

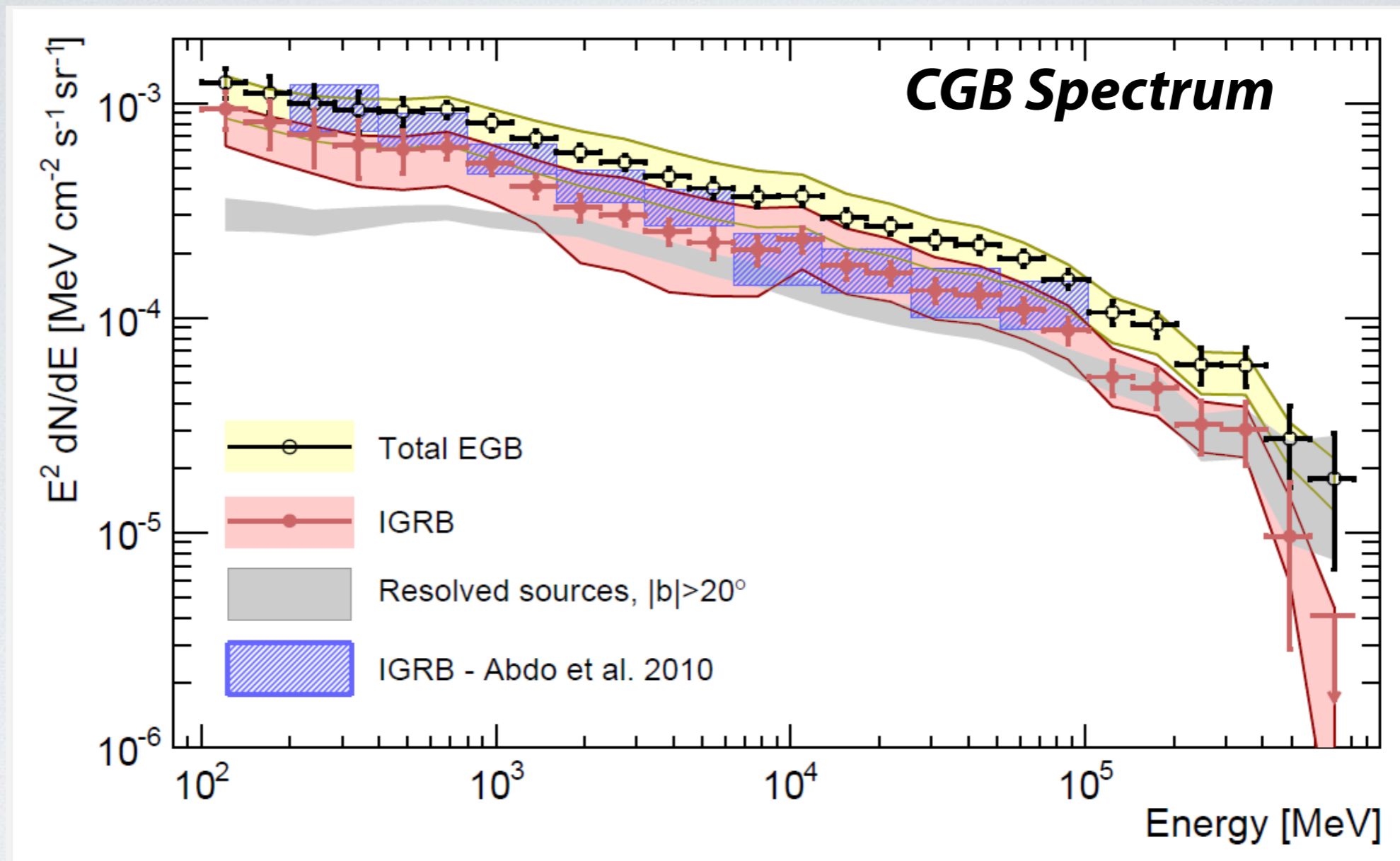
Lower and Upper Bounds on the Cosmic TeV Gamma-ray Background

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Collaborators: Yasuyuki T. Tanaka

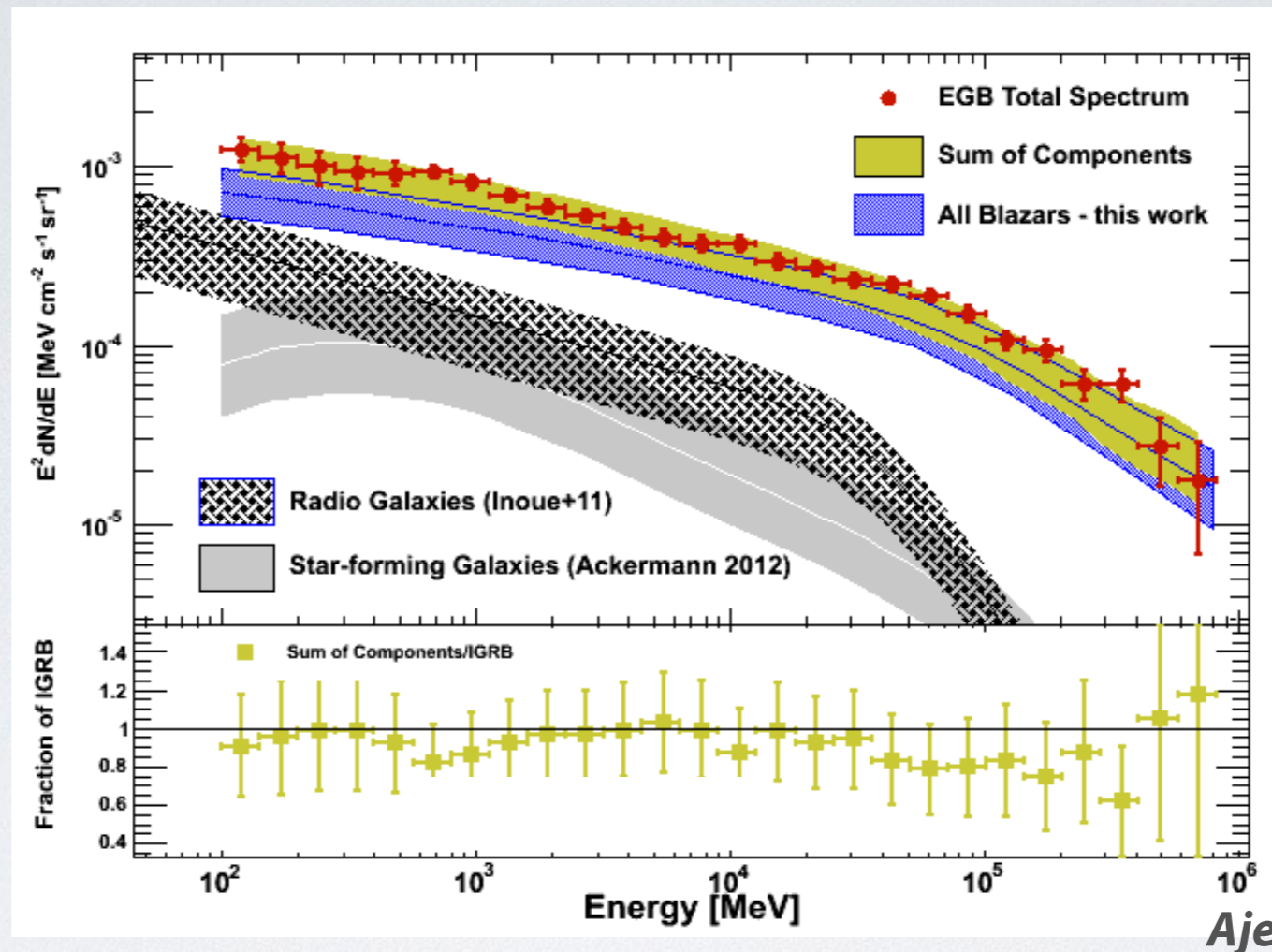
Cosmic Gamma-ray Background Spectrum at >0.1 GeV



Ackerman+'15

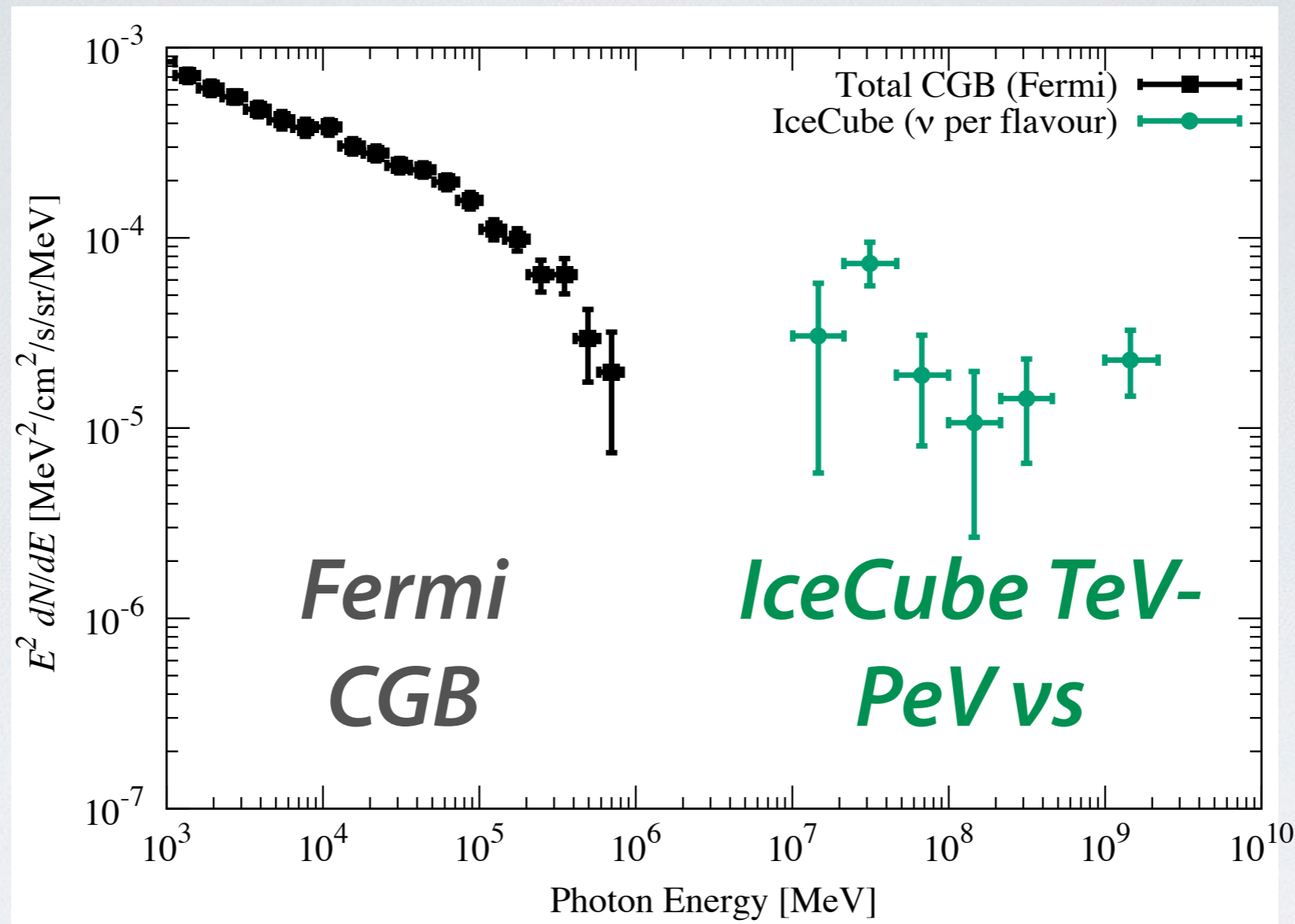
- Fermi has resolved 30% of the CGB at ~ 1 GeV and more at higher energies (see Di Mauro's talk).

Components of the Cosmic GeV Gamma-ray Background



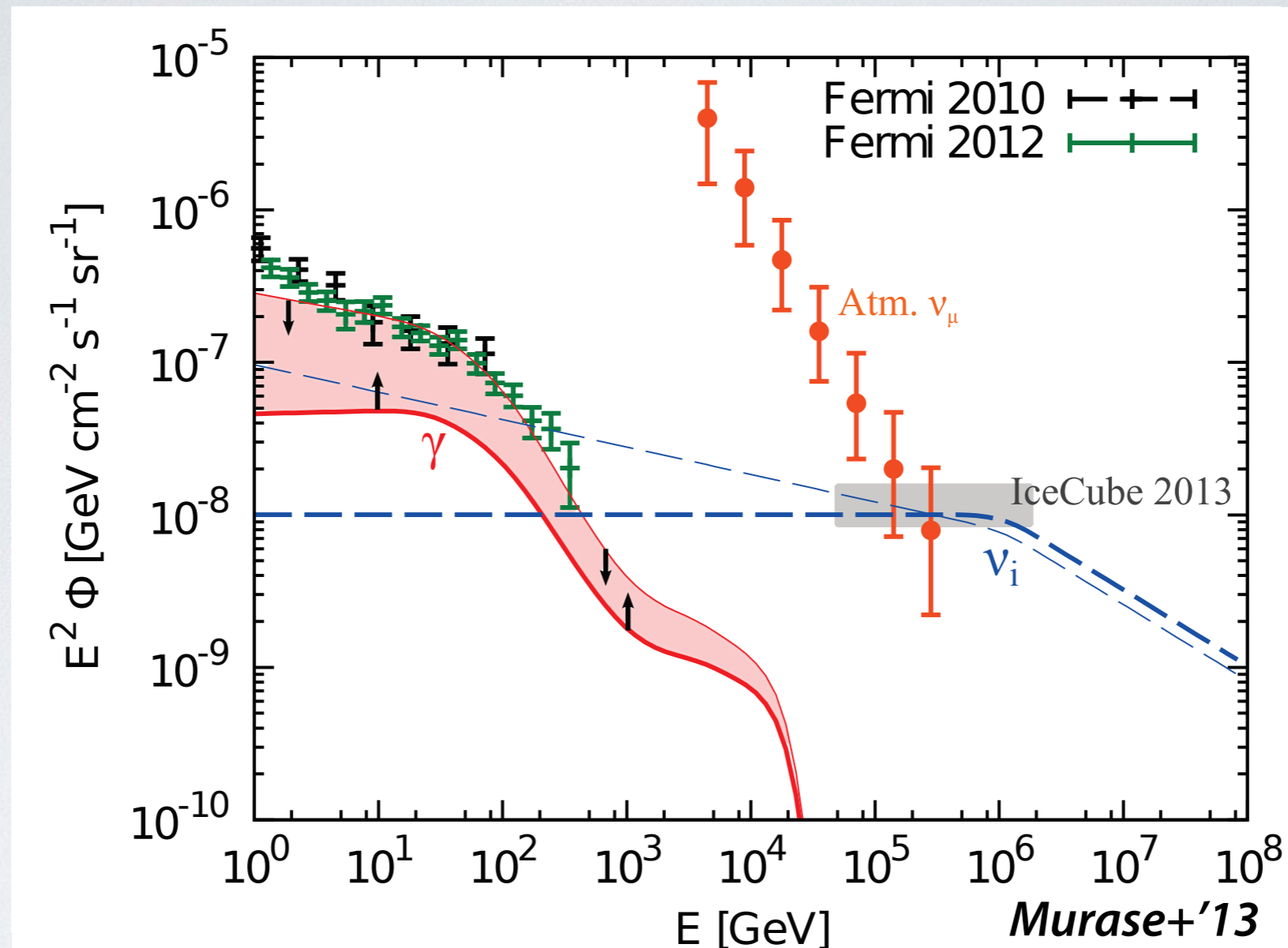
- Blazars (Ajello+'15), Radio gals. (YI'11), & Star-forming galaxies (Ackermann+'12) make up almost 100% of CGB from 0.1-1000 GeV.
- Next frontiers will be
 - Anisotropy (e.g. Ando & Komatsu '06, Ackermann+'11, Camero+'13, Shirasaki+'14)
 - Cosmic MeV Gamma-ray Background (e.g. YI+'08, Ajello+'09, YI+'13)
 - Cosmic TeV Gamma-ray Background (This talk)

Cosmic TeV Gamma-ray Background



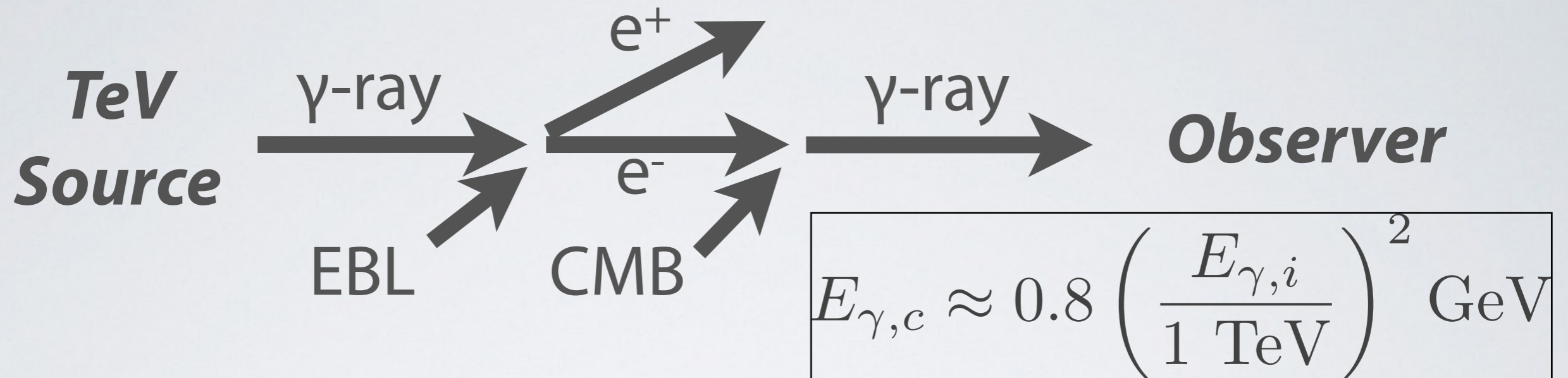
- Above 1 TeV, there is no gamma-ray data, though it is important for neutrino studies.
- extragalactic *pp* scenario for IceCube events is constrained by the CGB (Murase+'13; Bechtol+'15).

Cosmic TeV Gamma-ray Background



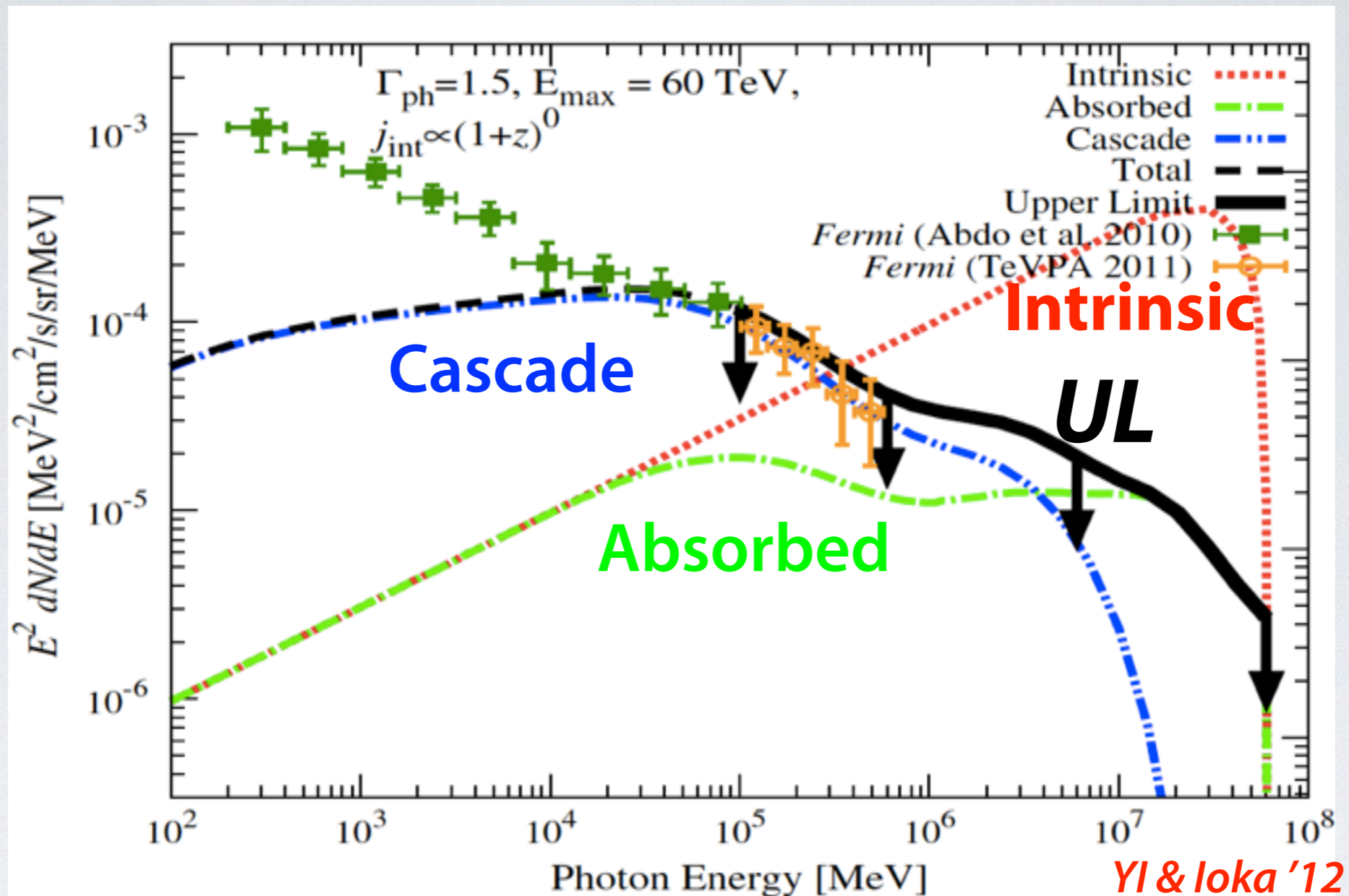
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GeV-TeV Gamma-ray Connection: Cascade



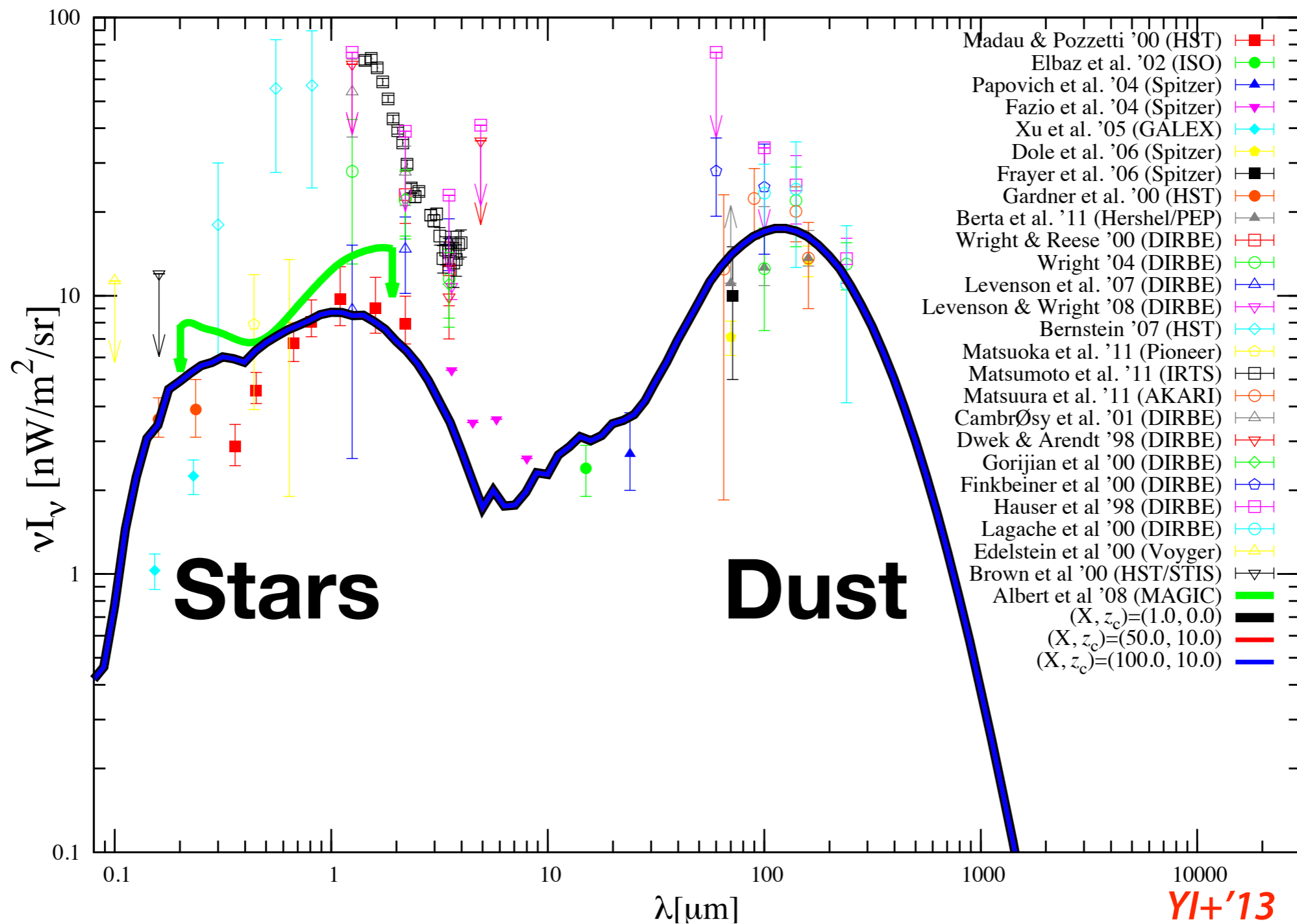
- TeV gamma-ray photons are absorbed by EBL
- electron-positron pairs are created
- pairs scatter CMB via inverse-Compton process
 - 1 TeV (primary) \rightarrow \sim 1 GeV (secondary)
- Note: plasma instability may suppress the cascade
(Broderick+'12, but see also Sironi & Giannios '14)

Upper Bound on the Cosmic Gamma-ray Background

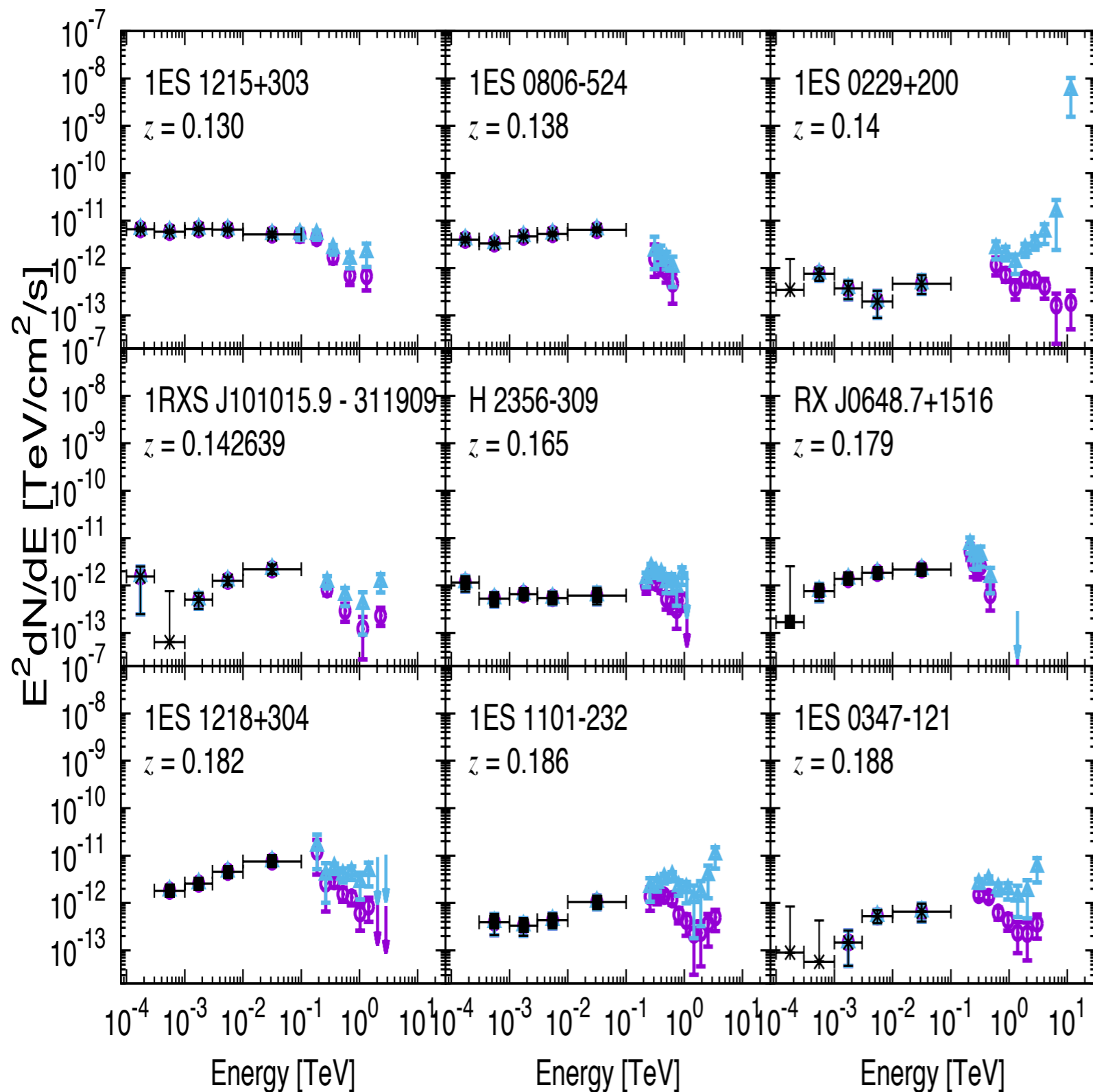


- Cascade component from the TeV background can not exceed the Fermi data (Coppi & Aharonian '97, YI & Ioka '12, Murase+'12, Ackermann+'14).
- No or negative evolution is required -> low-luminosity BL Lacs show negative evolution (Ajello+'14).

Galaxy counts: lower bound on the cosmic optical/Infrared Background

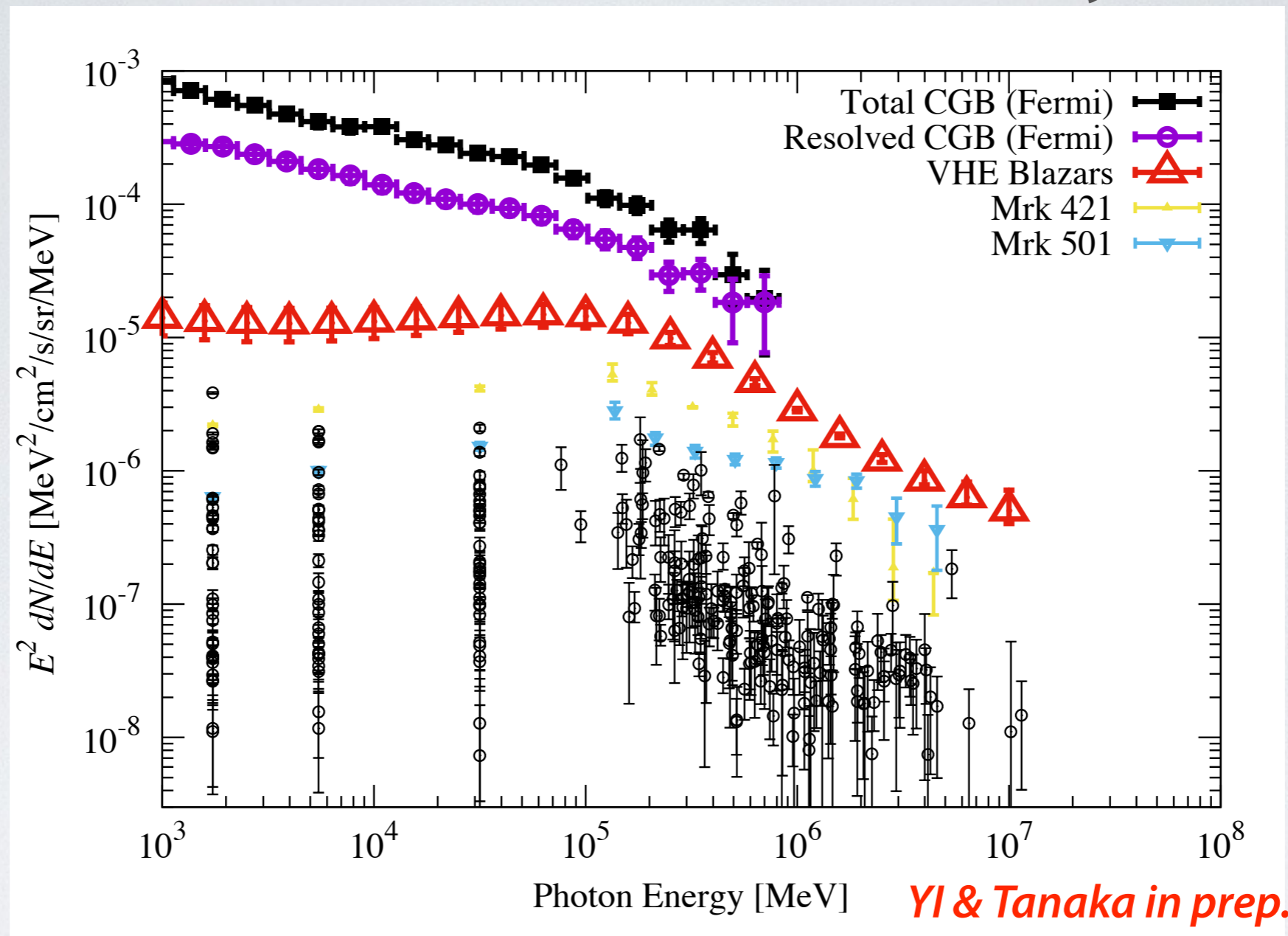


TeV blazar sample



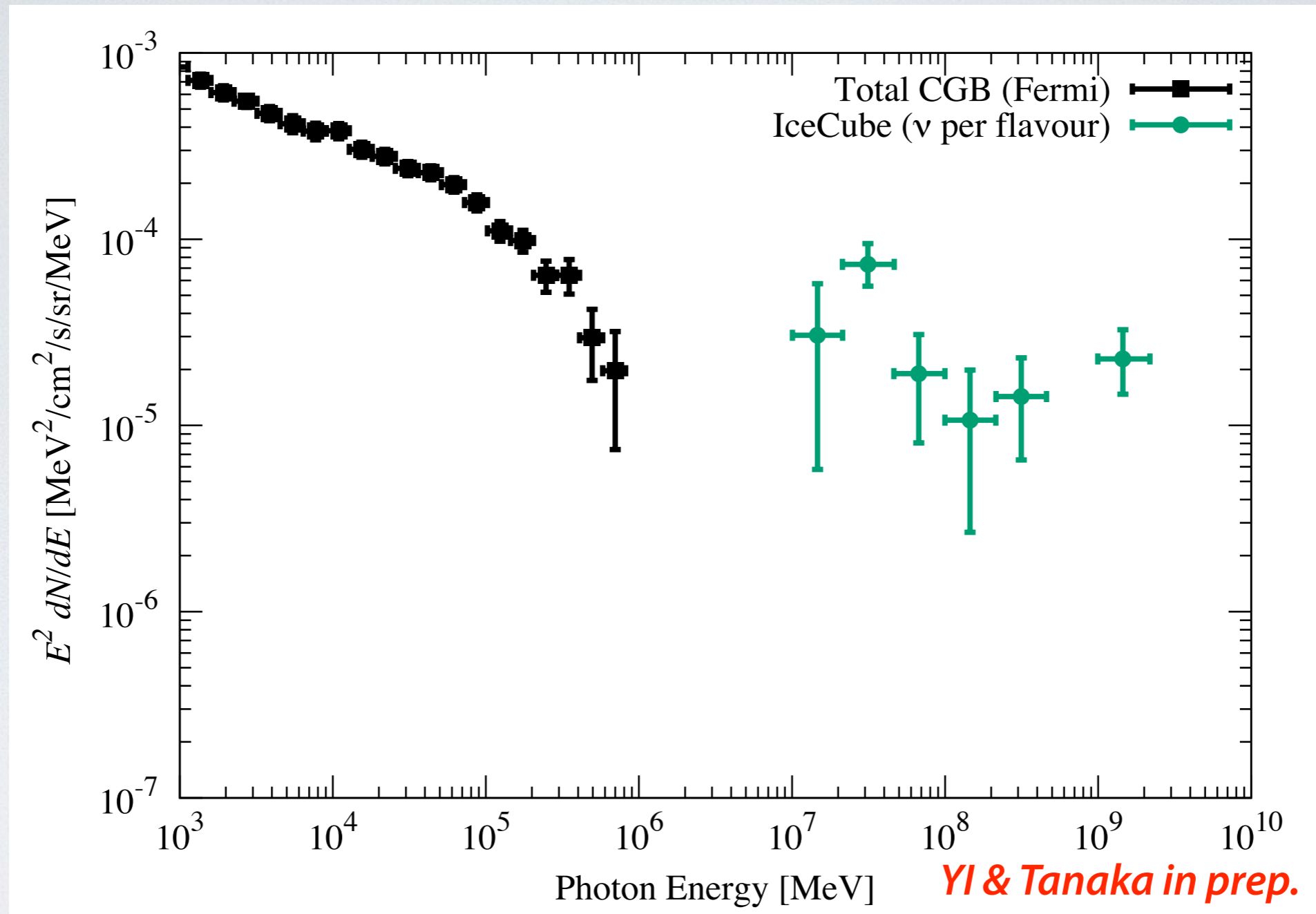
- Select 36 blazars the default TeVcat catalog.
- Low-state data are available for 31/36.
- 3FGL SED data for the GeV data.
- Radio galaxies and star-forming galaxies are not included yet.

Lower Bound on the Cosmic Gamma-ray Background



- TeV blazar counts give lower limit on to the cosmic gamma-ray background.
- Fermi has resolved more portion of the TeV sky than IACTs do?
 - CTA survey will be important (YI, Totani, & Mori 10; Dubus, YI, +'13)

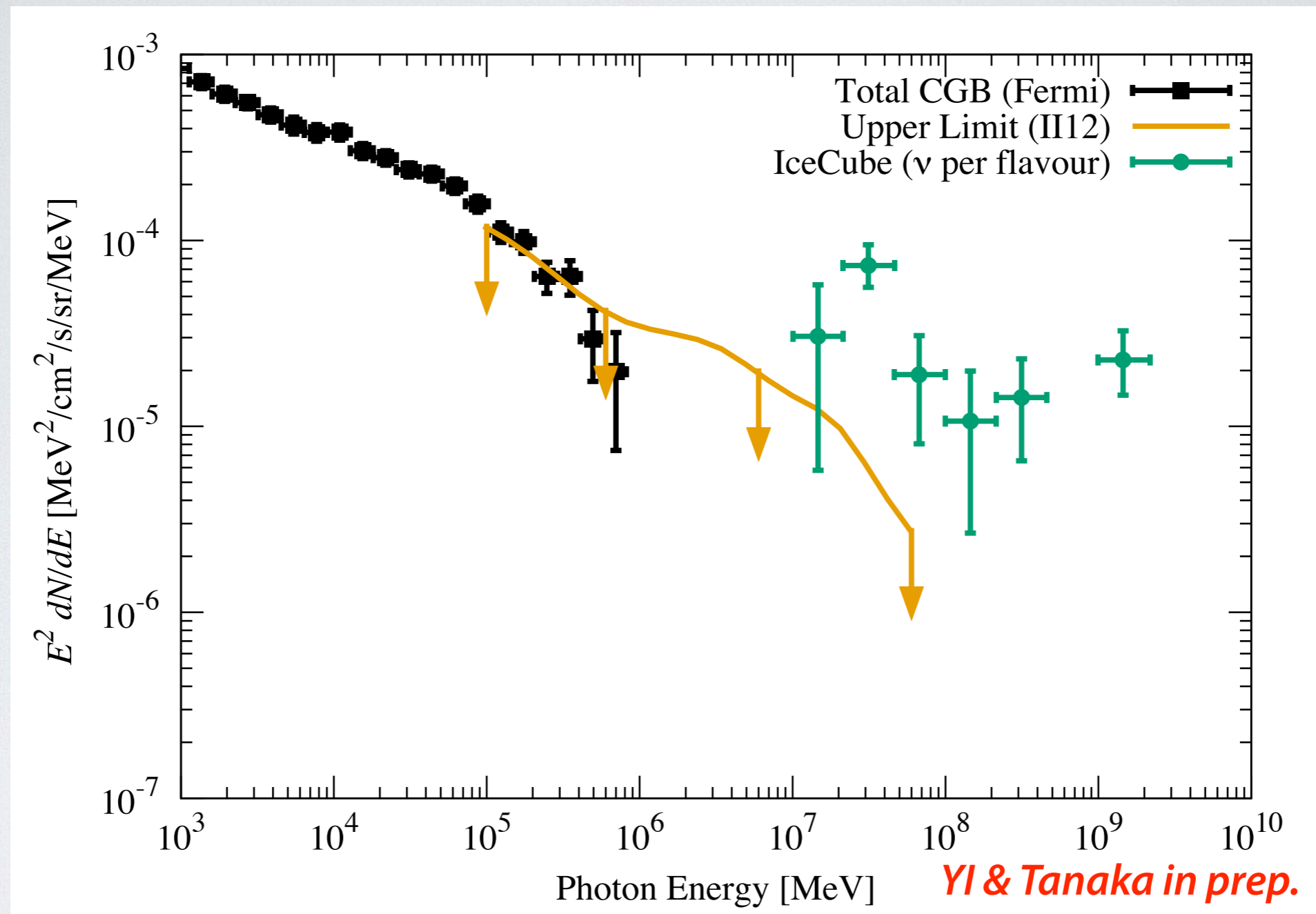
Bounds on the Cosmic TeV Gamma-ray Background



- Current limit at 0.3-10 TeV is

$$3 \times 10^{-5} \left(\frac{E}{100\text{GeV}} \right)^{-1} [\text{MeV}/\text{cm}^2/\text{s}/\text{sr}] < E^2 \frac{dN}{dE} < 5 \times 10^{-5} \left(\frac{E}{100\text{GeV}} \right)^{-0.7} [\text{MeV}/\text{cm}^2/\text{s}/\text{sr}]$$

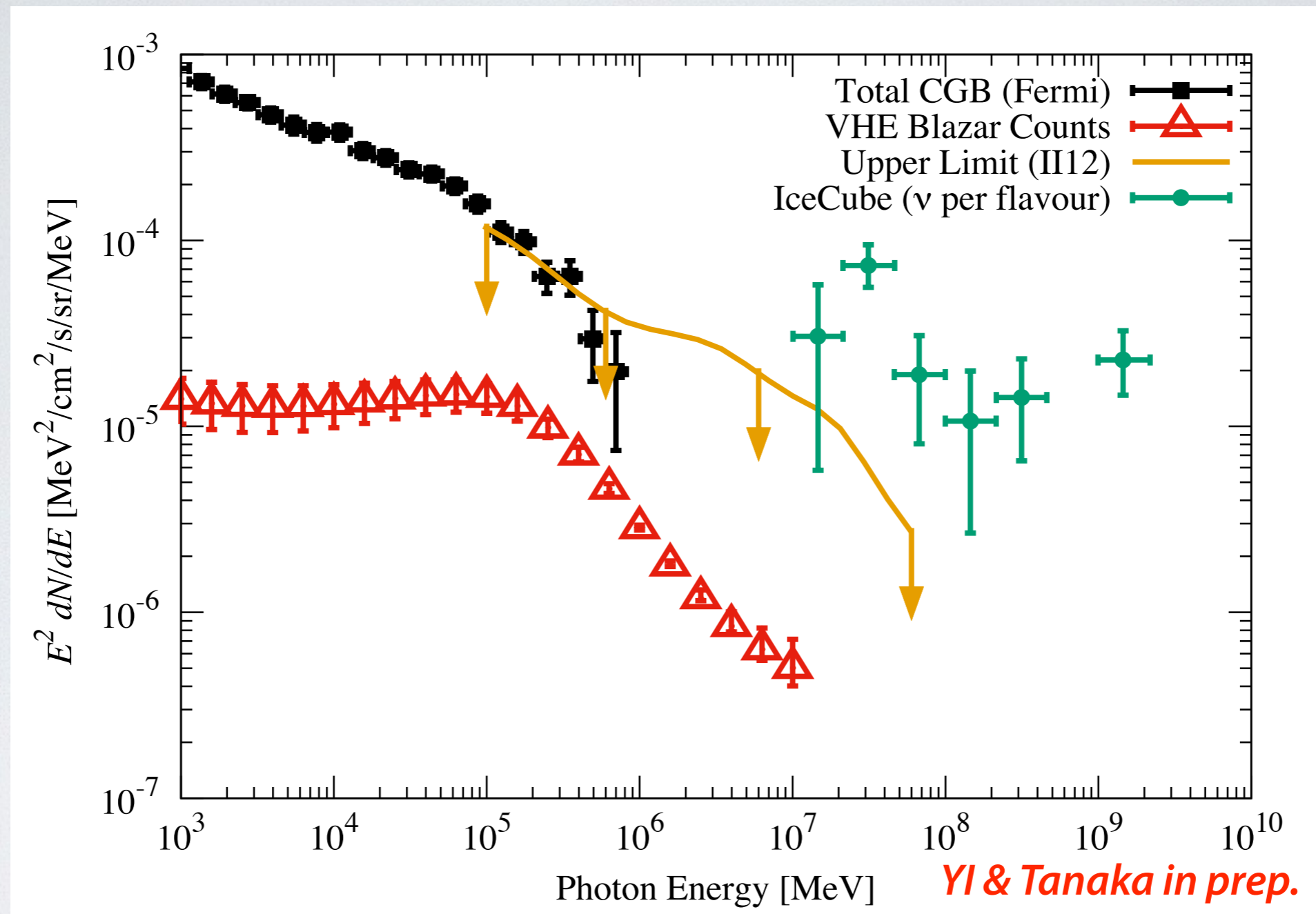
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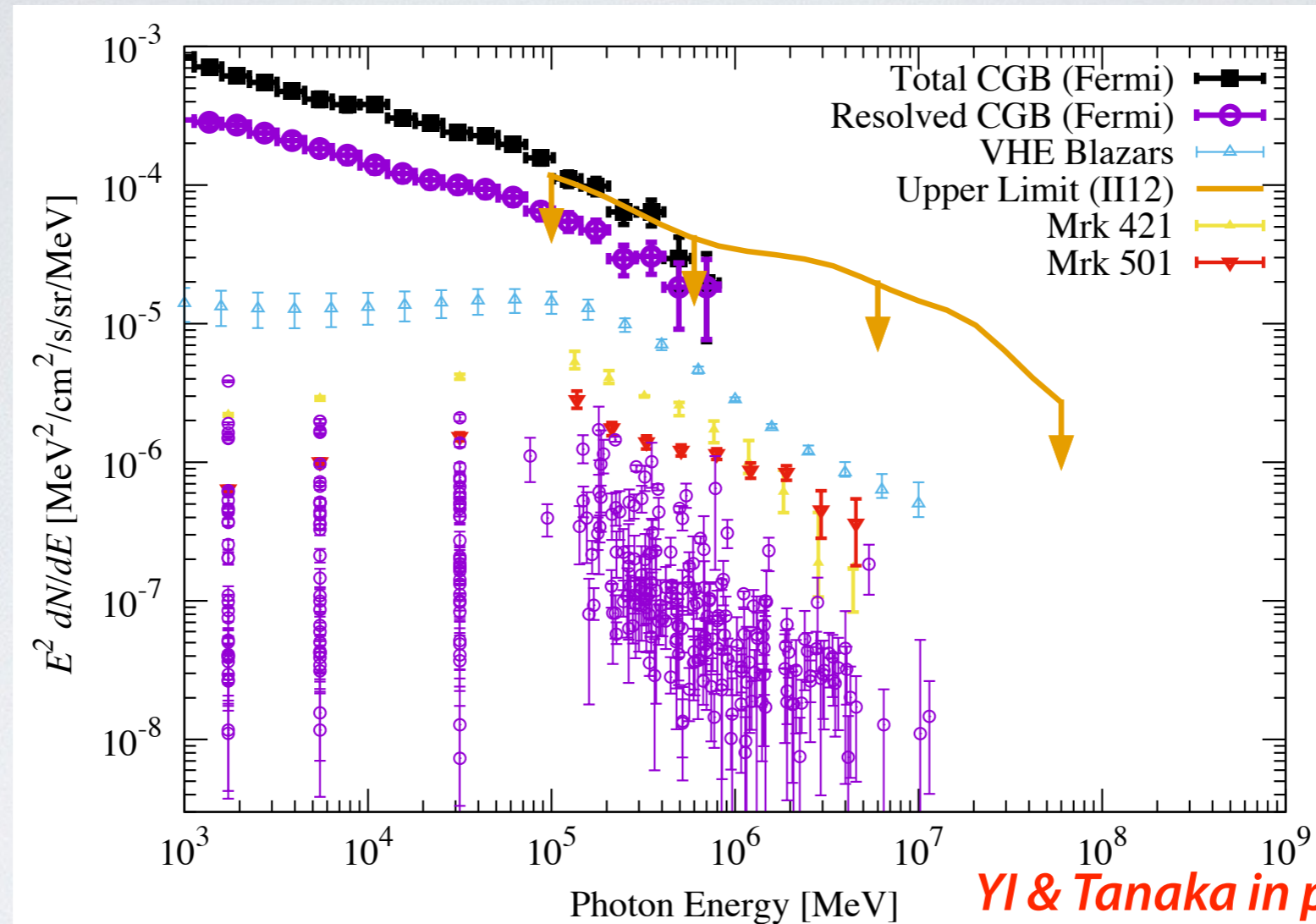
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Summary

- Cosmic TeV gamma-ray background is not well investigated yet.
- Current GeV gamma-ray background gives upper limits on the TeV gamma-ray background through the cascade argument
- Ensemble of low-state TeV blazar flux gives lower limit on to the cosmic gamma-ray background
- Current limit on the TeV background is

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Lower Bound on the Cosmic Gamma-ray Background



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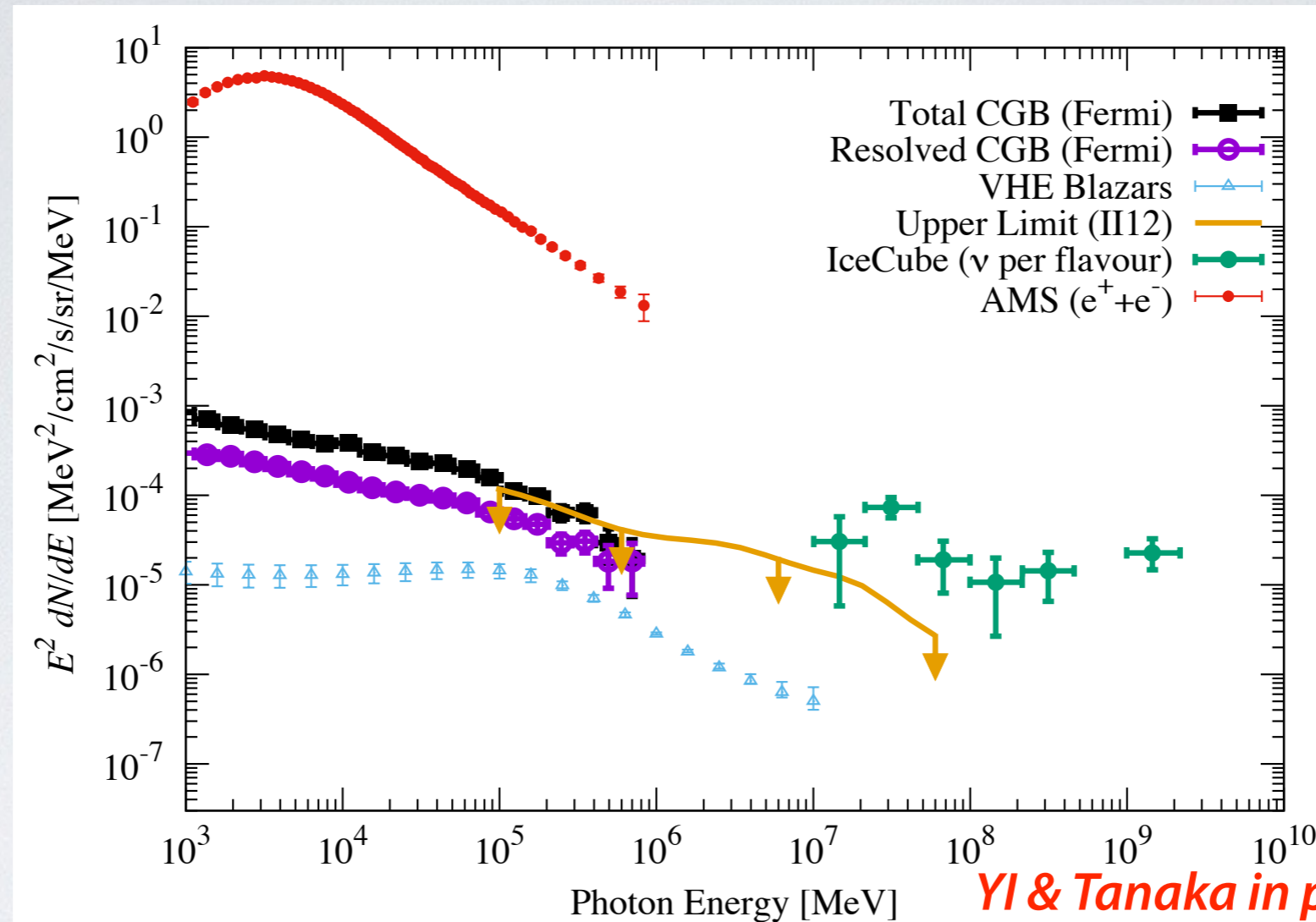
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- CTA survey will be important (YI, Totani, & Mori 10; Dubus, YI, +'13)

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VHE EGB Model

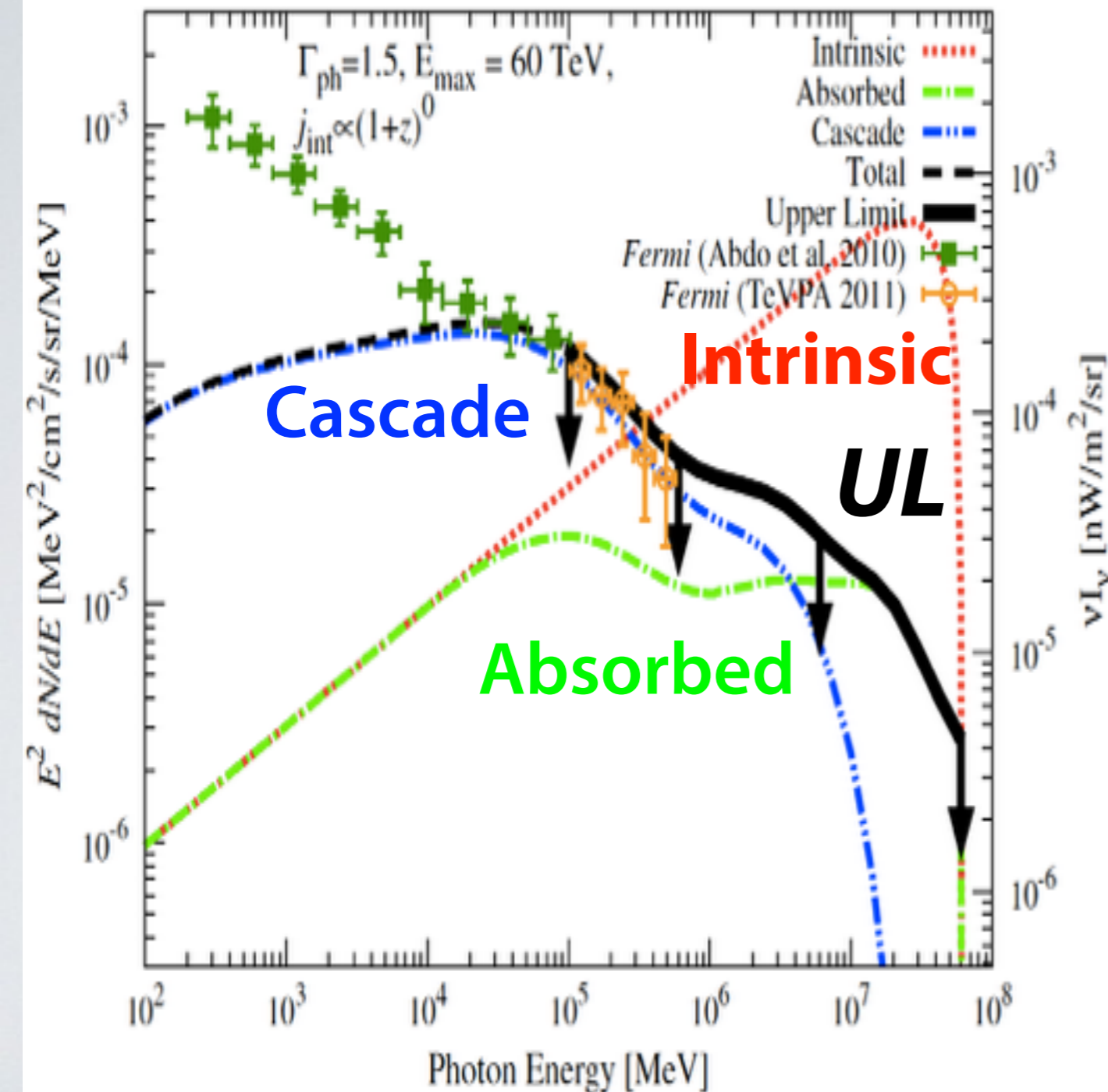
$$E^2 \frac{dN}{dE}(E_{\text{obs}}) = \frac{cE_{\text{obs}}^2}{4\pi} \int_0^{z_{\text{max}}} dz \left| \frac{dt}{dz} \right| (1+z) \\ \times \frac{dj}{dE_\gamma} [(1+z)E_{\text{obs}}, z] \exp[-\tau_{\gamma\gamma}(E_{\text{obs}}, z)],$$

$$j = j_{\text{int}} + j_{\text{cas}} \quad \text{MeV/s/MeV/cm}^3$$

$$\frac{dj_{\text{int}}}{dE_\gamma}(E_\gamma, z) = \begin{cases} j_0 E_\gamma^{-\Gamma_{\text{ph}}} (1+z)^{\beta_{\text{evo}}}, & E_\gamma \leq E_{\text{max}}, \\ 0, & E_\gamma > E_{\text{max}}, \end{cases}$$

- Parameters are
 - β_{evo} : Cosmological evolution of number density
 - Most of known sources show $\beta_{\text{evo}} > 0$
 - E_{max} : Maximum energy
 - Γ_{ph} : Photon index

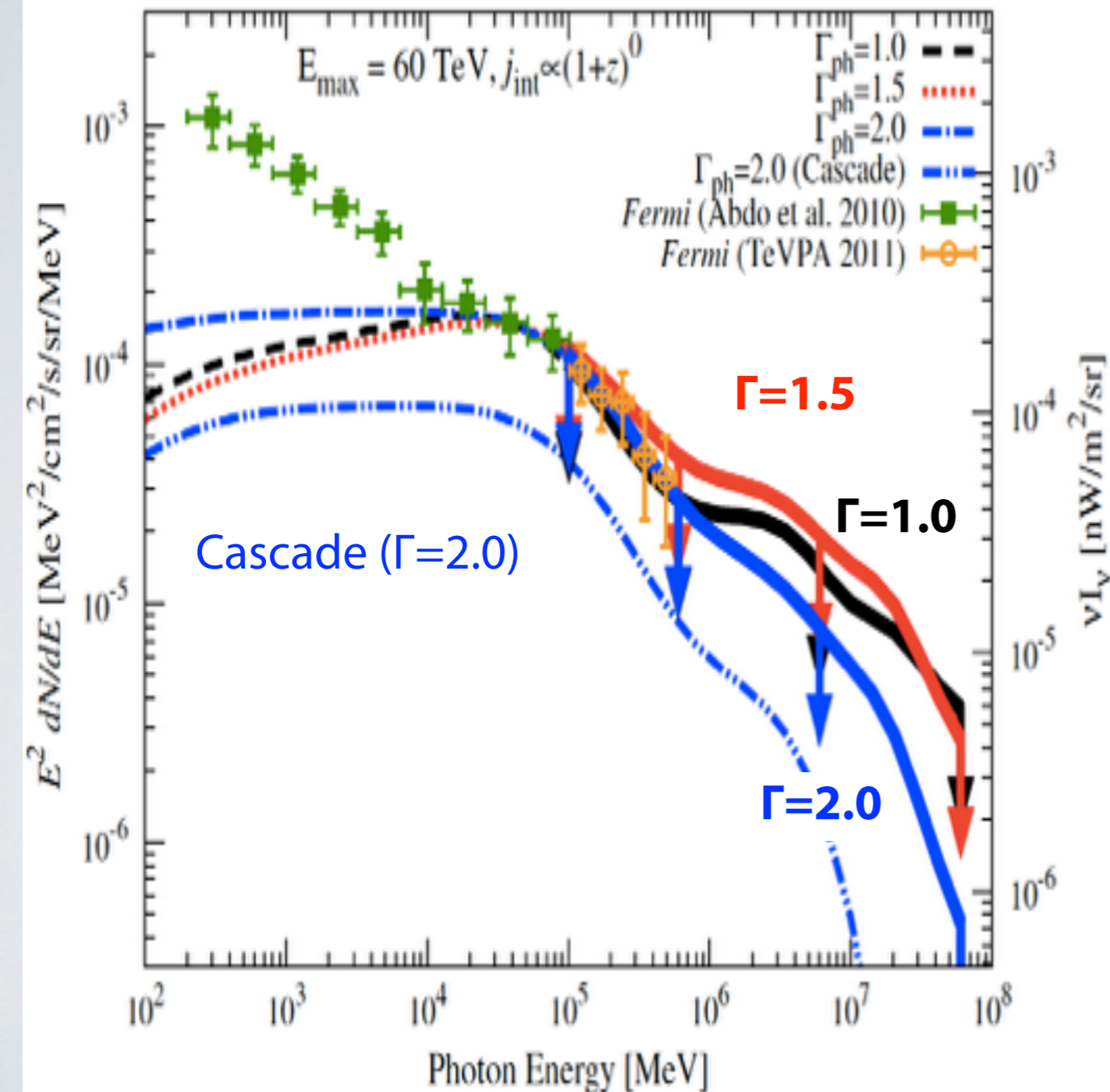
Upper Limit on EGB



- $\beta_{\text{evo}}=0$ (no evolution)
- $\Gamma_{\text{ph}}=1.5$ (Fermi acc. limit)
- $E_{\text{max}} = 60 \text{ TeV}$
- Normalization is fixed to the EGB data $< 100 \text{ GeV}$.
- No known source classes included.
- Upper limit is consistent with the Fermi VHE EGB obs.

• UL: $E^2 \frac{dN}{dE} < 1.1 \times 10^{-4} \left(\frac{E}{100 \text{ GeV}} \right)^{-0.5} \text{ MeV/cm}^2/\text{s/sr}$

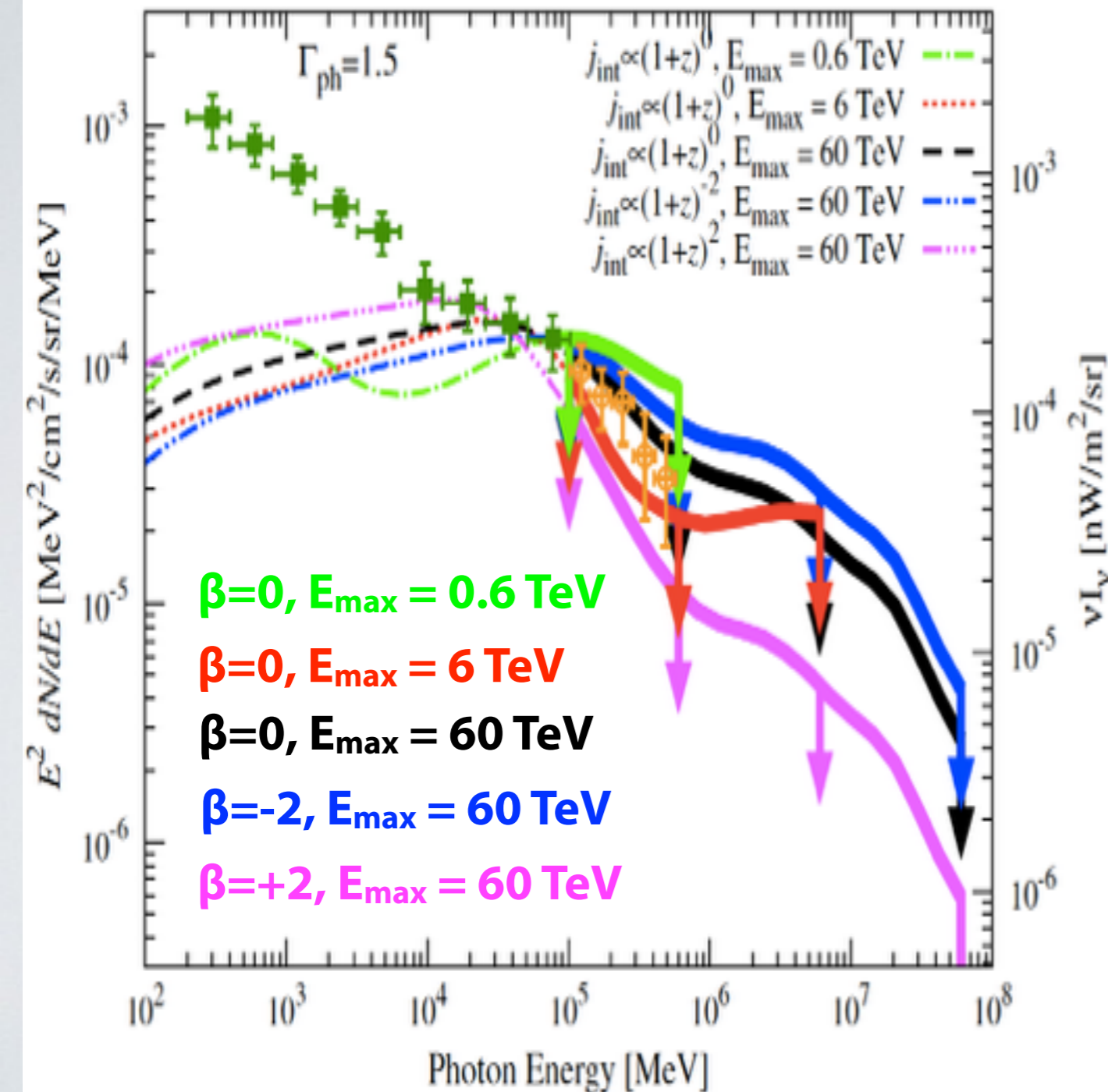
Different Photon Indices



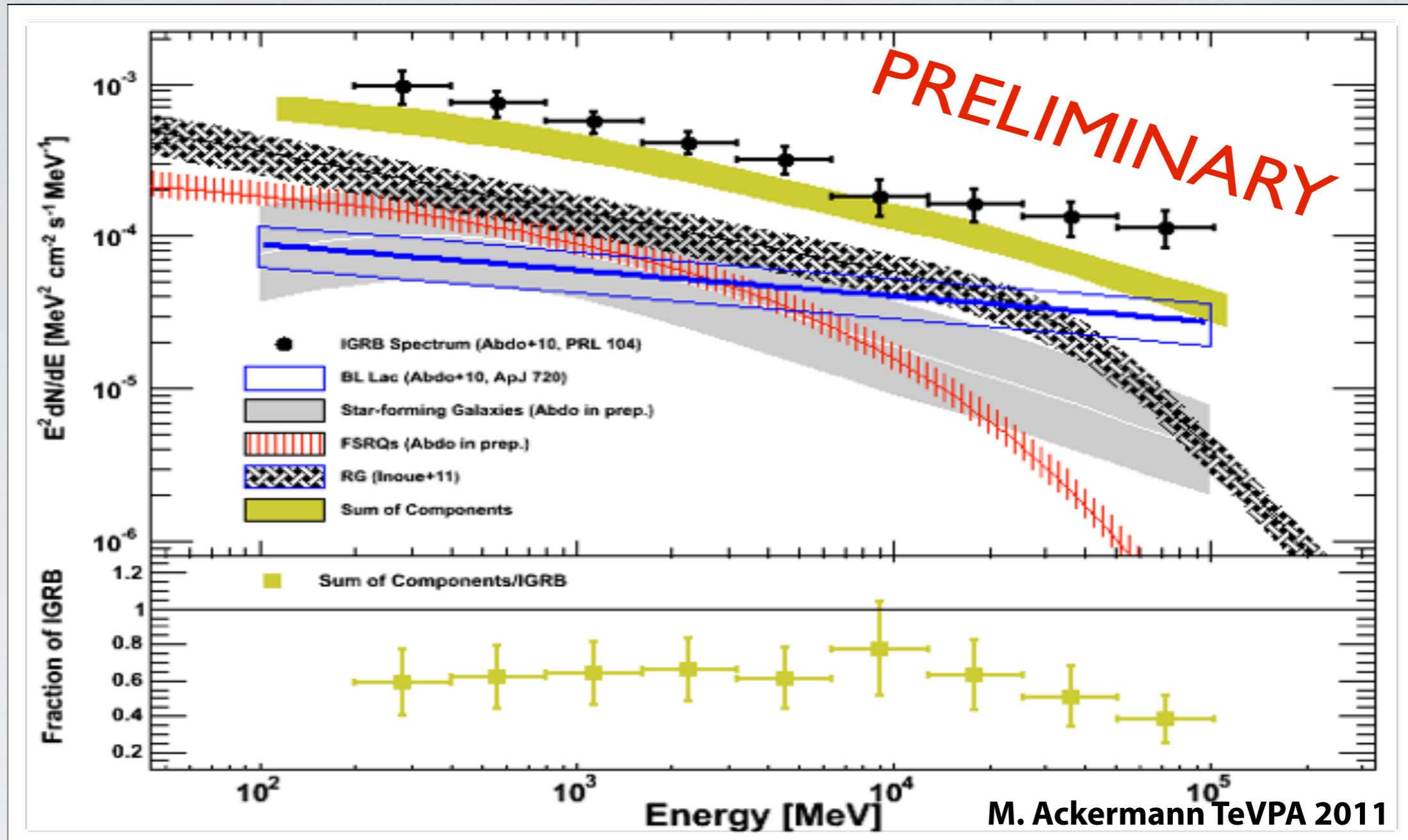
- $\Gamma \sim 1.5$ is the most conservative.
- Harder spectral model is limited by the cascade.
- Softer spectral model is limited by the primary.

Different E_{max} and evolution

- $\beta > 0$ violates the limit.
- $\beta < 0$ eases the limit.
- But, no known gamma-ray sources.
- low E_{max} (\sim sub-TeV) eases the limit.
- If cosmological,
 - sources should have a **hard spectrum** and show **no or negative evolution**.

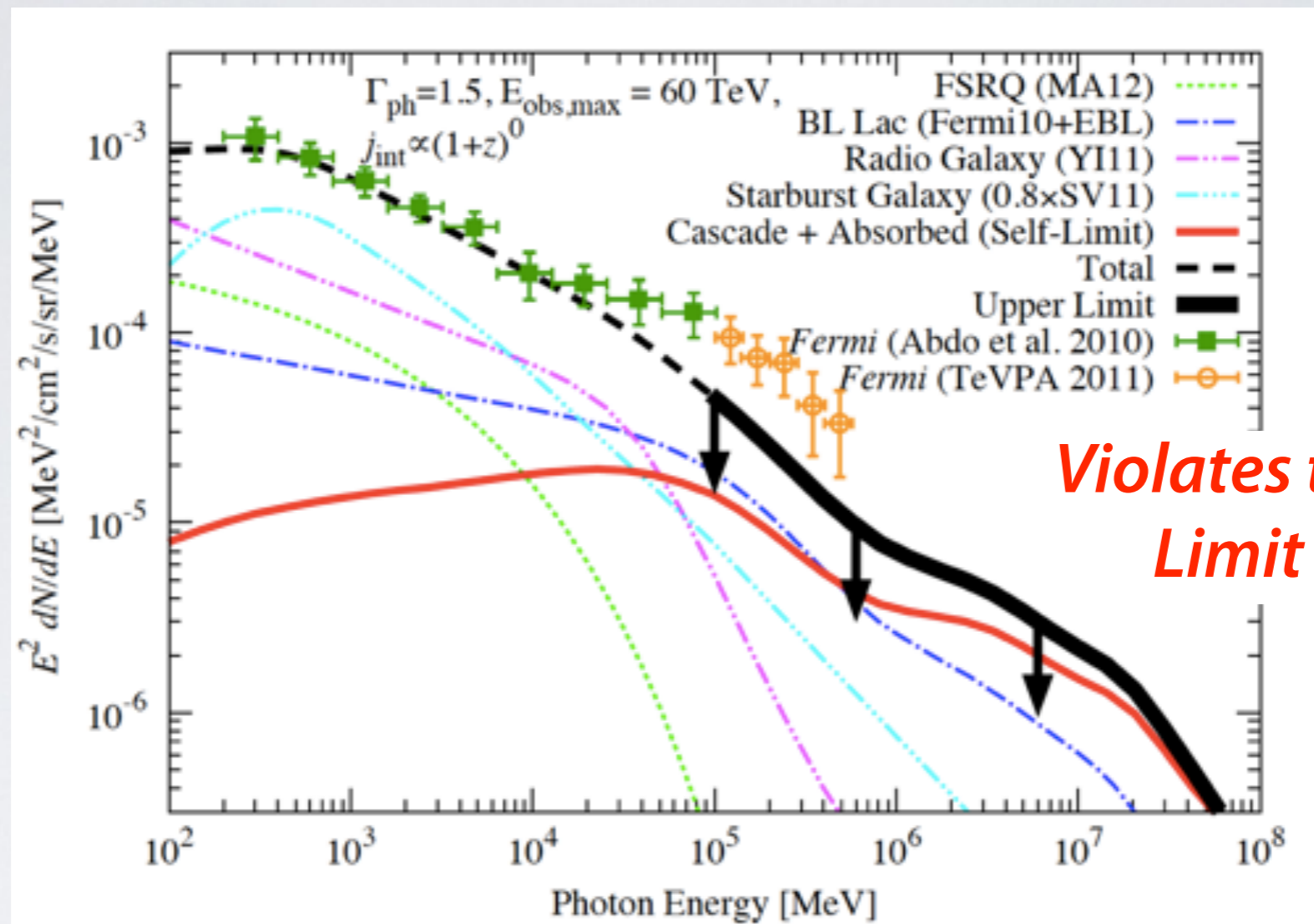


Components of EGB



- FSRQs (Ajello+'12), BL Lacs (Abdo+'10), Radio gals. (Yi'11), Starburst gals. (Stecker & Venters '11, Ackermann+'12) are guaranteed to contribute to EGB.
- We need to subtract them to evaluate the VHE EGB upper limit.

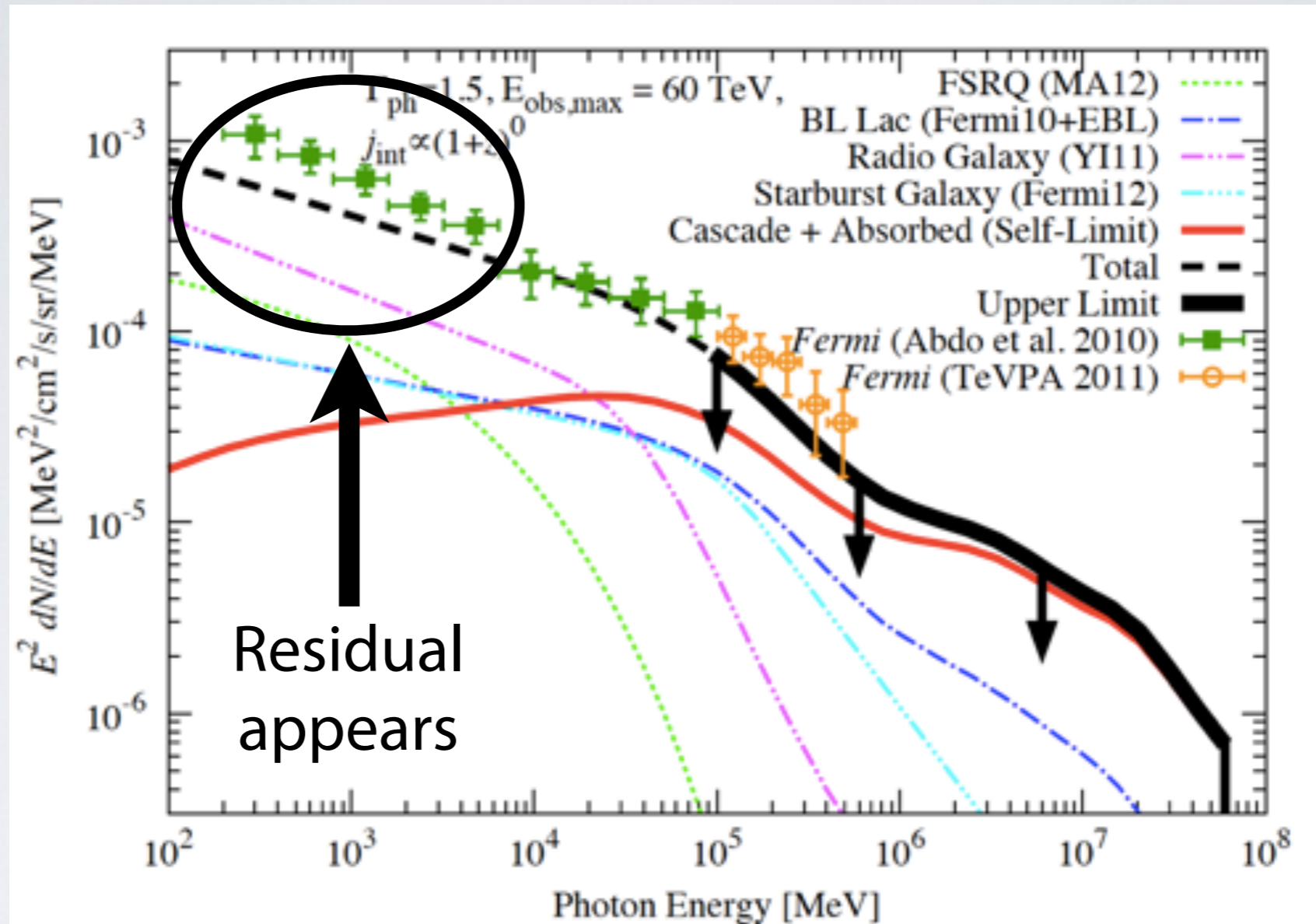
Upper Limit on EGB w/ known sources



- If we try to explain EGB at <10GeV, the observation violates the limit.

- UL:
$$E^2 \frac{dN}{dE} < 4.5 \times 10^{-5} \left(\frac{E}{100 \text{ GeV}} \right)^{-0.7} \text{ MeV/cm}^2/\text{s/sr}$$

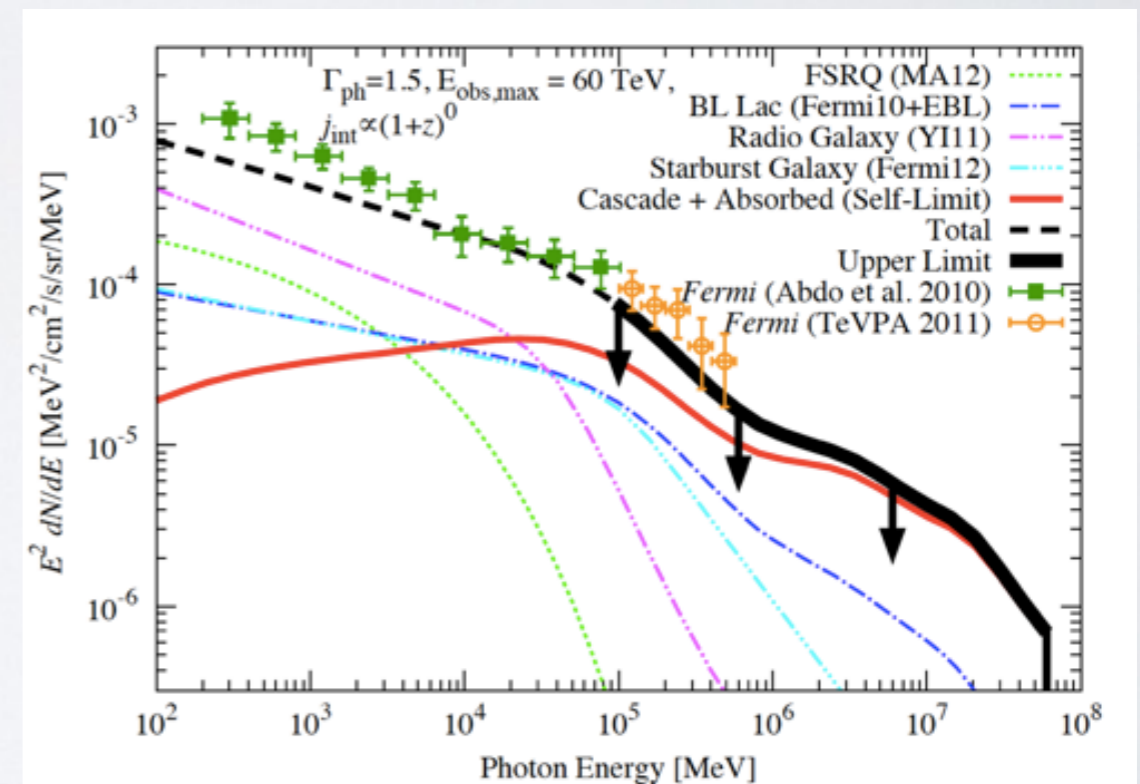
Upper Limit on EGB w/ other models



- If we try not to violate the limit, residual appears at $<10\text{GeV}$.

Possible Explanations

- Hard spectrum with sub-TeV E_{max} and $\beta < 0$
 - No known sources. TeV HBL? Low-luminosity GRBs?
- New Physics: Axion or Lorentz invariance violation?
- Dark matter in local?
- \sim GeV sources
 - pulsars? radio-quiet AGNs?
- Foreground uncertainty?
- See also Murase+'12



Our limit is useful for future:
Fermi, CTA, & CALET