CTA Extragalactic Survey Discovery Potential and the Impact of Axion-Like Particles and Secondary Gamma Rays

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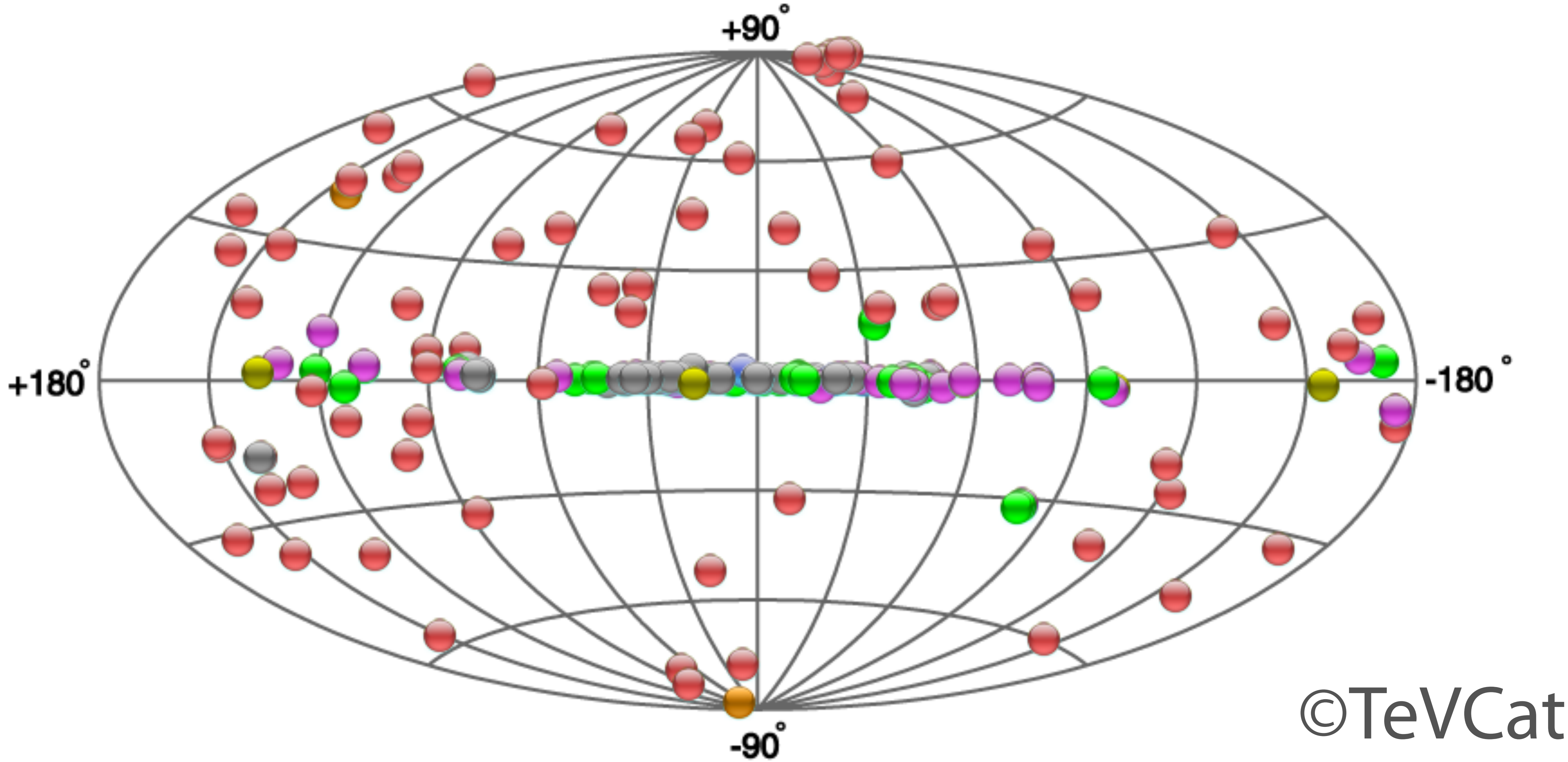
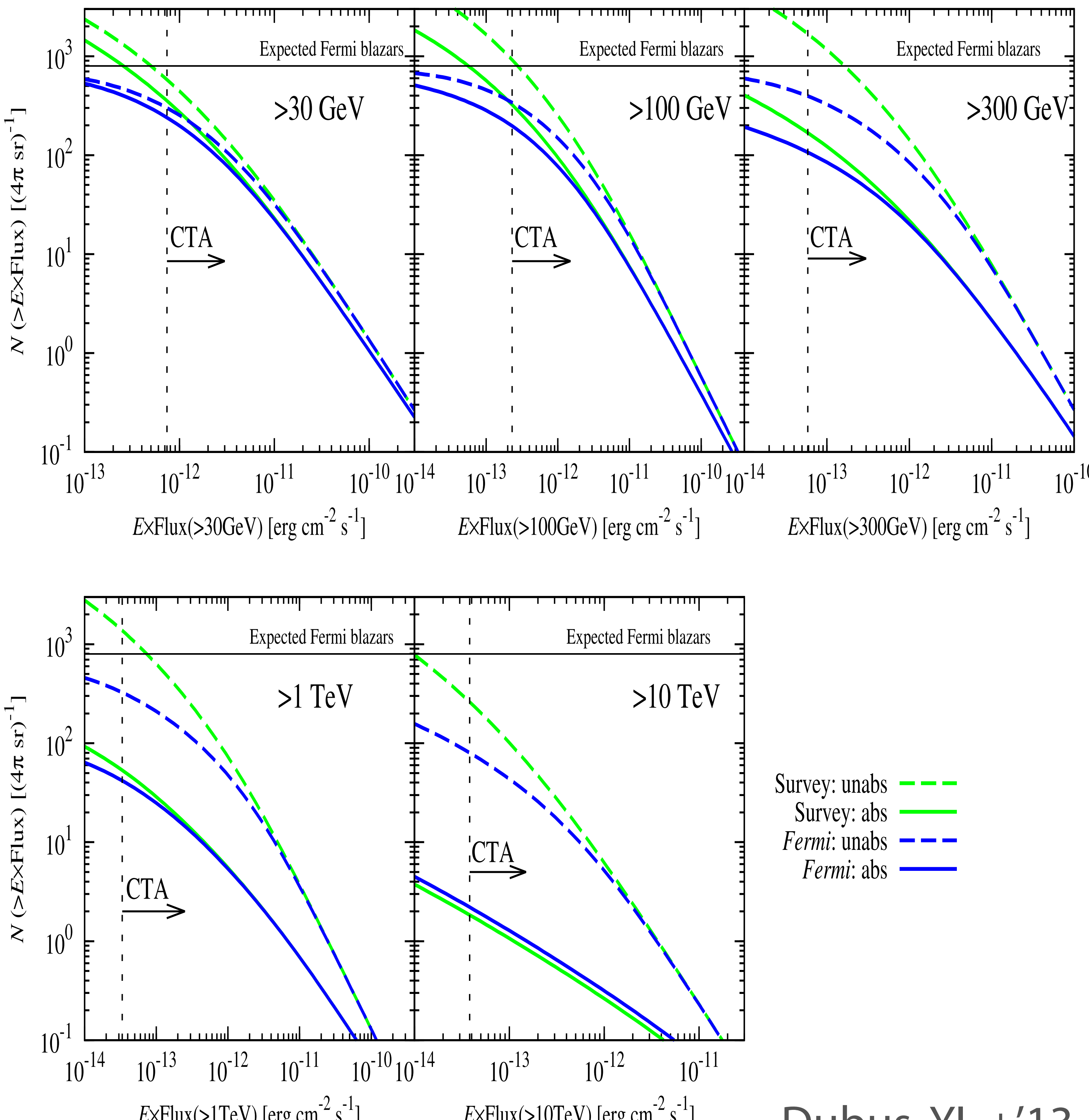
CTA-Japan Meeting @ Kashiwa, 2016-12-15

Current View of VHE Gamma-Ray Sky



- ~200 very high energy (VHE; >50 GeV) blazars by Fermi/LAT (see the 2FHL catalog)
- ~70 VHE blazars by imaging atmospheric Cherenkov telescopes (IACTs; see TeVCat)

VHE Extragalactic Sky Survey by CTA

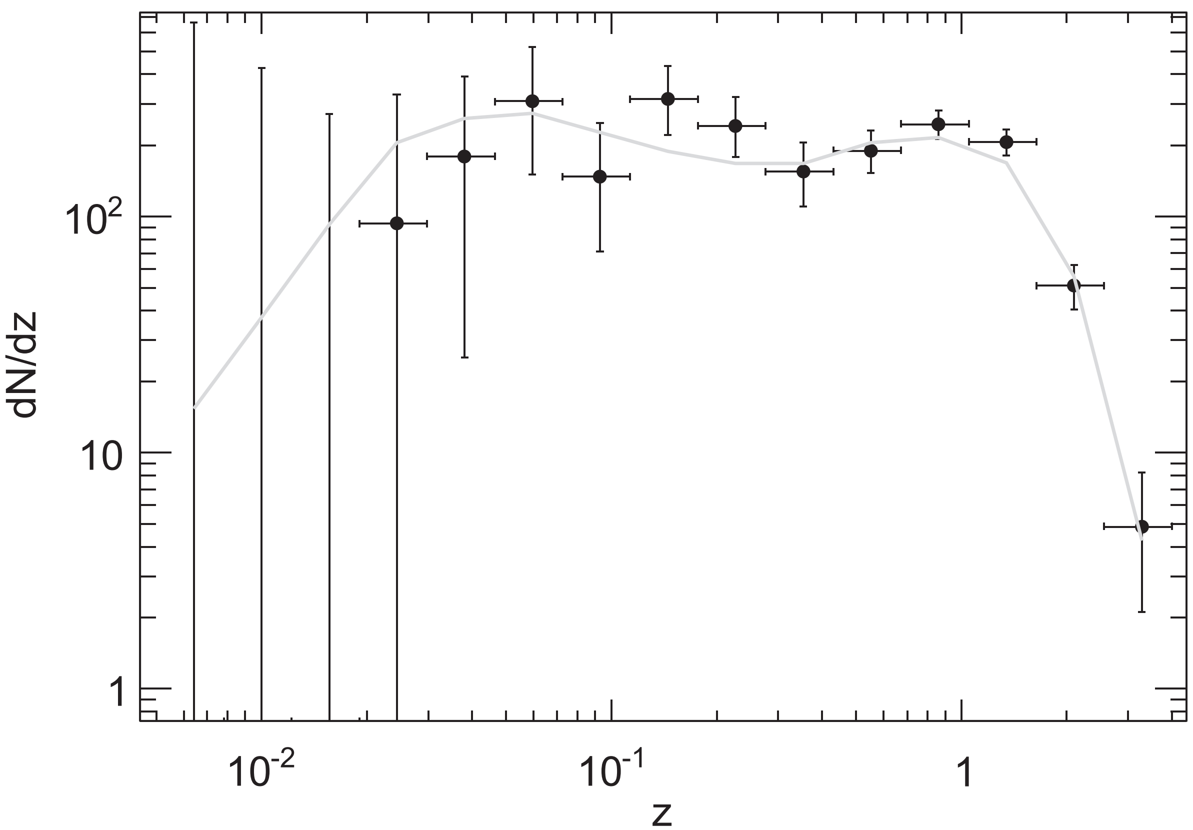


Dubus, YI, +'13
for CTA Special Issue

- Future survey will enable us to study
  - High energy phenomena around SMBHs
  - Cosmological evolution of blazars
- We have investigated the expected source counts (YI, Totani, & Mori '10; Dubus, YI+'13; YI, Kalashev, Kusenko+'14).

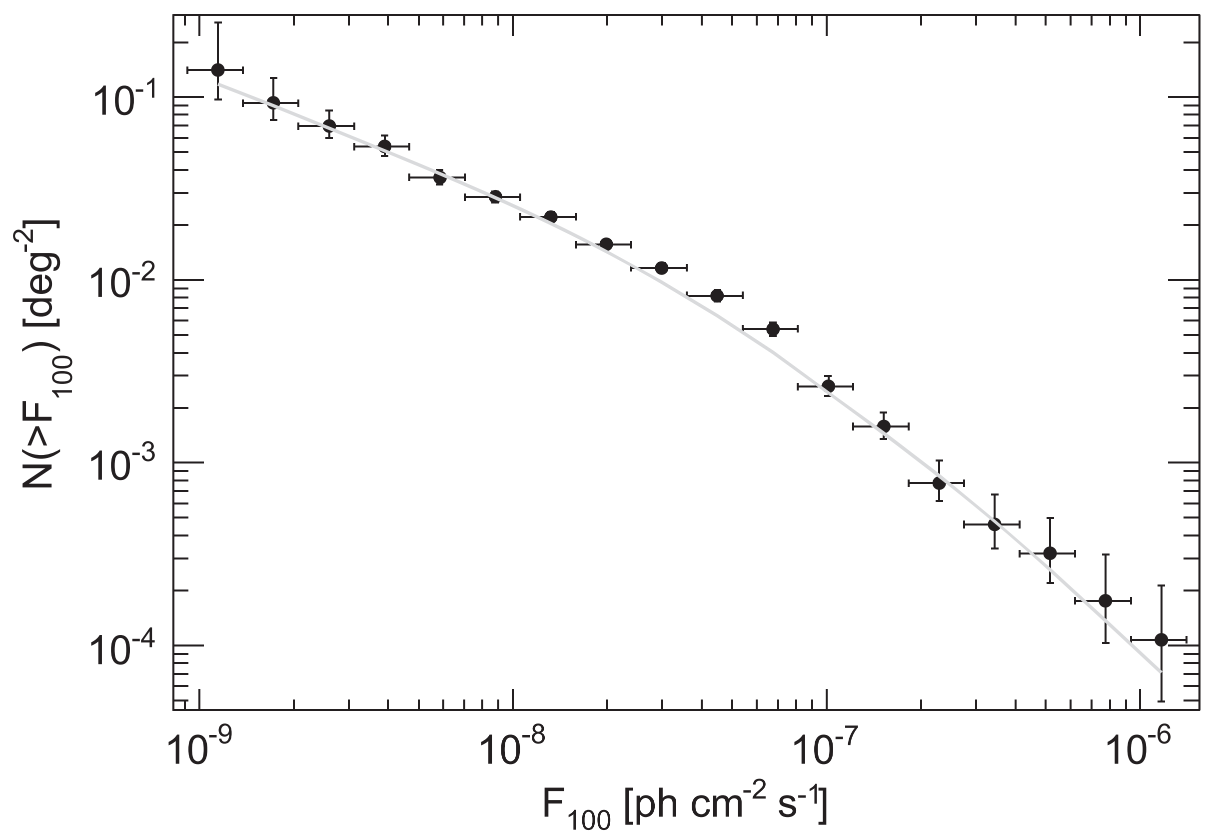
A New Blazar Luminosity Function

Redshift Distribution



Ajello, MASC, YI+’15

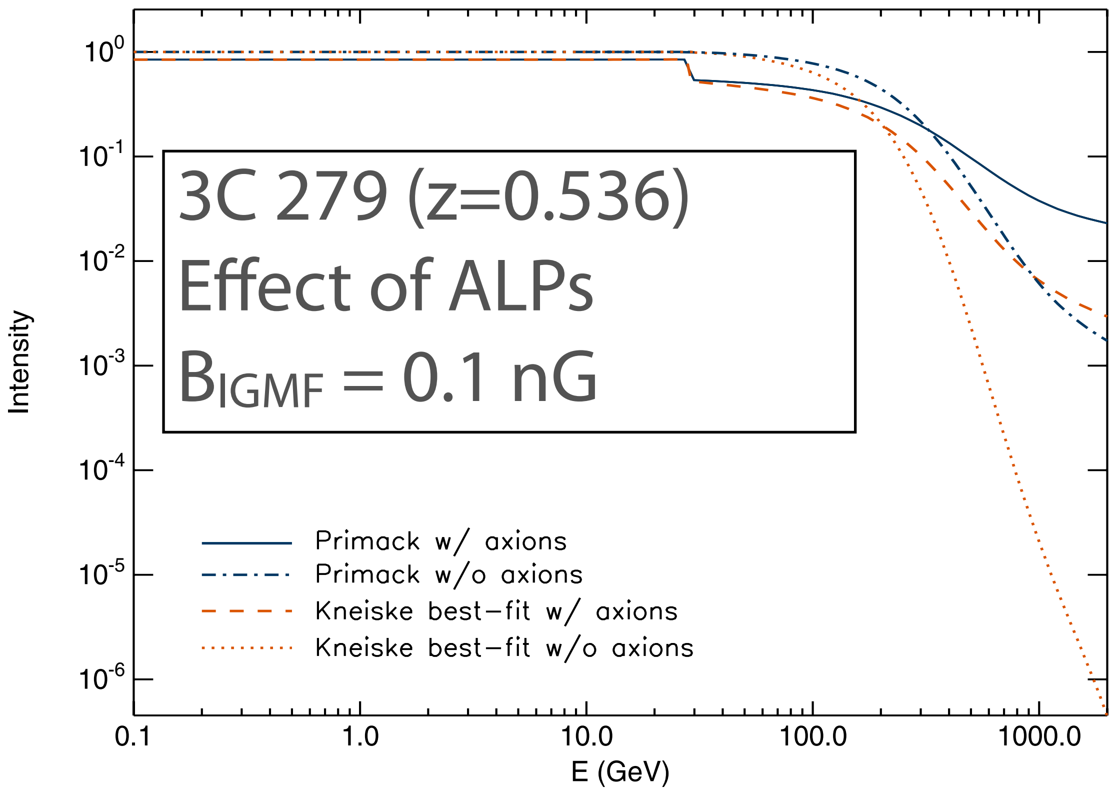
Source Count Distribution



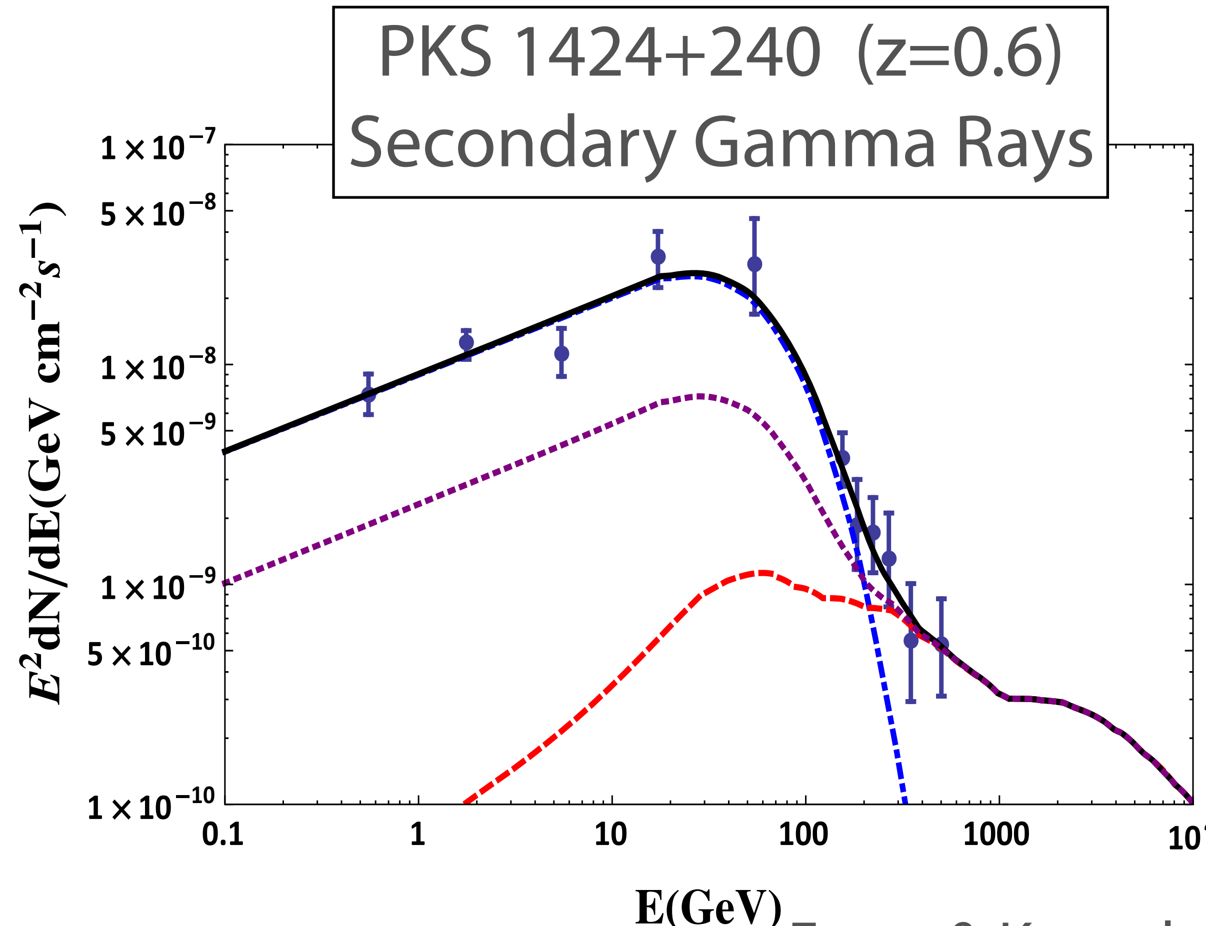
Ajello, MASC, YI+’15

- Utilizing the latest 403 Fermi/LAT blazar samples, a new blazar luminosity function is constructed (Ajello, MASC, YI,+’15).

Axion-Like Particles & Secondary γ-rays



Sánchez-Conde+’09

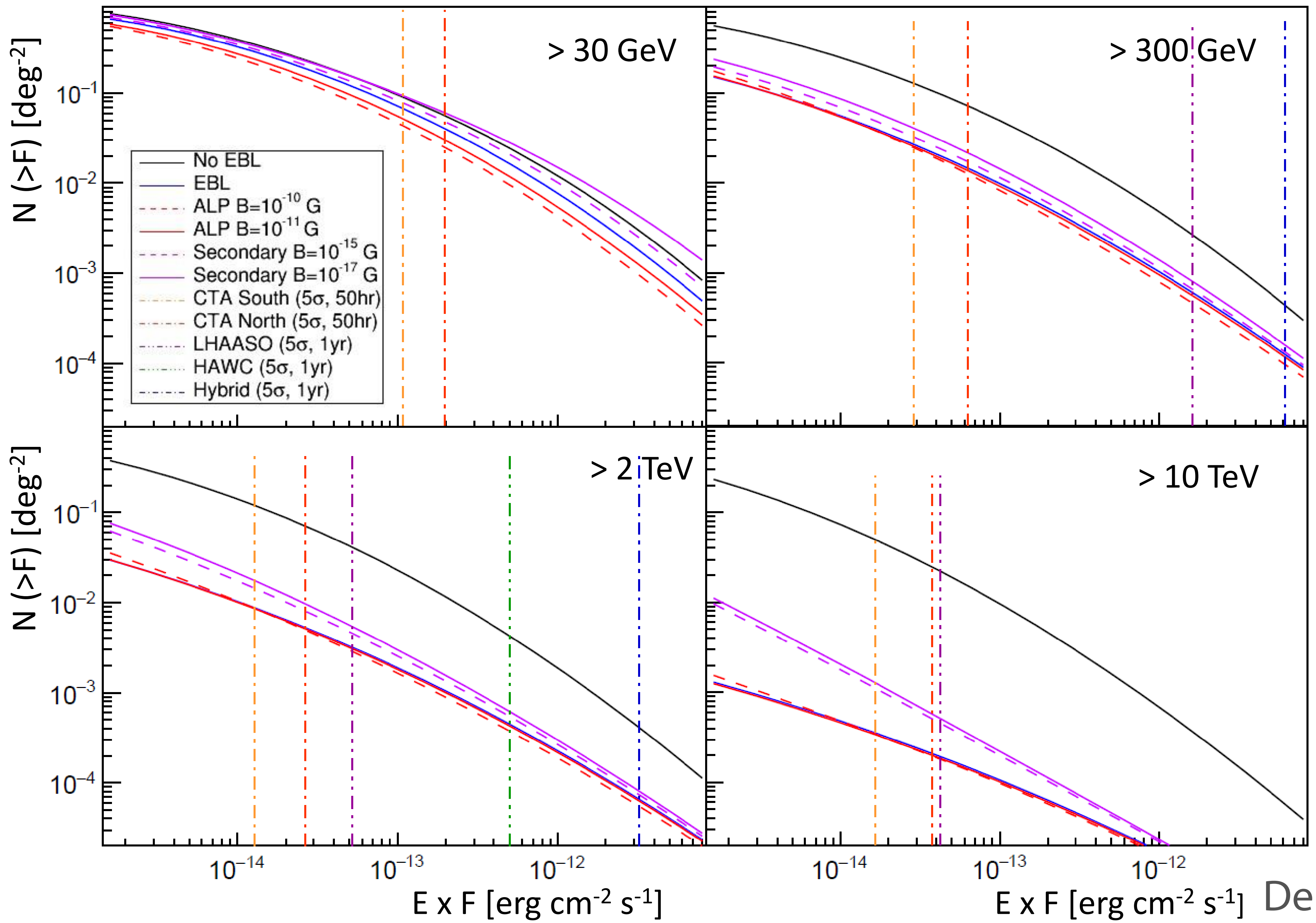


Essey & Kusenko ‘14

- Axion-Like Particles (ALPs) modify the gamma-ray attenuation effect (e.g. De Angelis+07; Sánchez-Conde+09; Horns+12).
- Secondary gamma rays from cosmic rays along line of sight

(e.g. Essey & Kusenko ’10, Essey+’10, Essey+’11, Murase+’12,Takami+’13).

Cumulative Source Count Distribution



De Franco+'17

Assuming EBL attenuation only and 50 hr obs. per FoV

>30 GeV	>300 GeV	>2 TeV	>10 TeV
5×10^{-2} deg^{-2}	2×10^{-2} deg^{-2}	5×10^{-3} deg^{-2}	3×10^{-4} deg^{-2}

200 hrs Blind Surveys

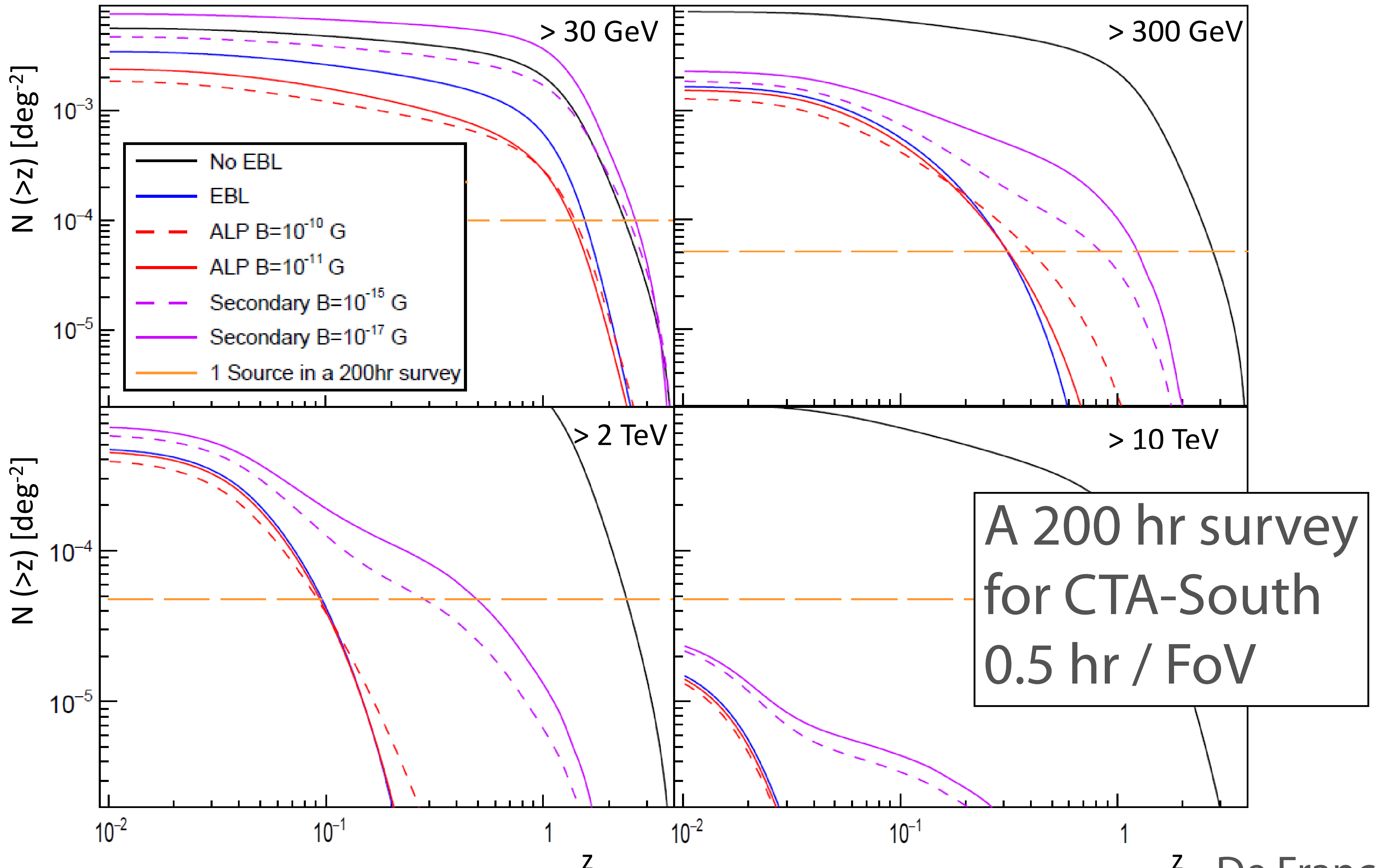
CTA-South/North – 0.5 hr

	>30 GeV	>300 GeV	>2 TeV	>10 TeV
EBL	35/13	32/15	10*/4	-/-
ALP (B=10^{-10} G)	19/7	25/12	8*/4	-/-
ALP (B=10^{-11} G)	24/9	30/14	10*/4	-/-
Secondary (B=10^{-15} G)	47/18	36/16	12*/5	1*/-
Secondary (B=10^{-17} G)	76/32	45/20	14*/6	1*/-

De Franco+'17

- FoV of 5°, 7°, 9° at >30 GeV, >300 GeV, >2 TeV
  - FoV of 7° at > 2 TeV for CTA-North (no SSTs)
- ALPs reduce # of blazars at >30 GeV.
- 2x more blazars with the secondary scenario.

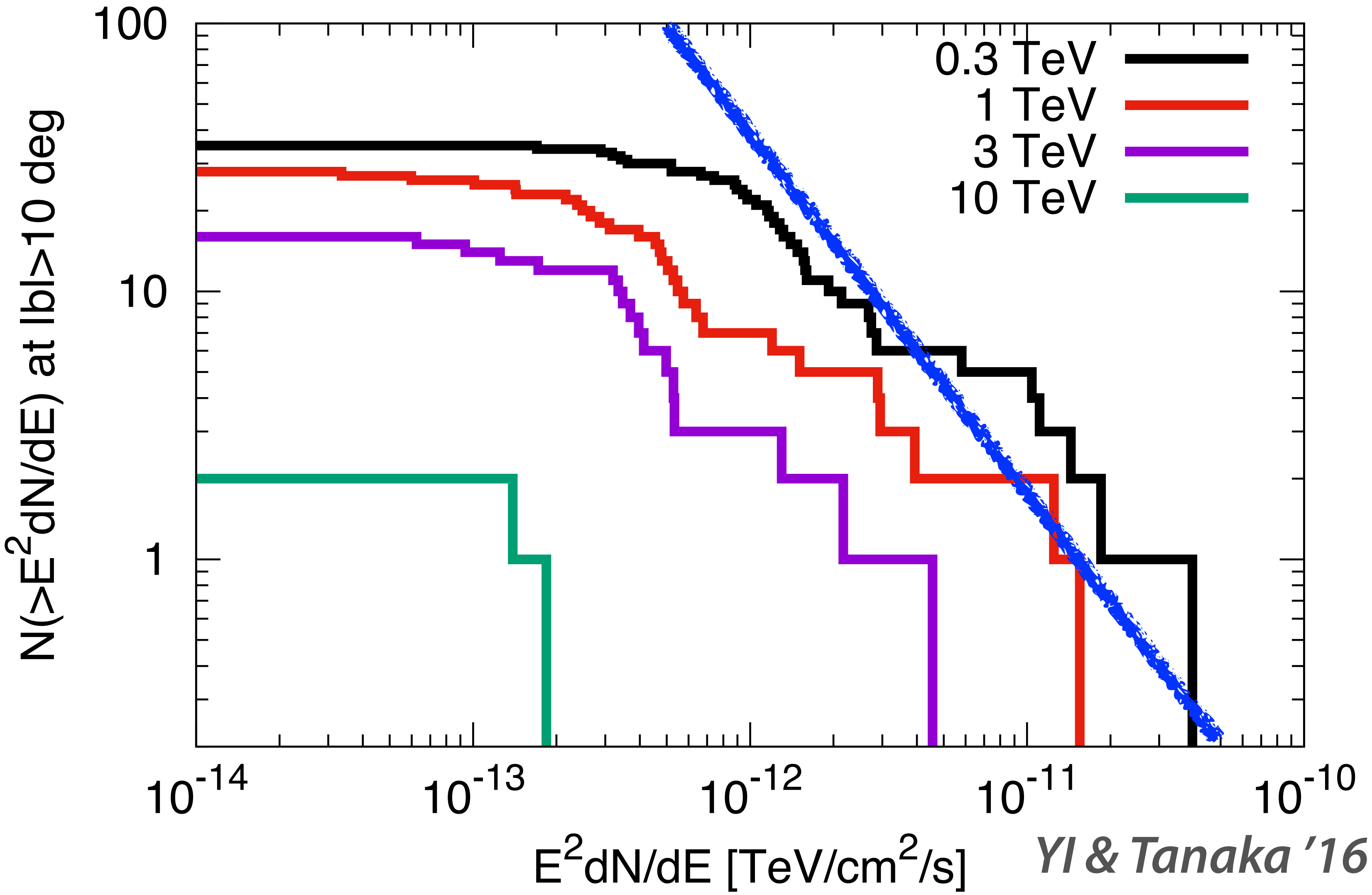
Cumulative Redshift Distribution



De Franco+'17

- z~2 blazars will be detected.
- Secondary gamma rays will enable us to detect z~0.4 objects even at >2 TeV (see also YI, Kalashev, & Kusenko '14).

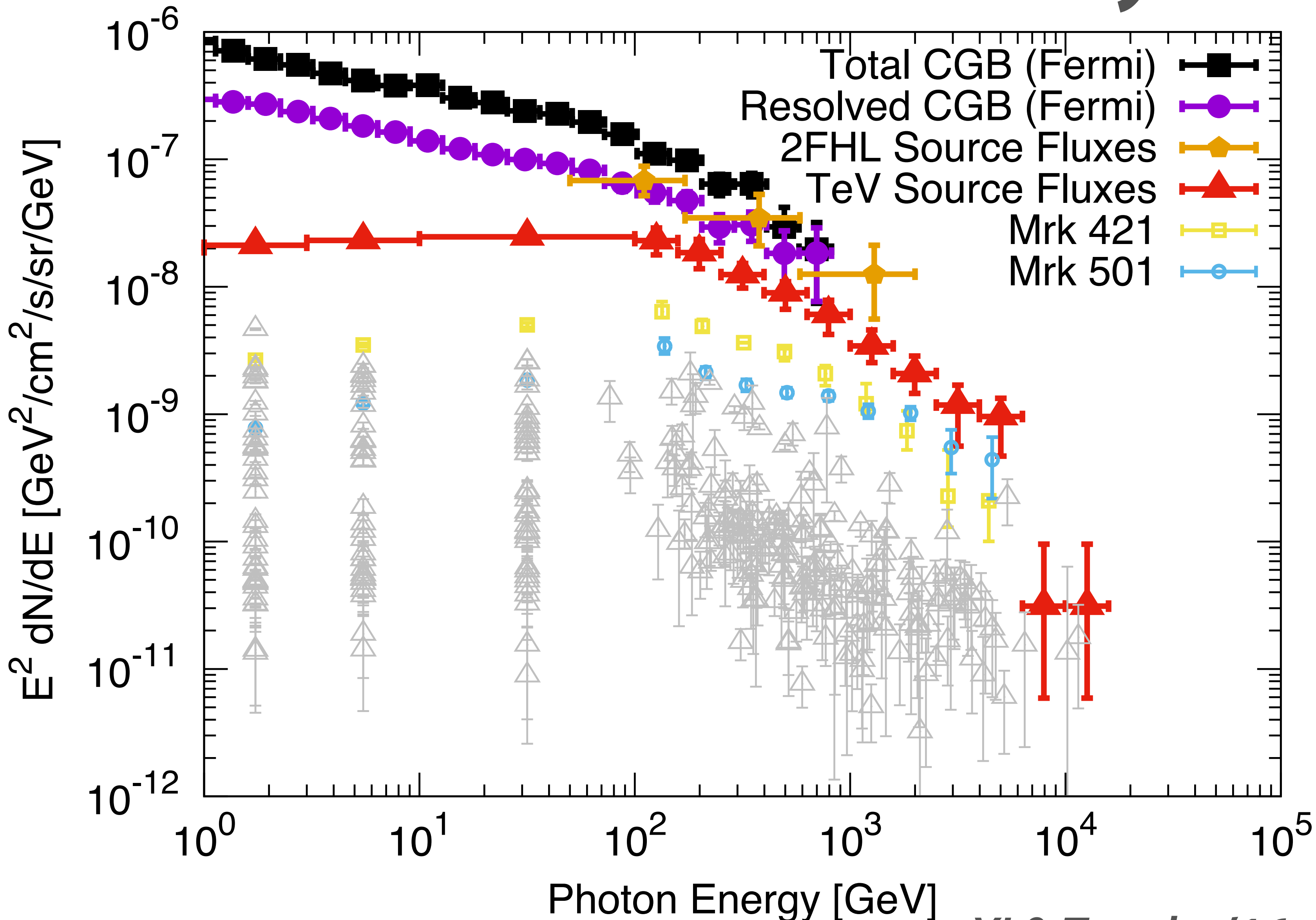
Source Count Distribution



YI & Tanaka '16

- With current IACTs' data
- different from a uniform distribution.
- More uniform and wide sky coverage is required.

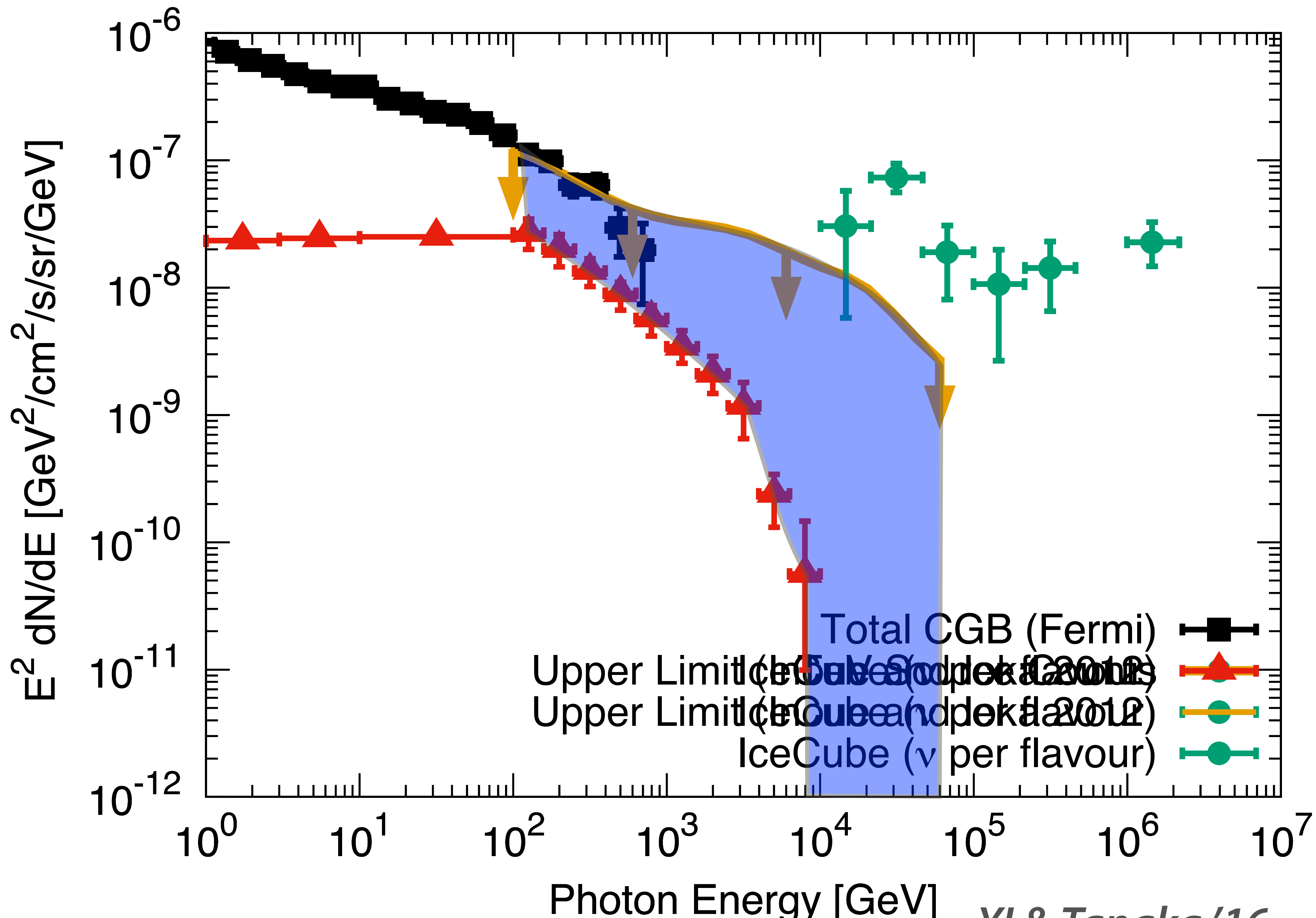
Lower Bound on the Cosmic Gamma-ray Background



YI & Tanaka '16

- TeV source counts give lower limit on to the cosmic gamma-ray background.
- Fermi has resolved more portion of the TeV sky than IACTs do.
  - CTA & HAWC surveys will be important in order to check this.

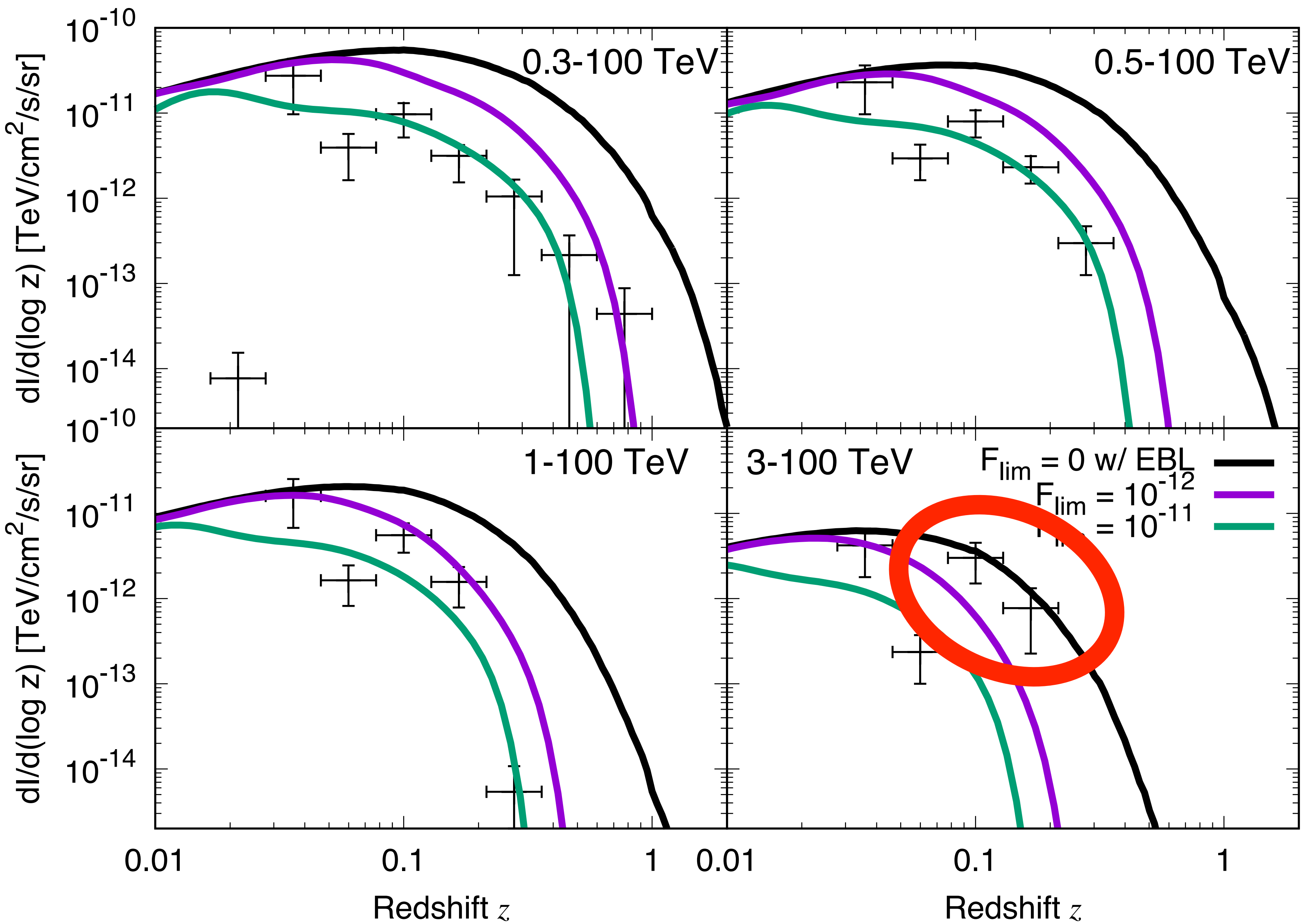
Bounds on the Cosmic TeV Gamma-ray Background



YI & Tanaka '16

- Current limit at 0.1-10 TeV is
  - 3×10^{-8} (E/0.1 TeV)$^{-0.8}$ exp(-E/2 TeV) < E^2dN/dE < 1×10^{-7} (E/0.1 TeV)$^{-0.5}$ [GeV/cm^2/s/sr]

Redshift Distribution

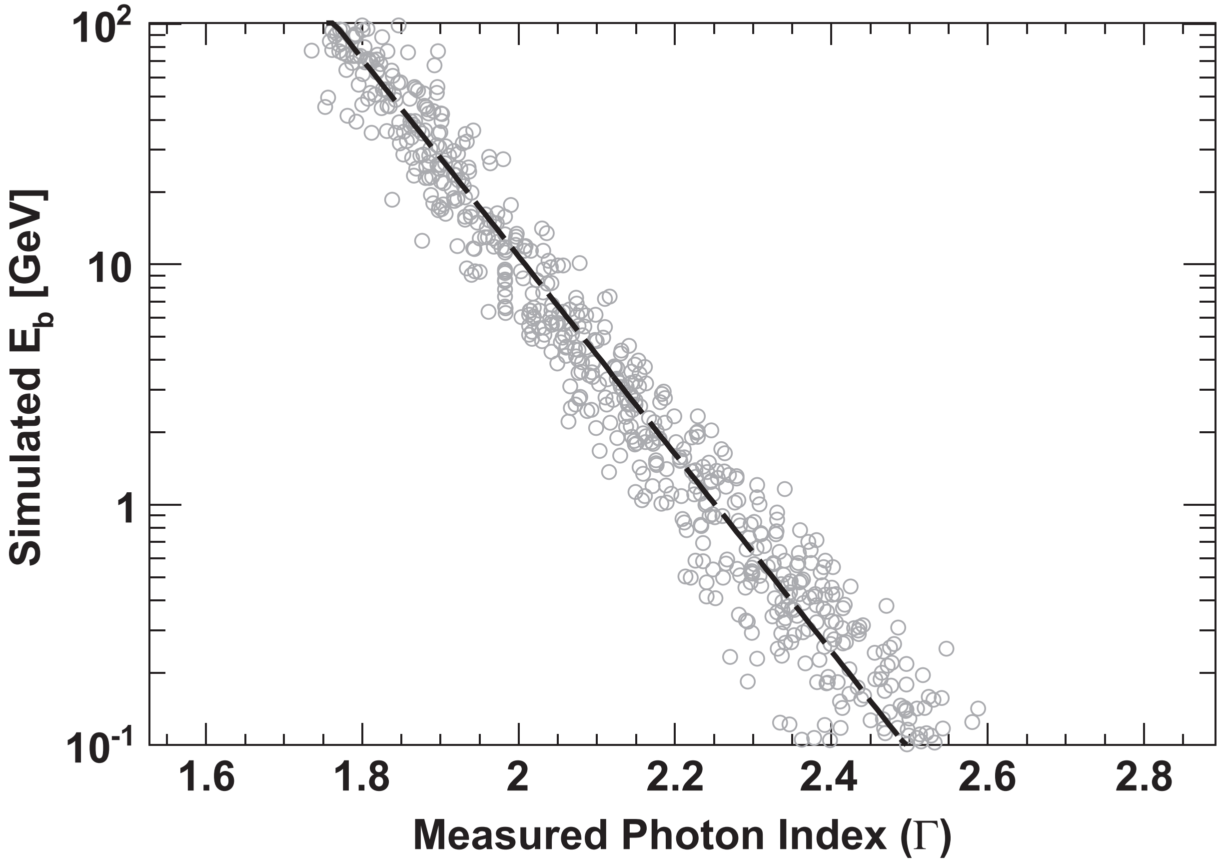


- Redshift distribution of gamma-ray fluxes
  - at high energies, samples are not enough.

Summary

- We revisit prospect for future CTA extragalactic survey taking into account 1): the latest blazar luminosity function, 2): axion-like particles, and 3): secondary gamma rays.
  - the source density will be 5×10^{-2} deg^{-2} at >30 GeV with 50 hr obs/FoV.
- 7-76 blazars will be detected at >30 GeV with two (North & South) 200 hr blind surveys (-> ***<u>less than a year</u>***).
- ALPs would reduce # of blazars at >30 GeV.
- Secondary gamma rays will allow us to see out to z~1 at >2 TeV.

Spectral Model in Ajello+'15



Ajello+'15

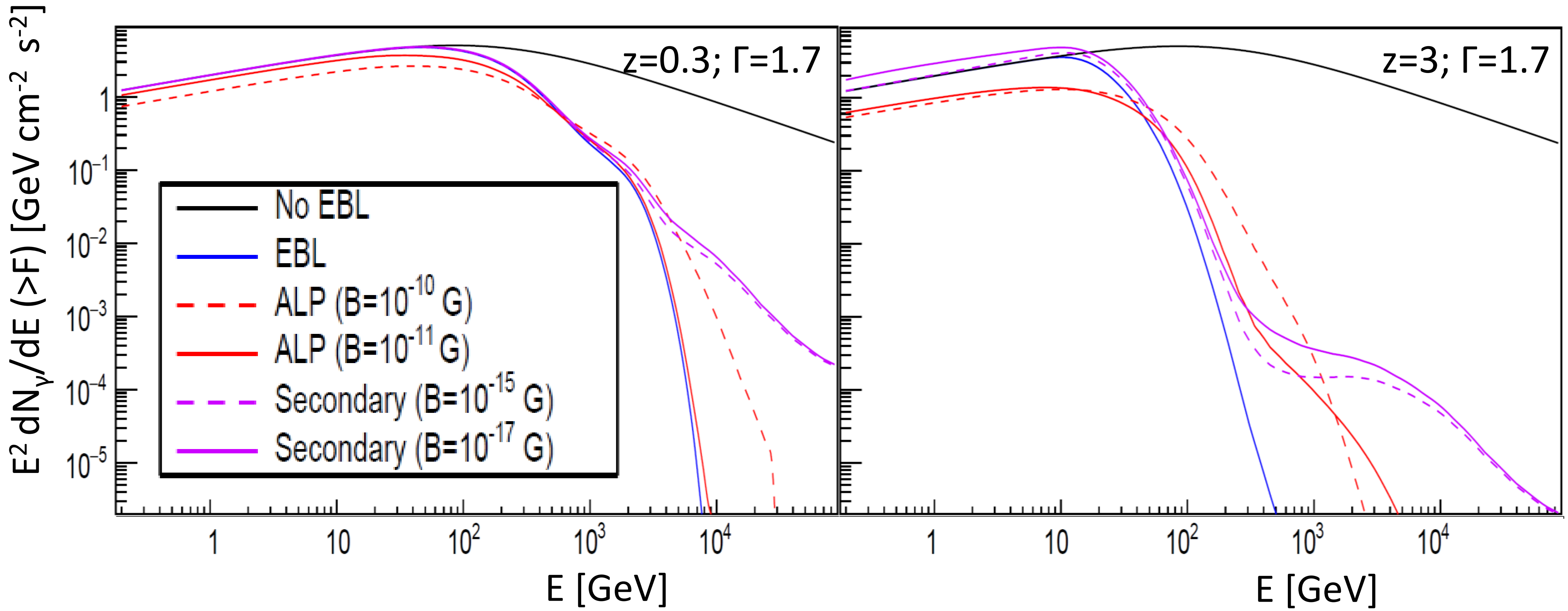
- Blazar SED template

$$\frac{dN_\gamma}{dE}(E,\Gamma,z) \propto \left[\left(\frac{E}{E_b}\right)^{1.7} + \left(\frac{E}{E_b}\right)^{2.6}\right]^{-1} e^{-\tau(E,z)}$$

- Break energy E_b

$$\log E_b(\mathrm{GeV}) = 9.25 - 4.11\Gamma$$

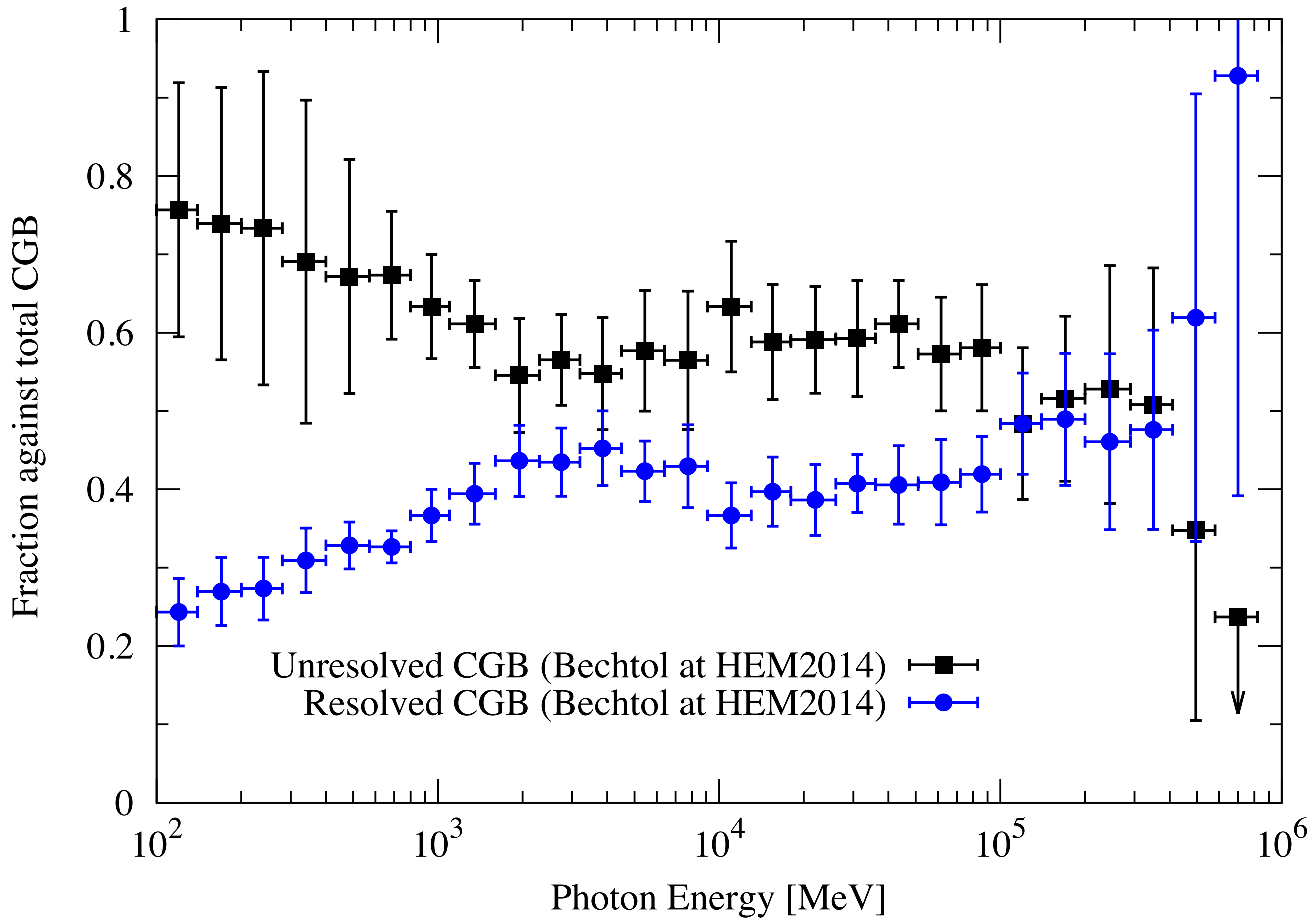
Spectral Modeling

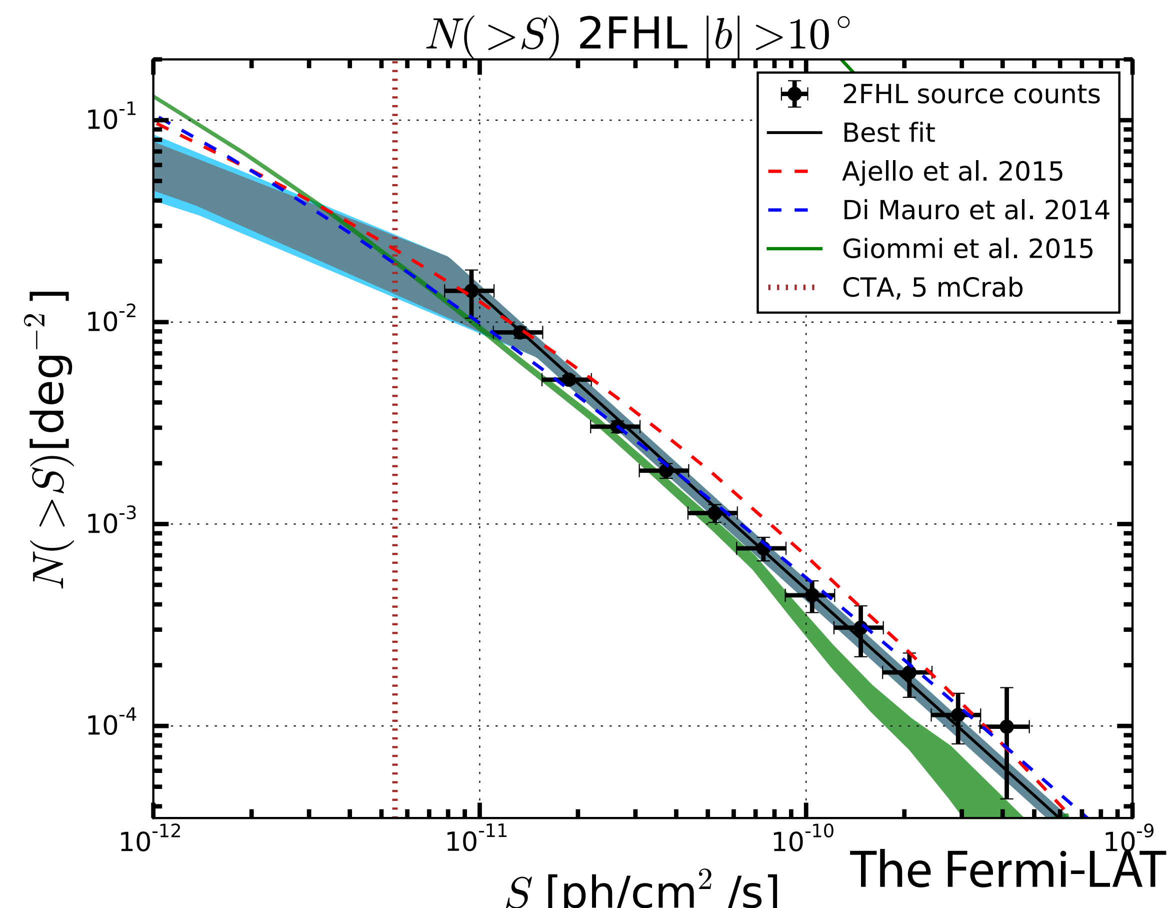


De Franco+'17

- We use an average blazar SED template in Ajello, MASC, YI+'15 and the YI+'13 EBL attenuation model.
- For ALPs, we use the model by MASC+'09 with B = 10^{-11} and 10^{-10} G.
- For secondary gamma rays, we use the model by Kalashev+'12 with B = 10^{-17} and 10^{-15} G

How large fraction of the VHE sky resolved by Fermi?

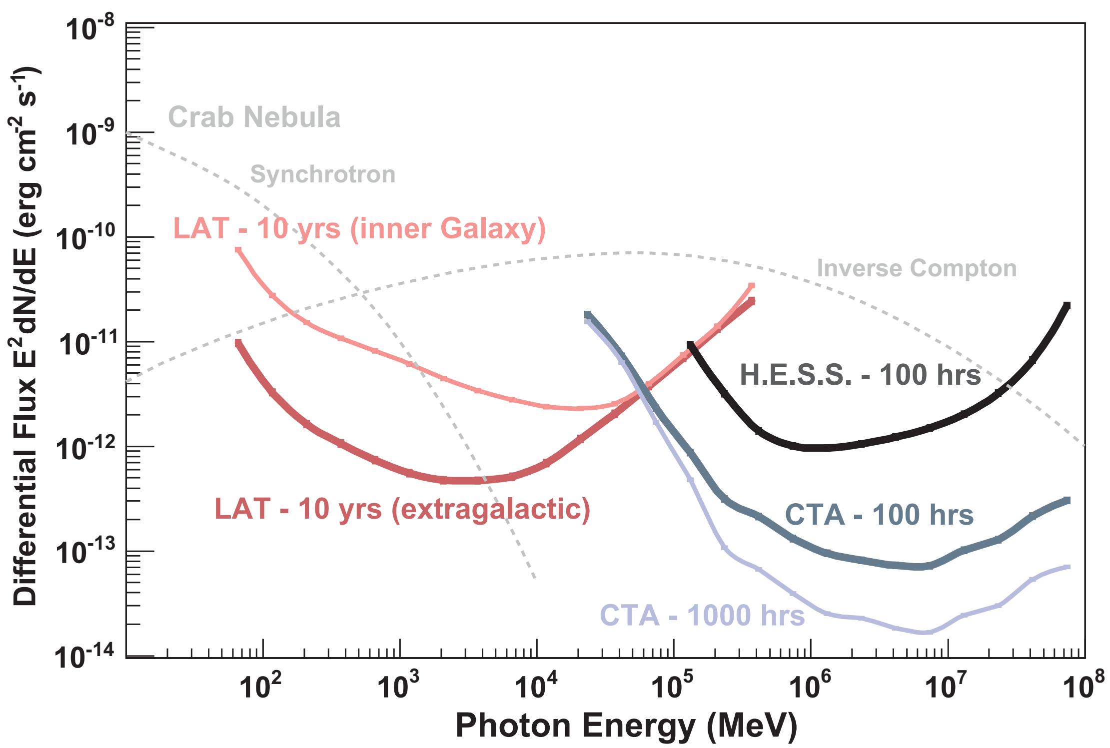


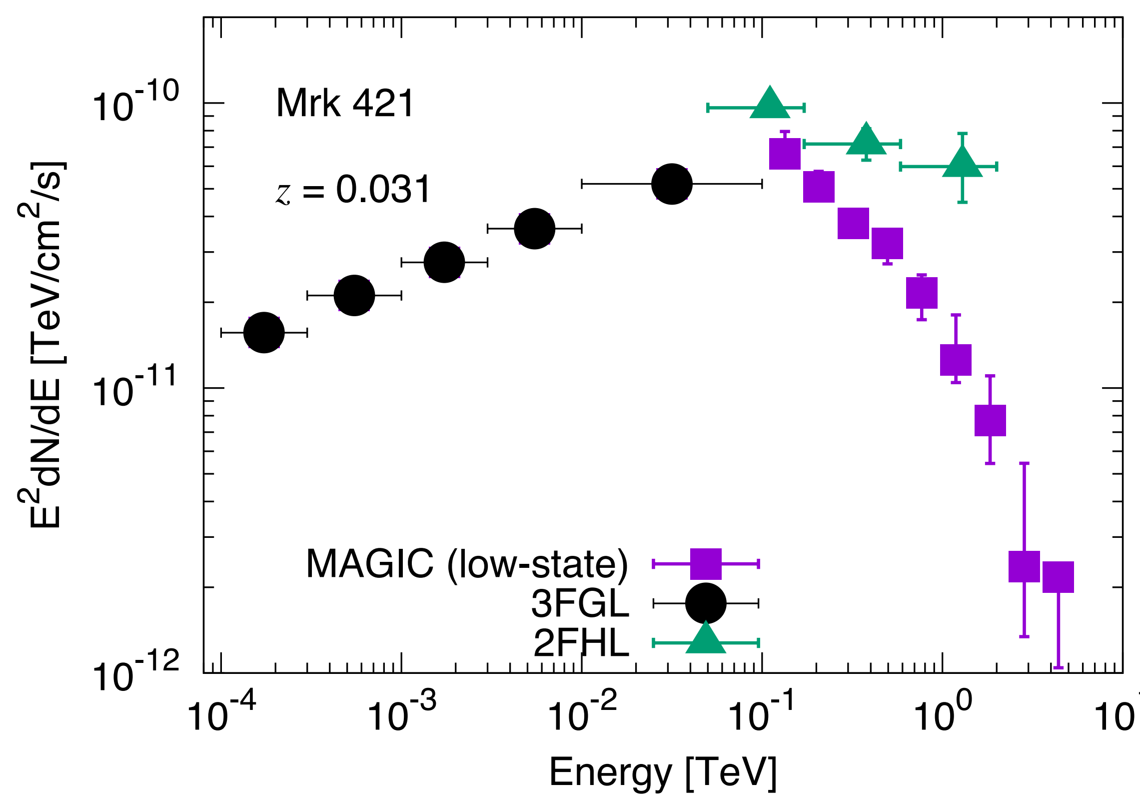


The Fermi-LAT collaboration '15

- Fermi has resolved 50-80% of the VHE sky (0.1-1 TeV).
- CTA survey (at >50 GeV) will not drastically change the source counts.

Why Fermi has resolved the sky more even at ~1 TeV?





- 14 sources at the highest energy (585-2000 GeV) bin in the 2FHL samples, while 30 sources at >585 GeV in our sample. ⇒ Sky coverage is not the cause.
- The dominant object Mrk 421 is variable.
  - The CGB is the time-averaged spectrum. e.g. Fermi accumulated data 80 months for 2FHL.
  - We need long-term monitoring of TeV sources. ⇒ HAWC & current IACTs in the CTA era.