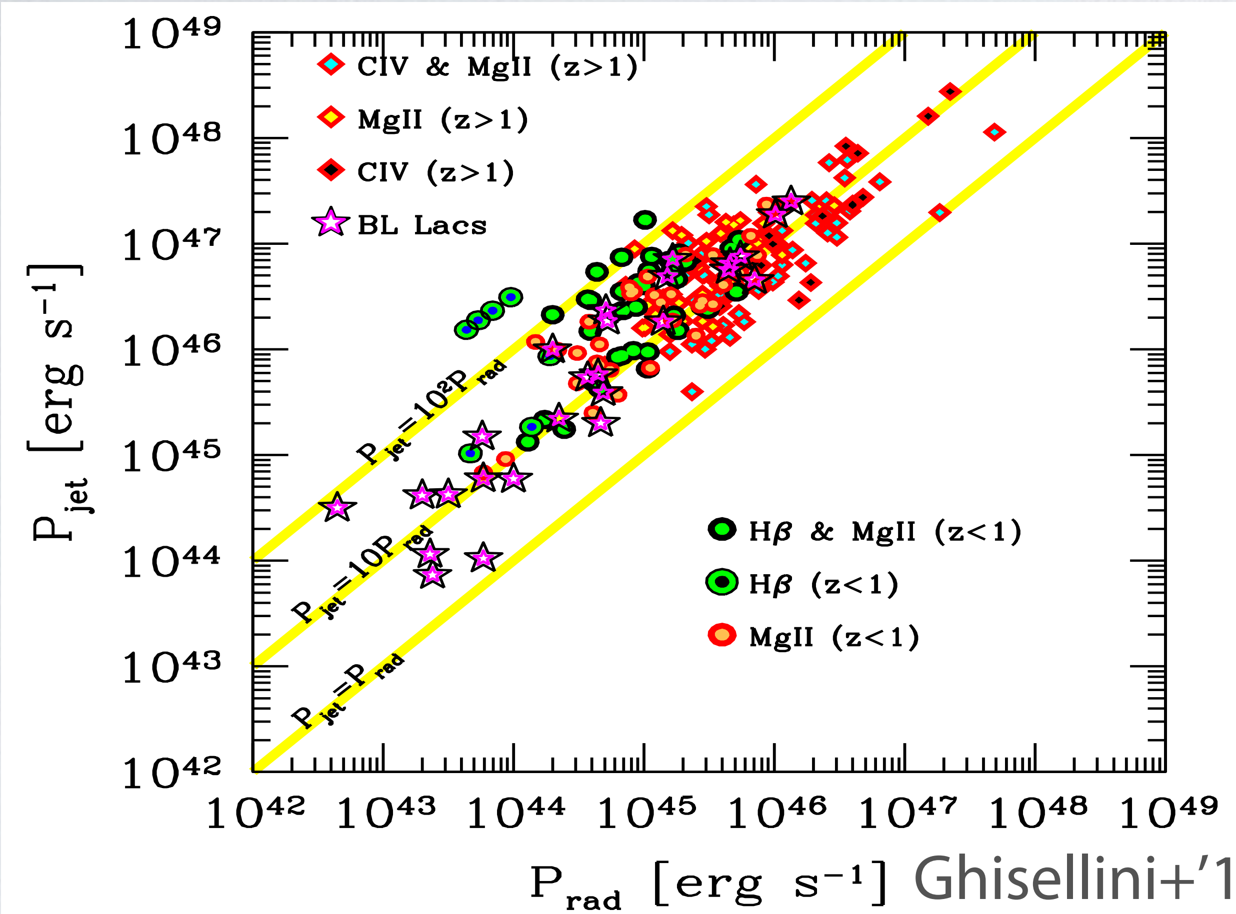
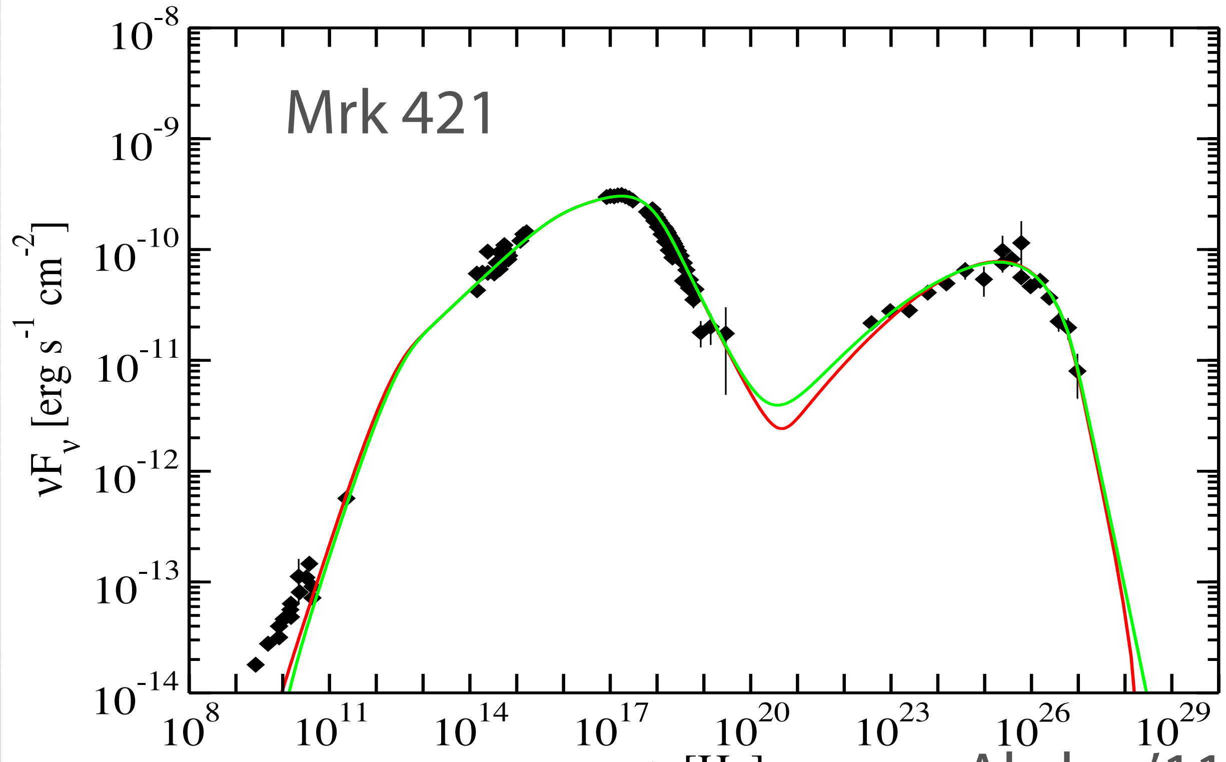
Systematic Study of Blazars



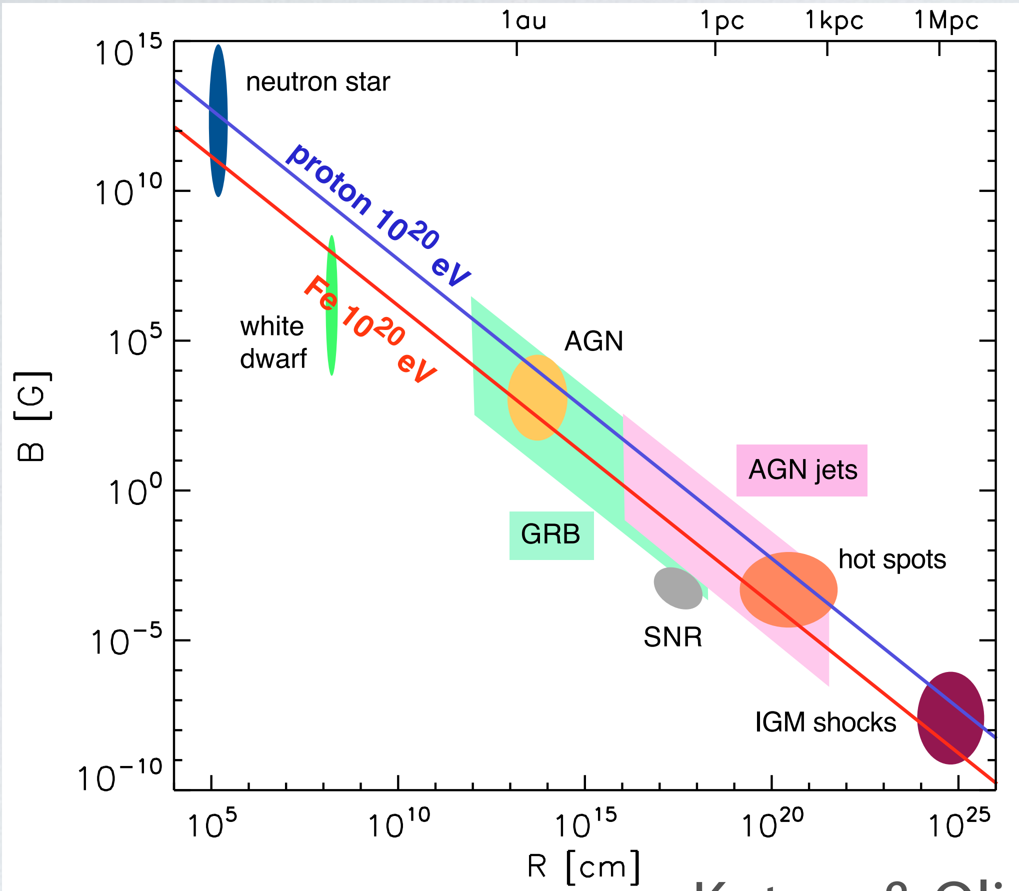
Ghisellini+'14



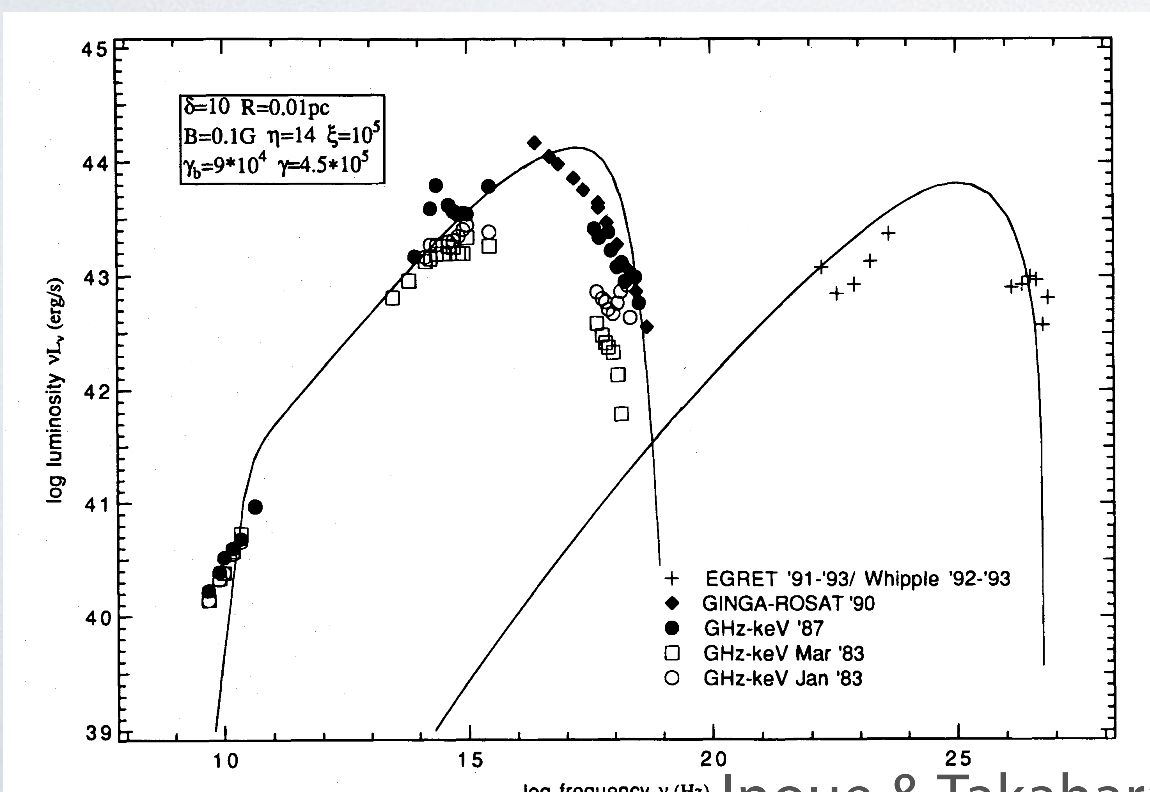
Abdo+'11

- **<u>What is AGN jet energetics?</u>**
  - Fermi allows us systematic study
    - P_{rad} ~ 0.1 P_{jet} (Ghisellini+'14)
  - but, only luminous blazars
    - ➡ HBLs: MAXI, BAT, LAT, IACTs
  - based on phenomenological models: e.g. 12 parameters for Mrk 421.
    - ➡ physically connected parameters.

Particle Acceleration Efficiency



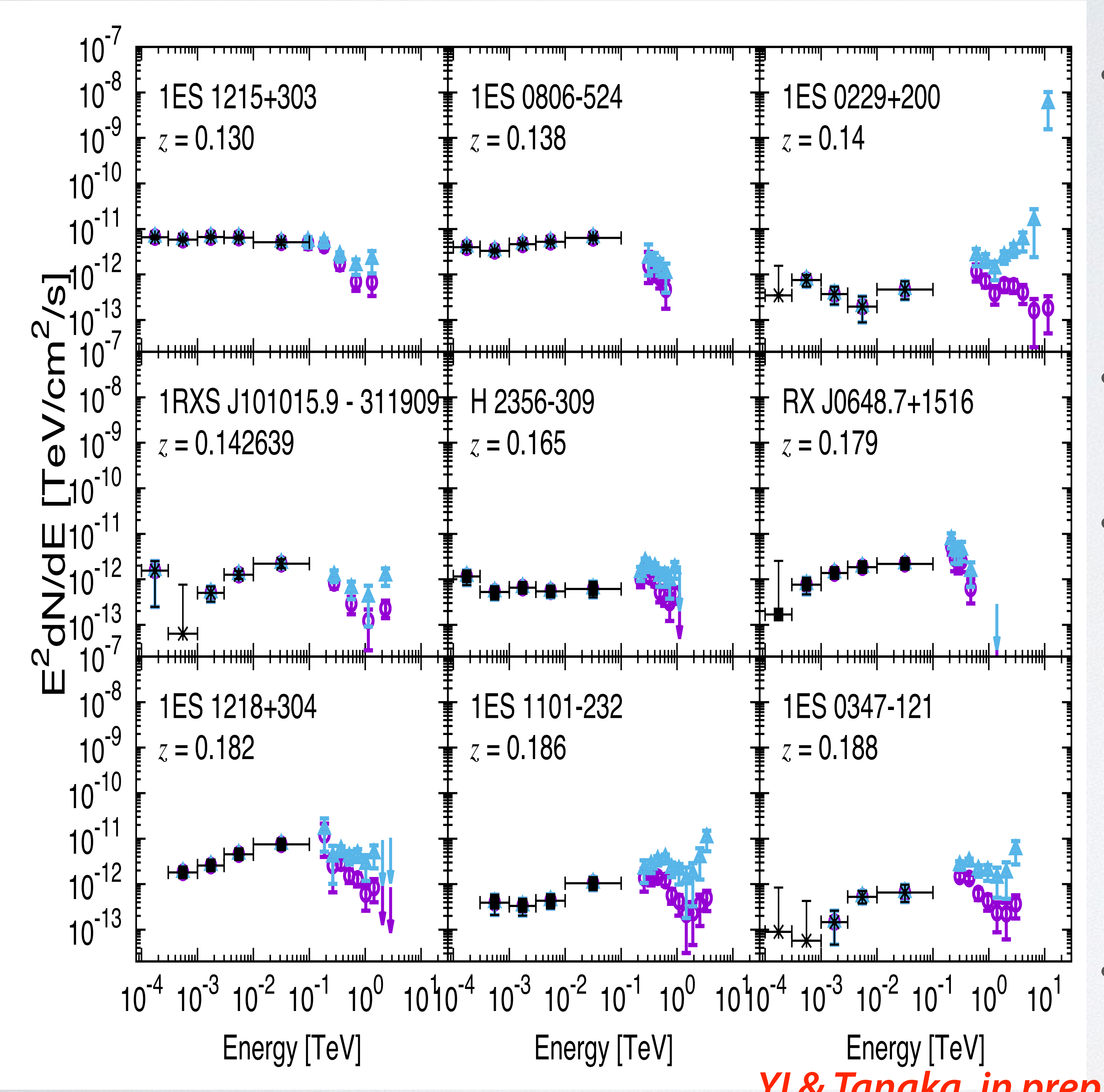
Kotera & Olinto '11



Inoue & Takahara '96

- **<u>Are AGN jets efficient particle accelerators?</u>**
  - primary candidates for UHECR acceleration sites.
    - But, particle acceleration efficiency is not well understood.
  - Past SED fittings suggested low efficiency ($\eta \sim 10^5$; Inoue & Takahara '96, Sato+'08, Finke+'08).
    - But, not simultaneous data and no systematic studies.

TeV Blazar Sample



YI & Tanaka, in prep.

- Select 36 blazars with z from the default TeVcat catalog.
- 3FGL SED data.
- Low-state data are available for 31/36.
  - 13 HBLs have BAT data.
- CIB correction by YI +'13.

Emission Modeling

- One-zone synchrotron self Compton (e.g. Finke+'08)
- Beaming factor "δ" = bulk Lorentz factor "Γ"
- Angular size of the blob "θ" = the jet opening angle "θ_j"
- $\Gamma\theta_j = 1 \rightarrow \theta = 1/\delta$
- Assume spherical emitting plasma at $r = 1000\ r_s$ from BH.
  - ~1 day variability for $M_{BH} = 10^9\ M_{sun}$ & $\delta = 10$.

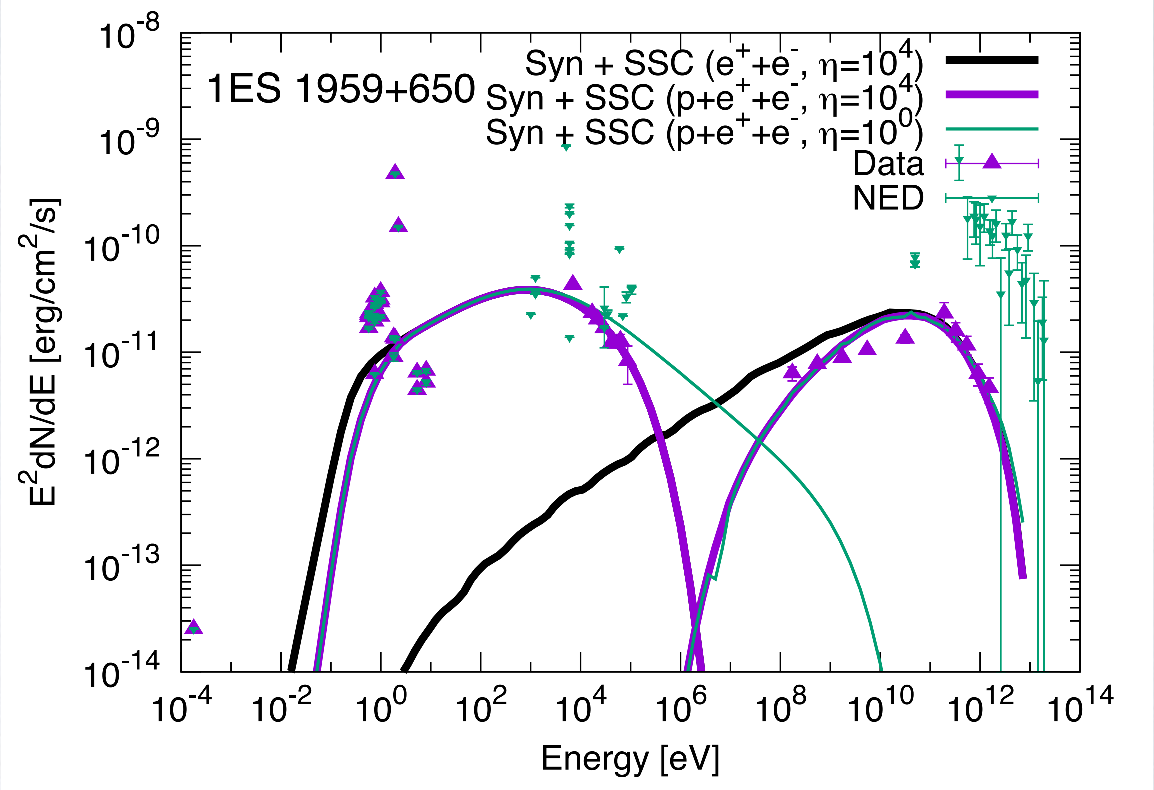
Electron Distribution

- Assume diffusive shock acceleration.
- broken-power law plus hyper-exp cutoff

$$N'_e(\gamma') = K_e \gamma_b'^{p_1} \left[\left(\frac{\gamma'}{\gamma'_b} \right)^{p_1} + \left(\frac{\gamma'}{\gamma'_b} \right)^{p_2} \right]^{-1} \exp \left[- \left(\frac{\gamma'}{\gamma_c} \right)^2 \right]$$

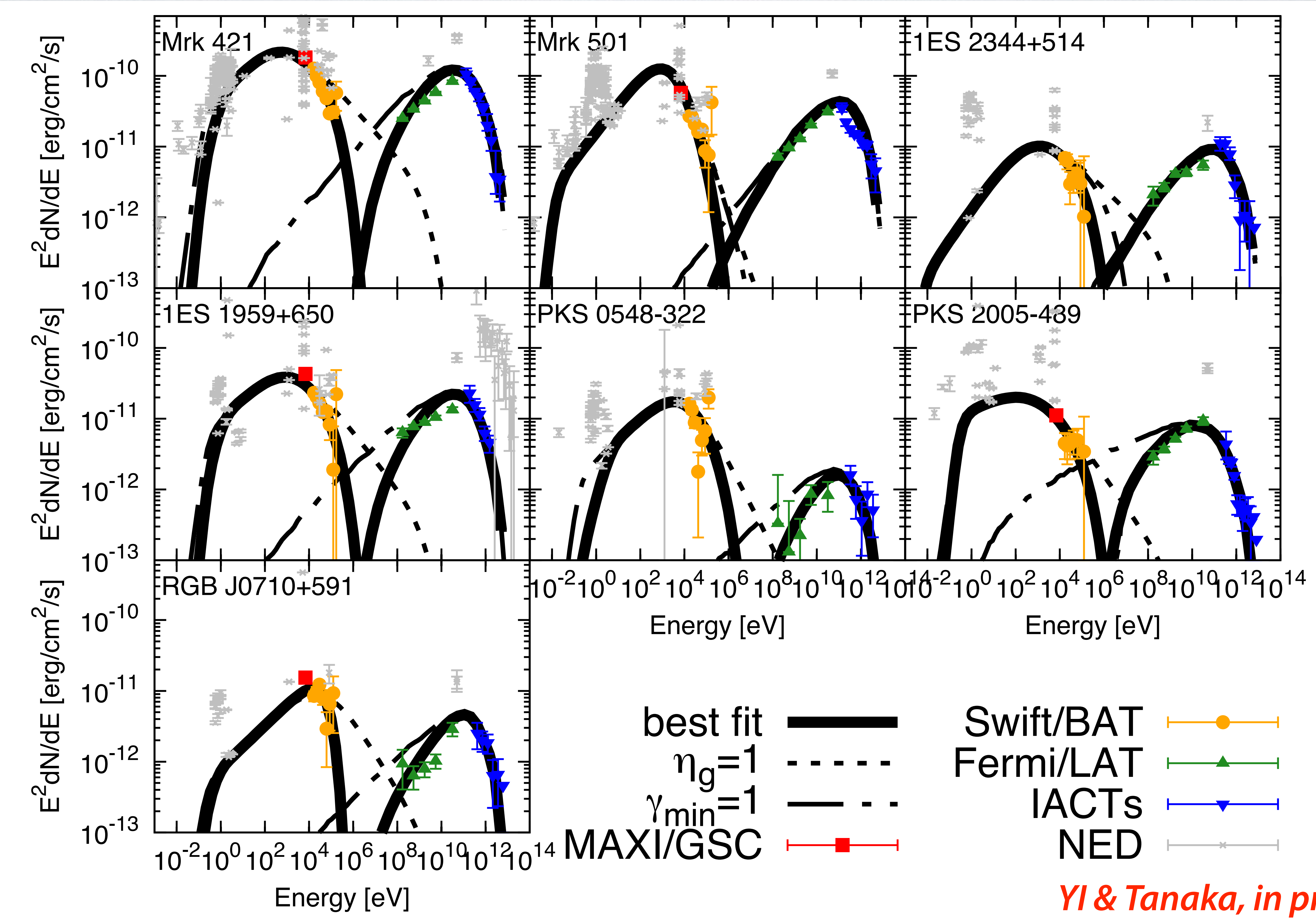
  - It should be $p_2 = p_1 + 1$. But, photon spectrum steeping can be steeper in inhomogeneous fluid (e.g. Reynolds '09).
  - By setting p_2 as a free parameter, we phenomenologically consider inhomogeneity of the emission region.
- cooling break : syn. + SSC cooling = dynamical time.
- maximum Lorentz factor : acc. time = syn. + SSC cooling.
- minimum electron Lorentz factor is set by shocked thermal proton energy.

How to find parameters



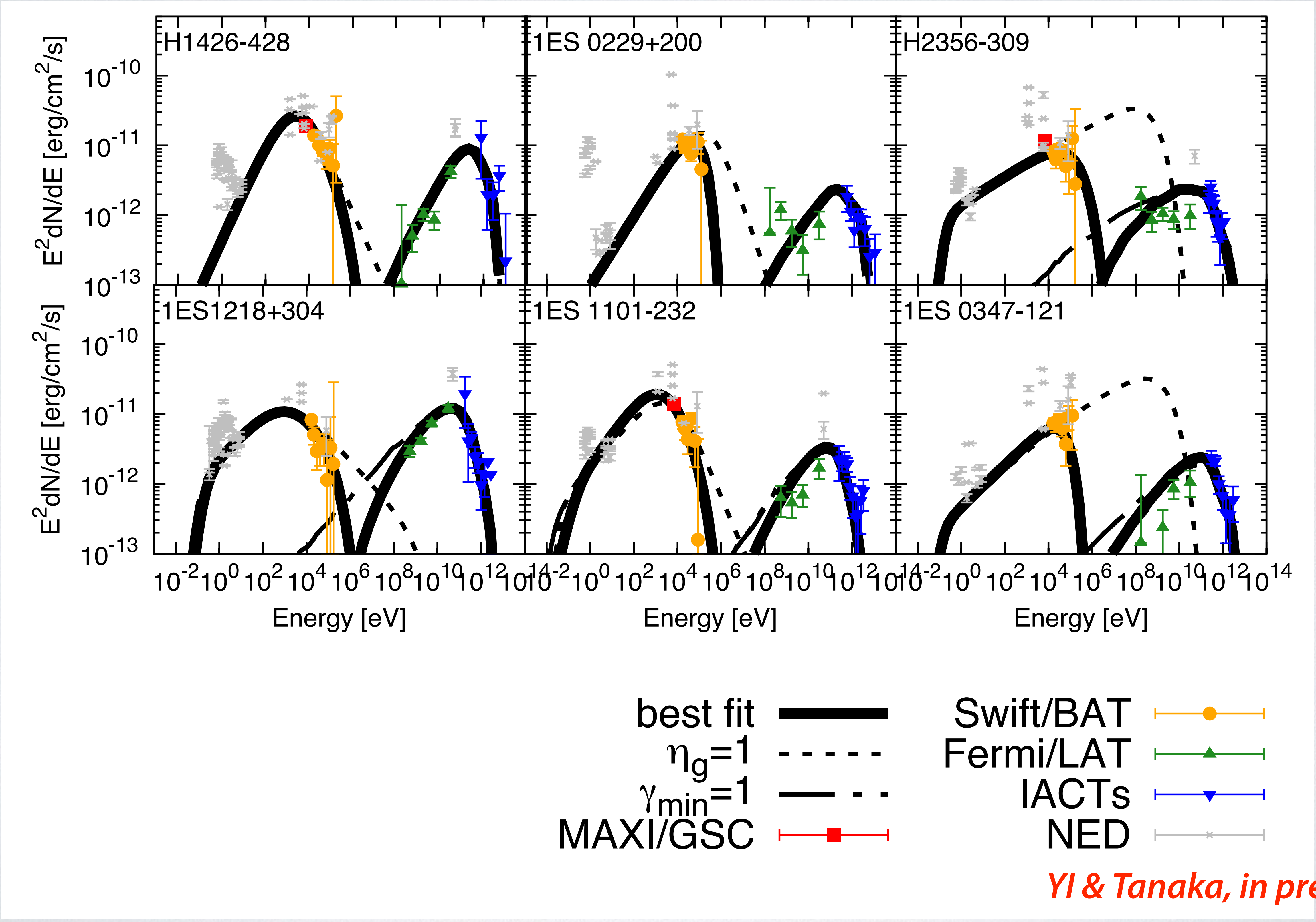
- Free parameters are
  - K_e, p_1, p_2, B, δ, η_g
- Global fit to low-state data but not including errors.
- Then, perform fit to BAT data including errors setting only η_g as a free parameter.

Spectral Fitting Results



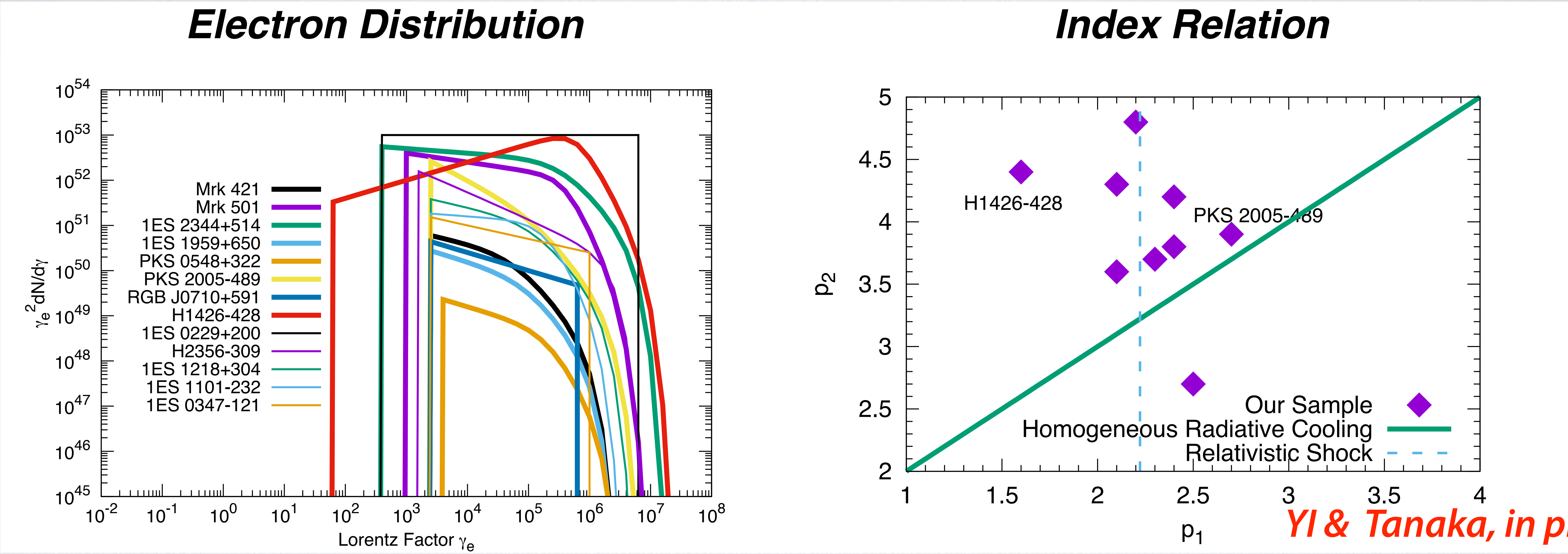
YI & Tanaka, in prep.

Spectral Fitting Results



YI & Tanaka, in prep.

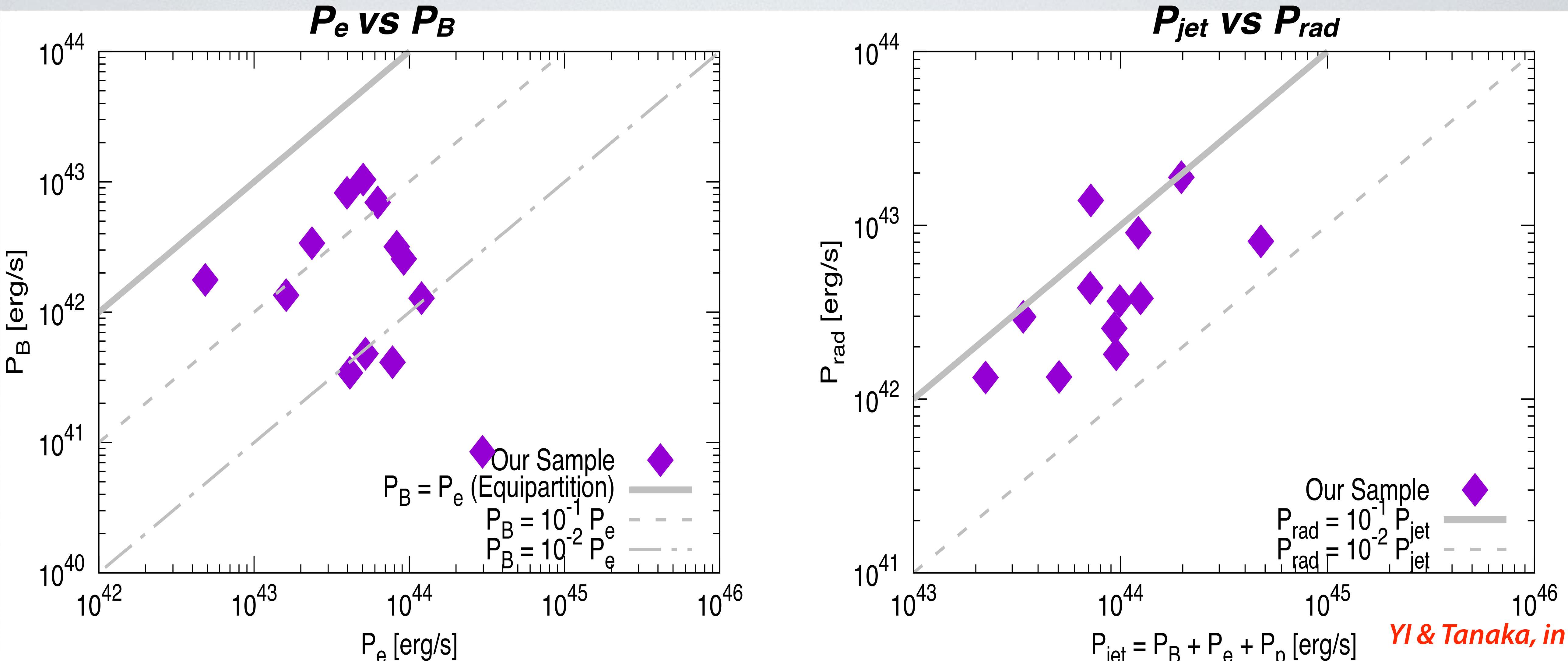
Electron Distribution



YI & Tanaka, in prep.

- Most objects show $p_1 \sim 2.2$ which is expected for relativistic shocks (e.g. Kirk+’00, Keshet & Waxman ’05, Sironi+’15)
  - However, $p_1 \sim 1.6$ is required for H1426-428. Stochastic acceleration?
- Some are consistent with homogeneous radiative cooling ($p_2 \sim p_1+1$), but others not. Due to inhomogenity in the source?

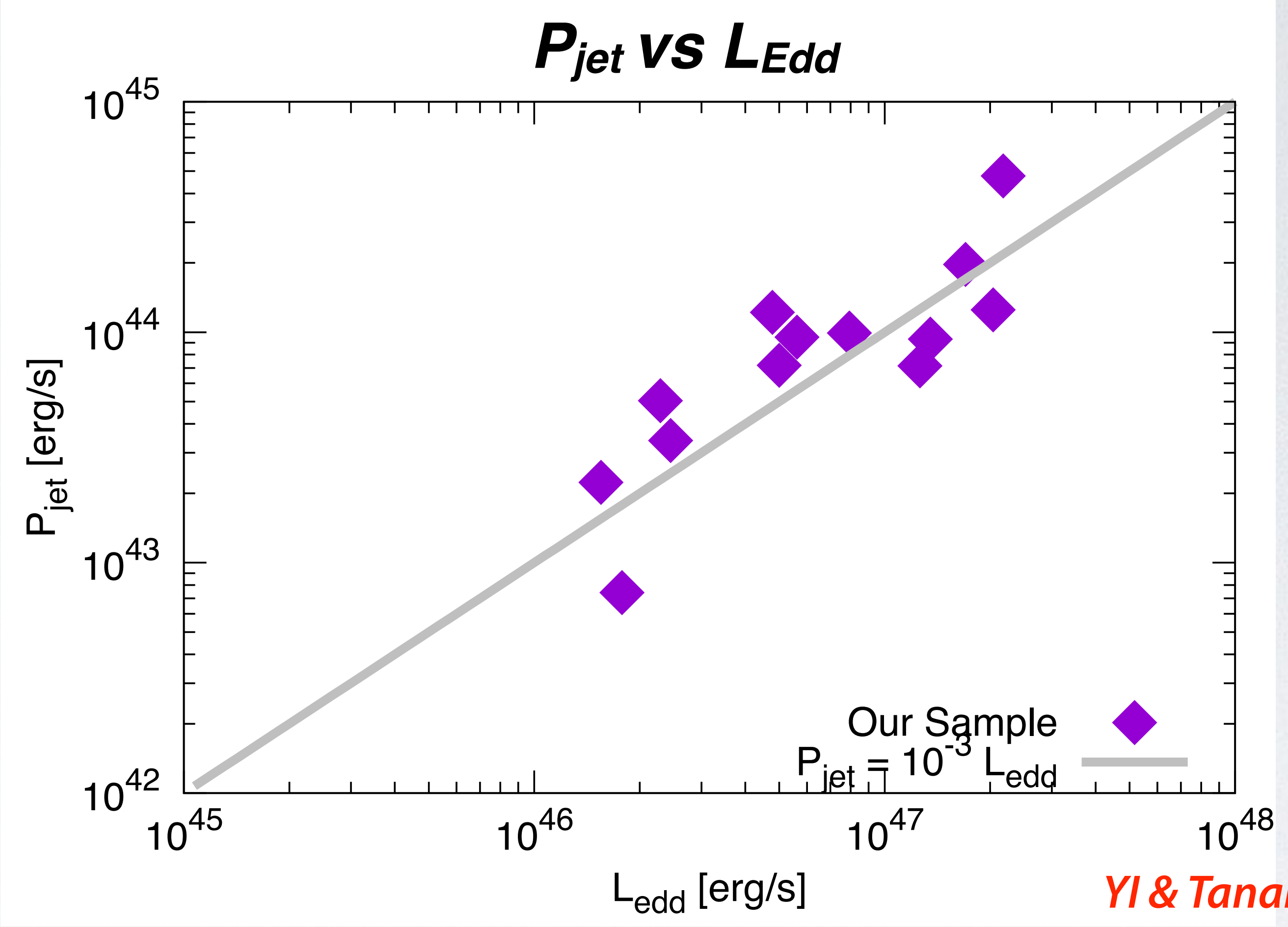
Jet Energetics of HBLs



YI & Tanaka, in prep.

- All of our samples are near equipartition: $P_B \sim 0.1\ P_e$
- Assuming cold protons only, radiative efficiency is 0.06.
  - similar to FSRQ samples (Ghisellini+'14)

Accretion vs Jet

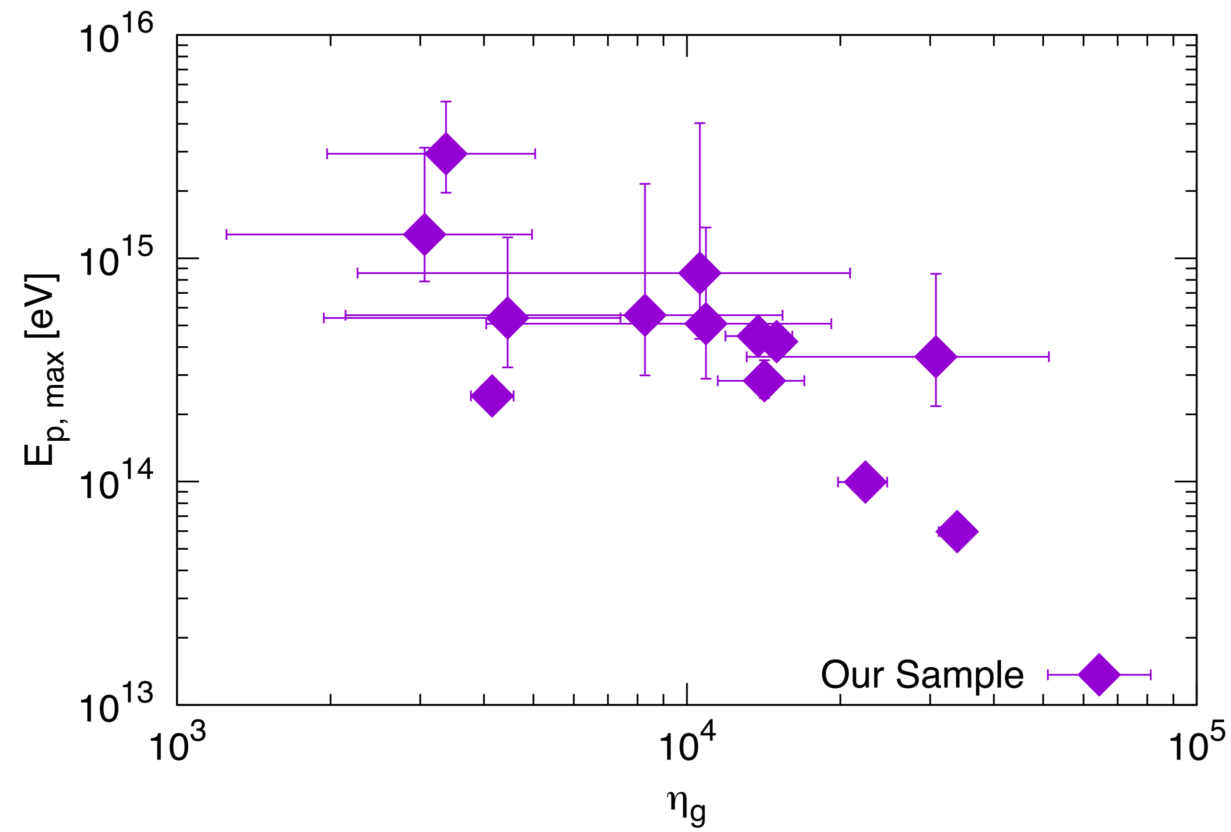


YI & Tanaka in prep.

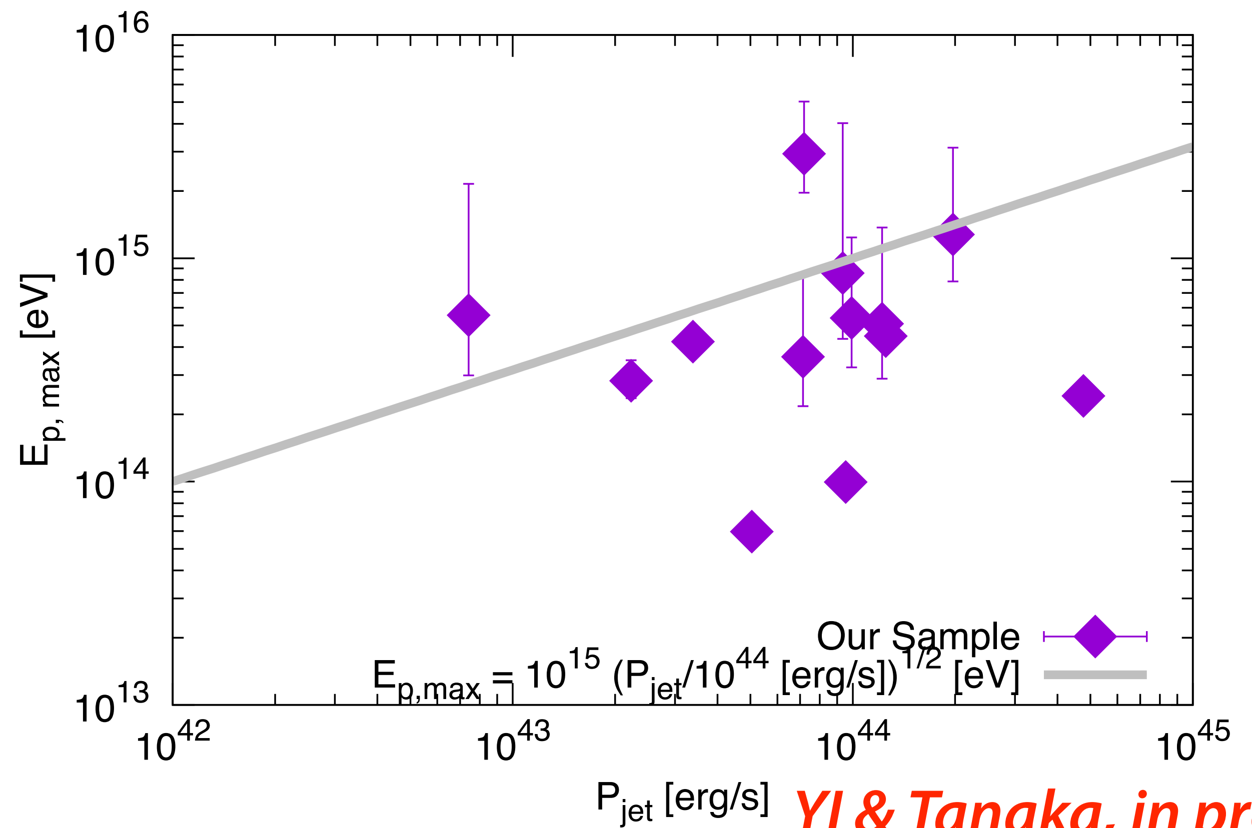
- $P_{jet} \sim 10^{-3} L_{Edd}$
- The mass accretion rate of HBLs is about $\dot{m} \simeq 1.2 \times 10^{-2}$ (Wang+'02).
  - ~0.1% of accreted mass loaded on the jet in HBLs.
    - But, ~100% mass loaded in the case of FSRQs (Ghisellini+'14)
  - RIAFs inevitably generate outflows ejecting ~30% of mass as a disk wind (Blandford & Begelman '99; Totani '06)

Acceleration Efficiency

η_g vs $E_{p,max}$



P_{jet} vs $E_{p,max}$



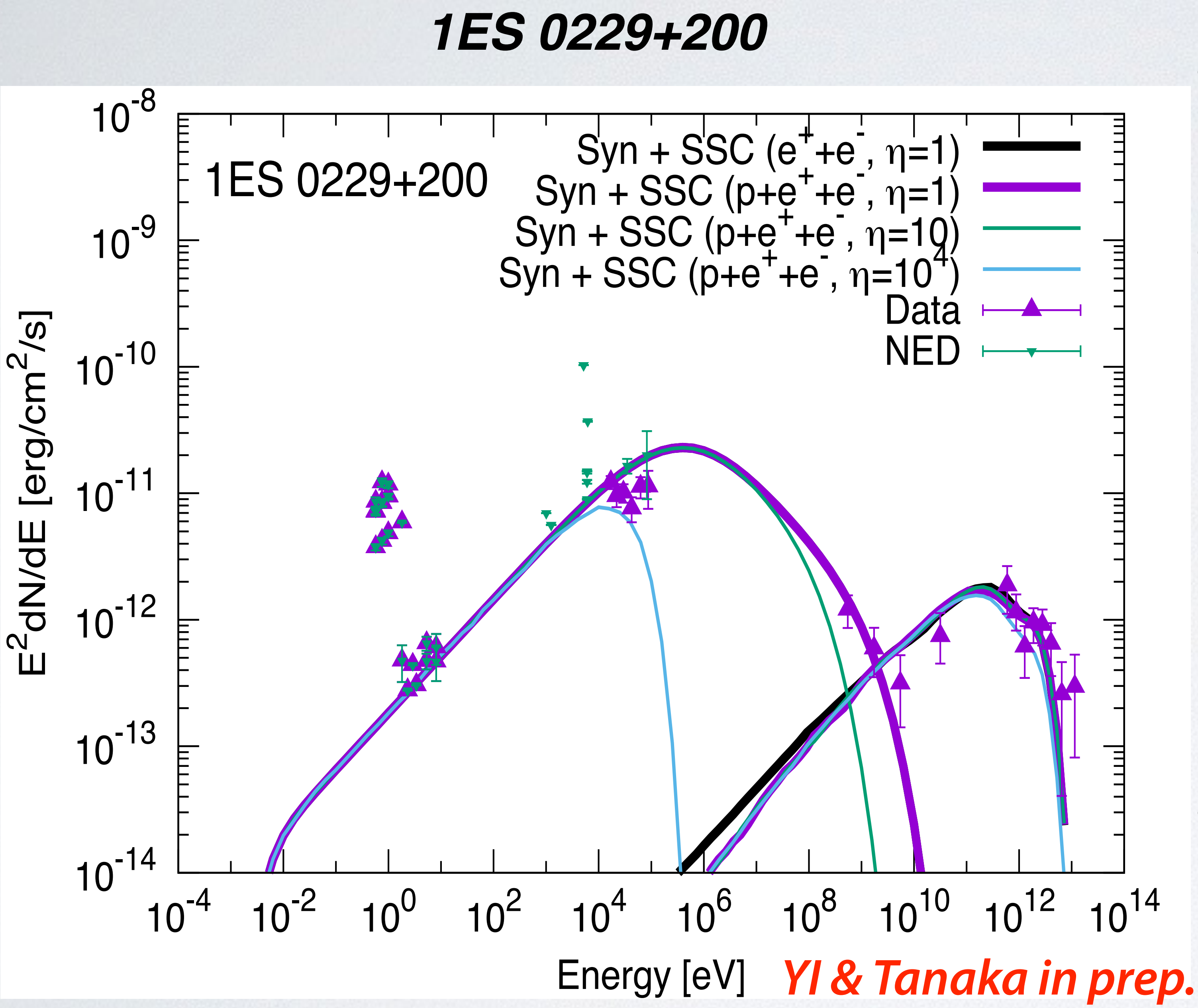
YI & Tanaka, in prep.

- HBLs are not efficient accelerators having $\eta_g \sim 10^4$.
- We have $P_B \sim 0.06\ P_{jet}$. Then, the maximum proton energy can be

$$E_{p,\max} = \frac{2e}{\eta_g}\sqrt{\left(\frac{f_B P_{\rm jet}}{c}\right)}$$

$$\simeq 1\times 10^{15}\left(\frac{f_B}{0.06}\right)^{1/2}\left(\frac{P_{\rm jet}}{10^{44}\ {\rm erg/s}}\right)^{1/2}\left(\frac{\eta_g}{10^4}\right)^{-1}\ [{\rm eV}].$$

1ES 0229+200



- Very hard HBL
- 3FGL data shows a soft spectrum at GeV band.
  - this comes from Synchrotron emission?
- A possible contamination:
  - Sun & moon occultation?

Summary

- Systematic spectral study of 13 TeV HBLs using MAXI, BAT, LAT, & IACTs data under the DSA scenario.

  - $P_B \sim 0.1\ P_e$

  - $P_{rad} \sim 0.06\ P_{jet}$ similar to FSRQs assuming cold protons only.

  - 0.1 % of accreted mass is loaded on to the jet.

  - acceleration efficiency is $\eta_g \sim 10^4$.

  - But 1ES 0229+200 can have $\eta_g \sim 1$. Caused by Sun & moon occultations?