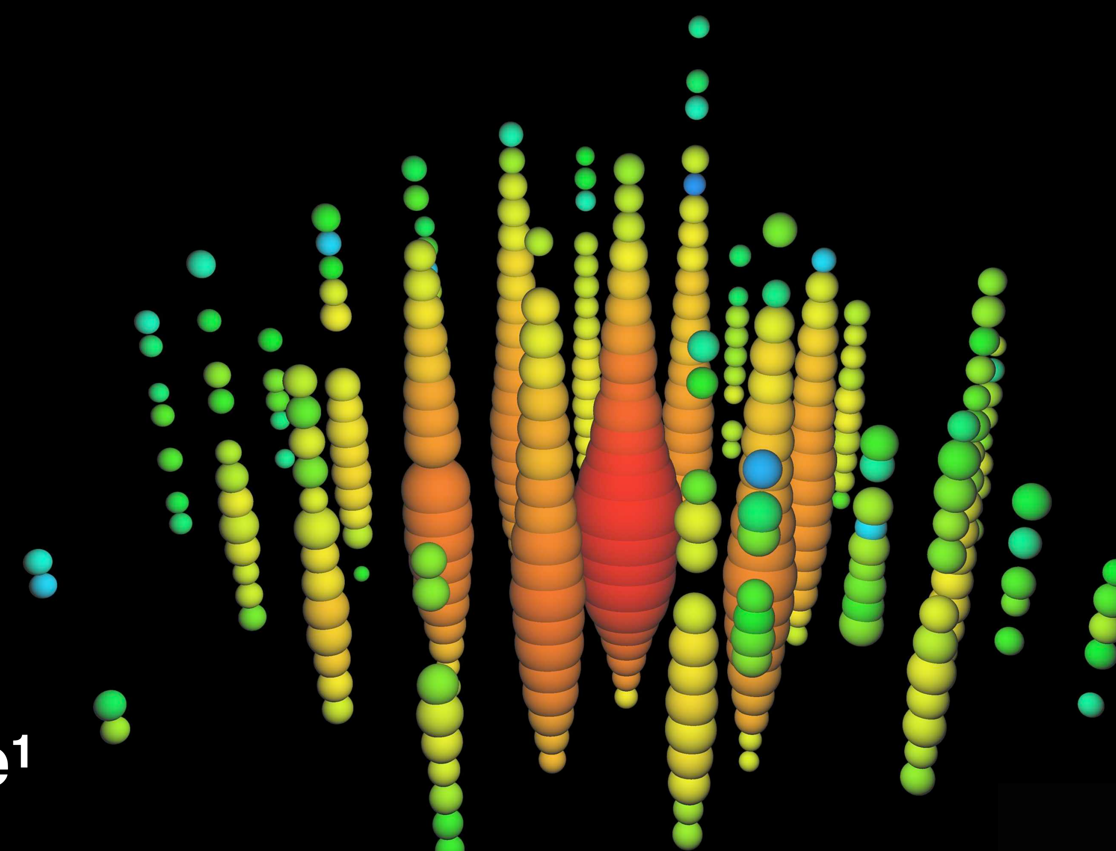
Evidence Against Starburst Galaxies as the Primary Source of IceCube Neutrinos

arXiv:1511.00688



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Markus Ahlers[1], Mattia DiMauro[2],
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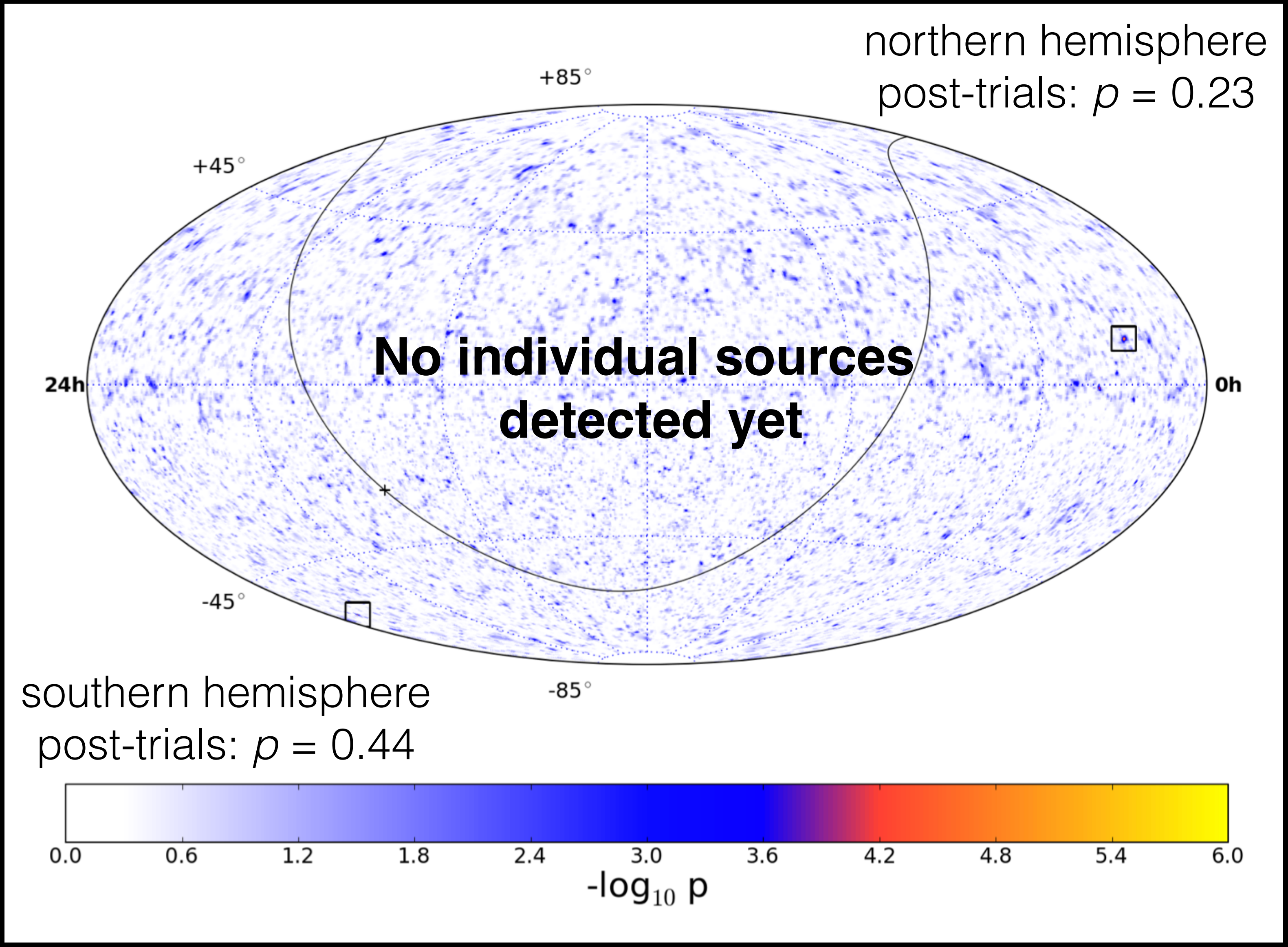
Perspectives on the Extragalactic Frontier

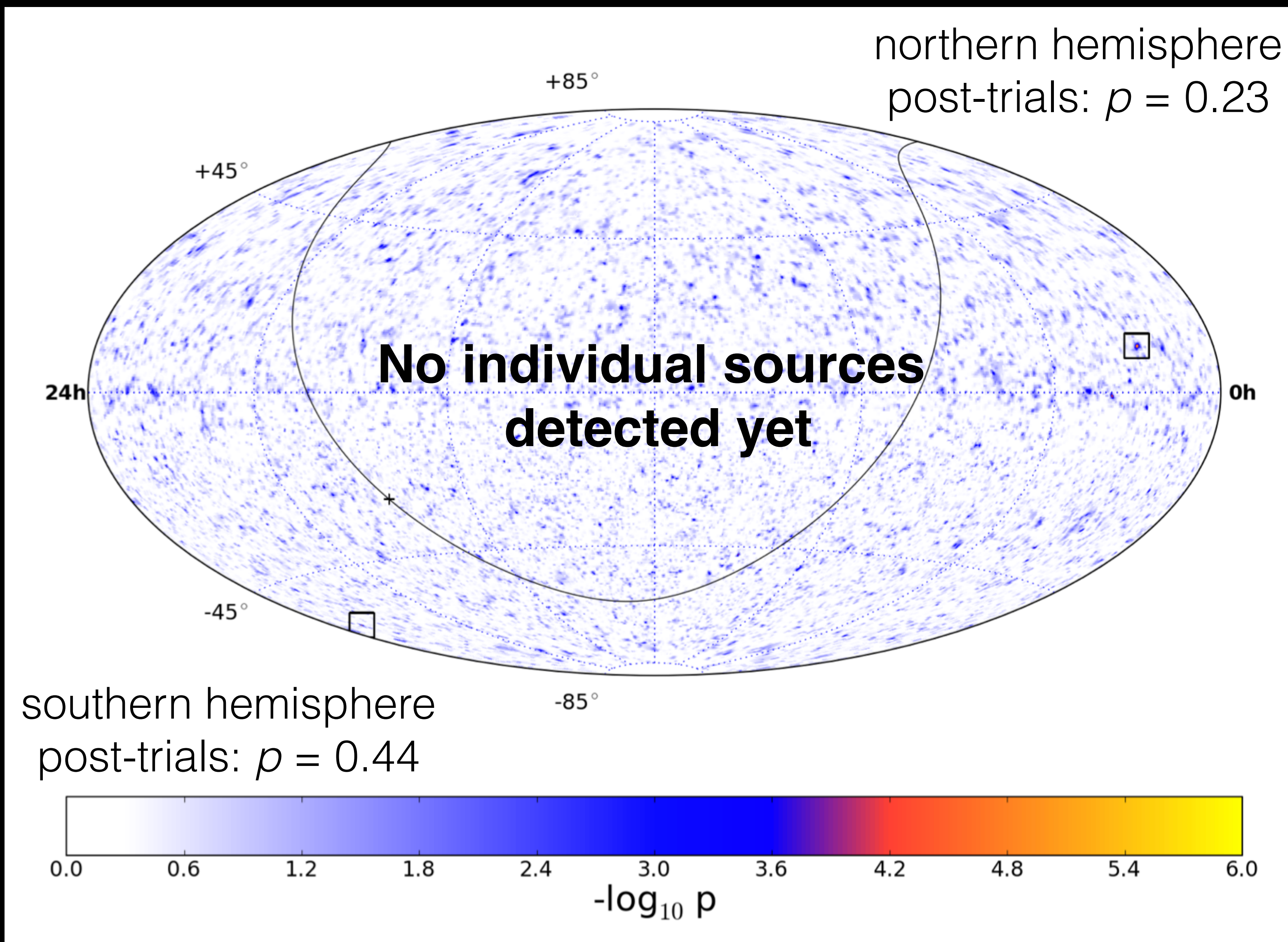
3 May 2016

Starburst Galaxies as a Candidate Source Class of High-Energy Neutrinos



IceCube 2014, arXiv:1406.6757

Starburst Galaxies as a Candidate Source Class of High-Energy Neutrinos



IceCube 2014, arXiv:1406.6757

Contribution to IceCube signal from dedicated population studies

Gamma-ray blazars: < 20%

Glusenkamp et al. (IceCube) 2015
arXiv:1502.03104

Gamma-ray bursts: < 1%

IceCube 2015
arXiv:1412.6510

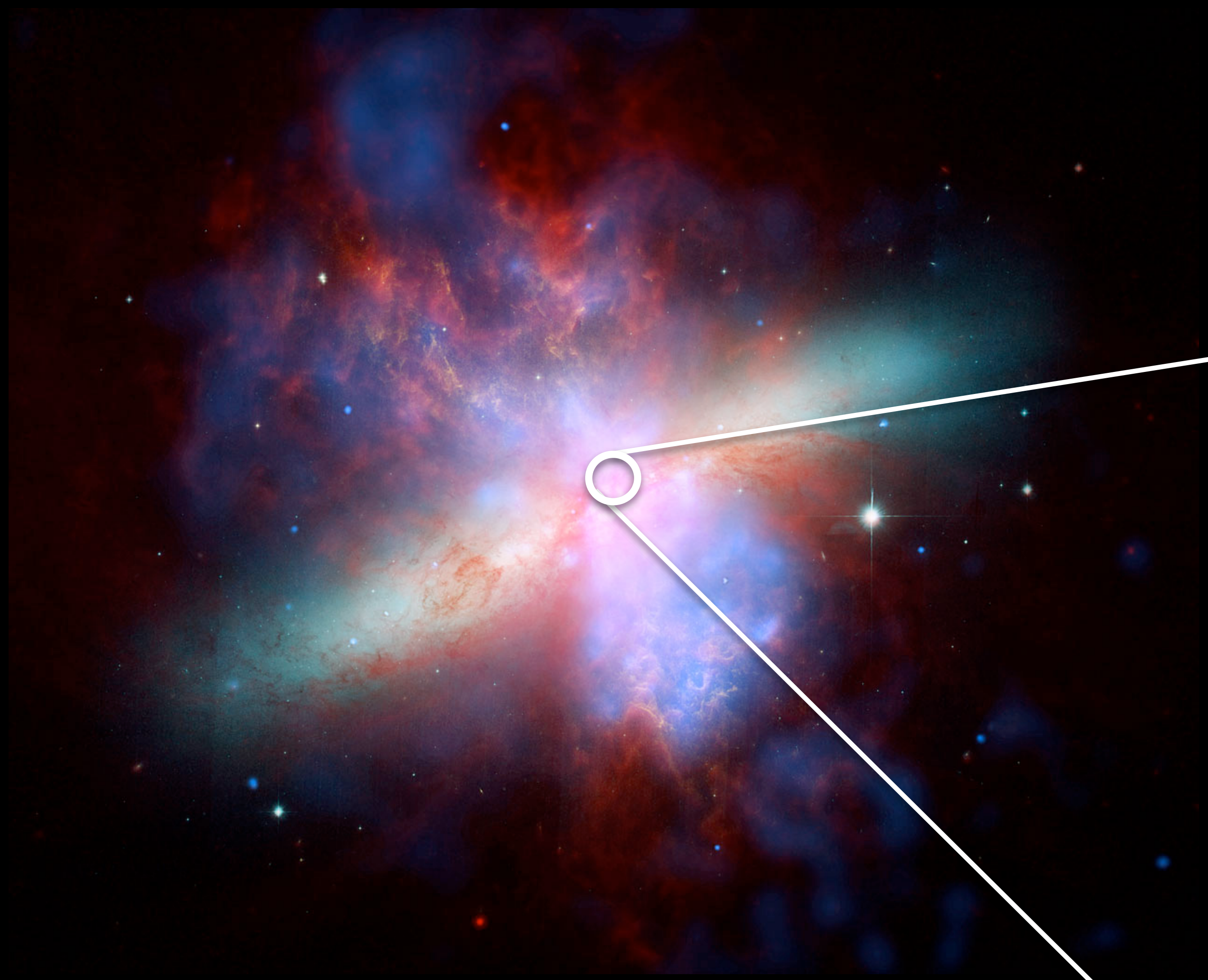
Point-source searches are not yet sensitive enough to strongly constrain starburst models

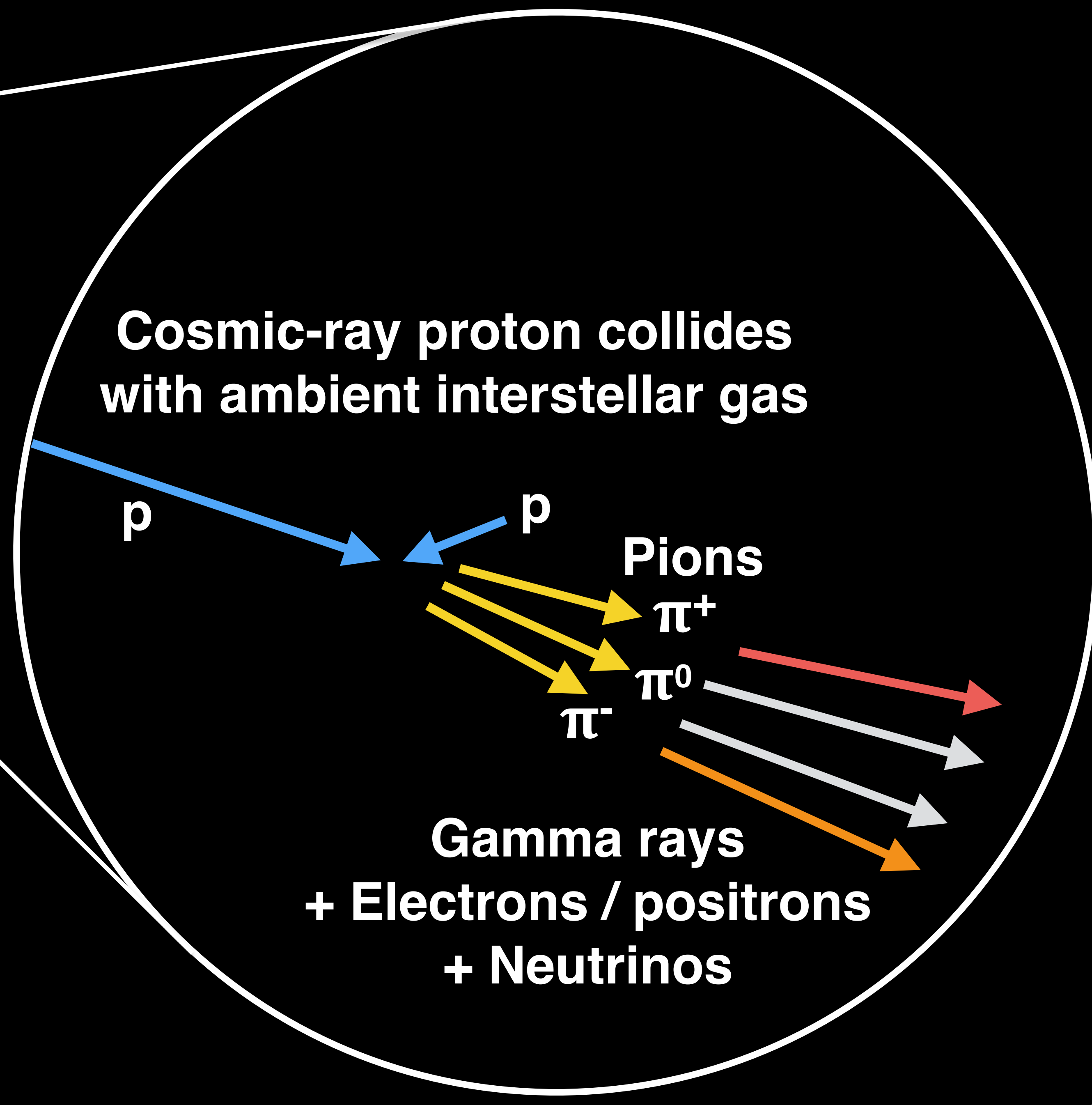
e.g., Loeb & Waxman 2006, Murase et al. 2013, He et al. 2013, Anchordoqui et al. 2014, Chang et al. 2014, Senno et al. 2015

→ ***Suggests population of numerous but individually faint extragalactic sources (e.g., starbursts) rather than rare bright sources***

Starburst Galaxies as a Candidate Source Class of High-Energy Neutrinos

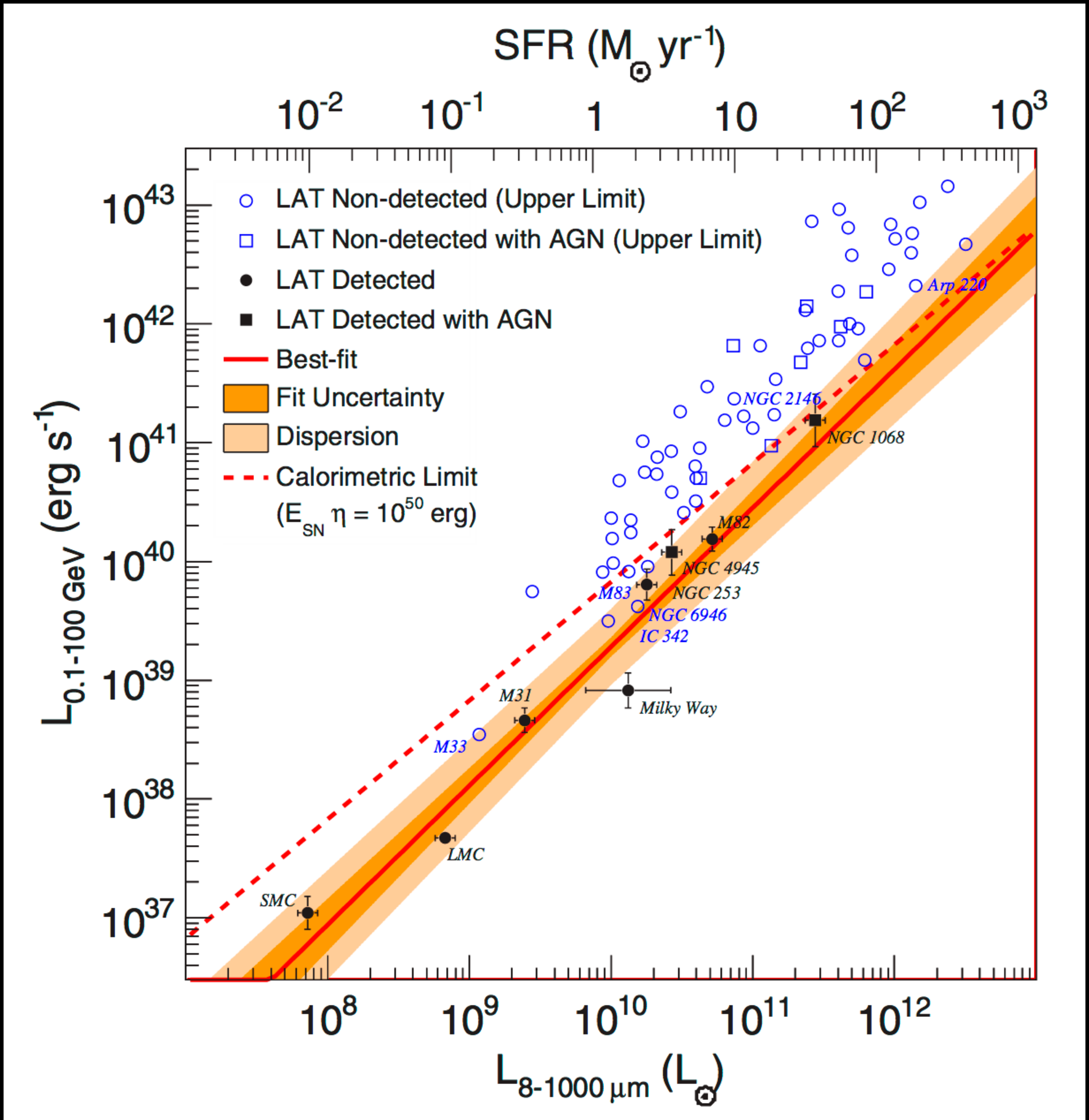
Gamma-ray detection of nearby starbursts indicate large cosmic-ray energy densities





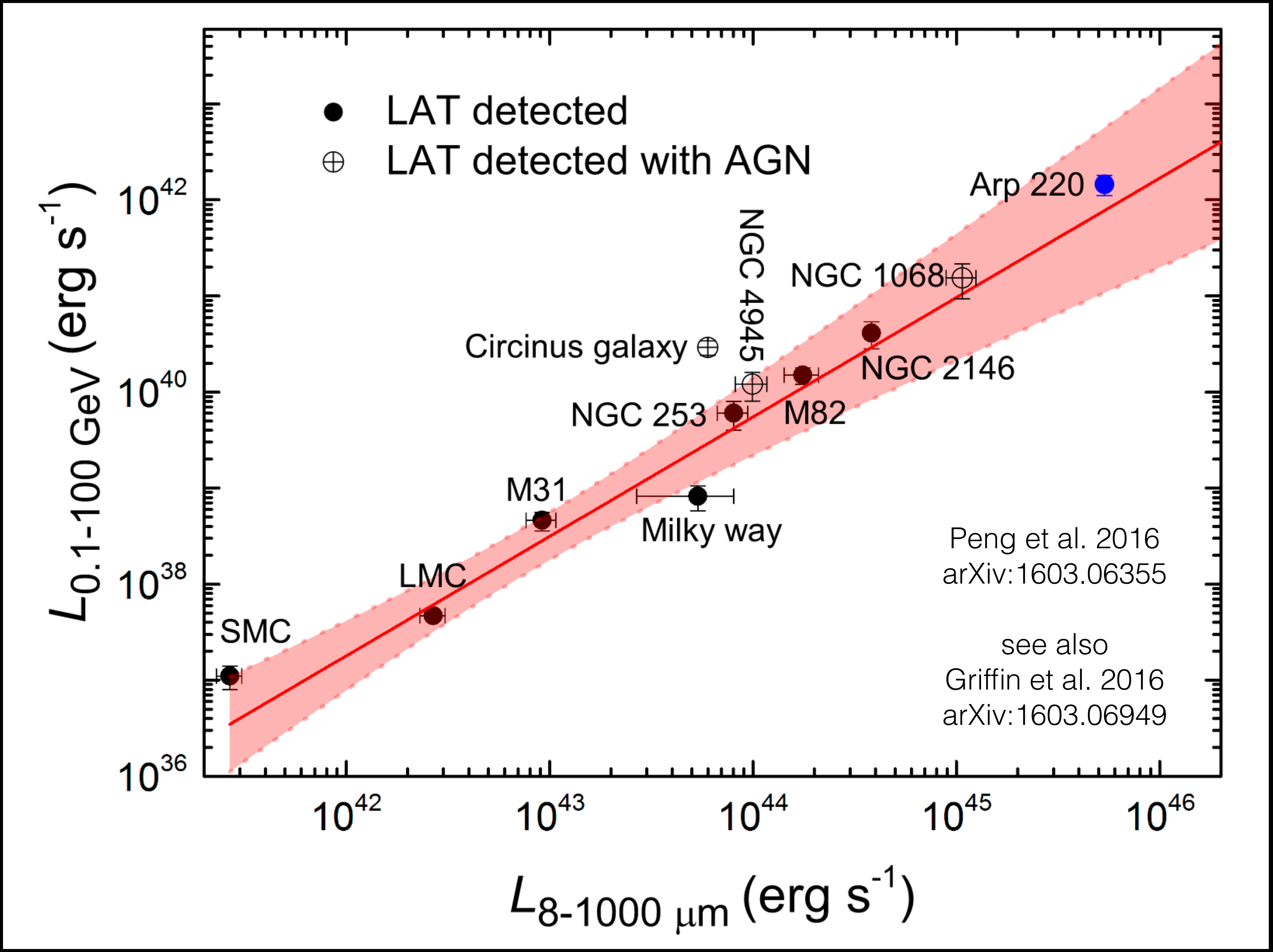
Inevitable production of gamma rays from the same hadronic interactions that create neutrinos

Gamma-ray Detected Starbursts: Luminosity Scaling Relations



Ackermann et al. 2012

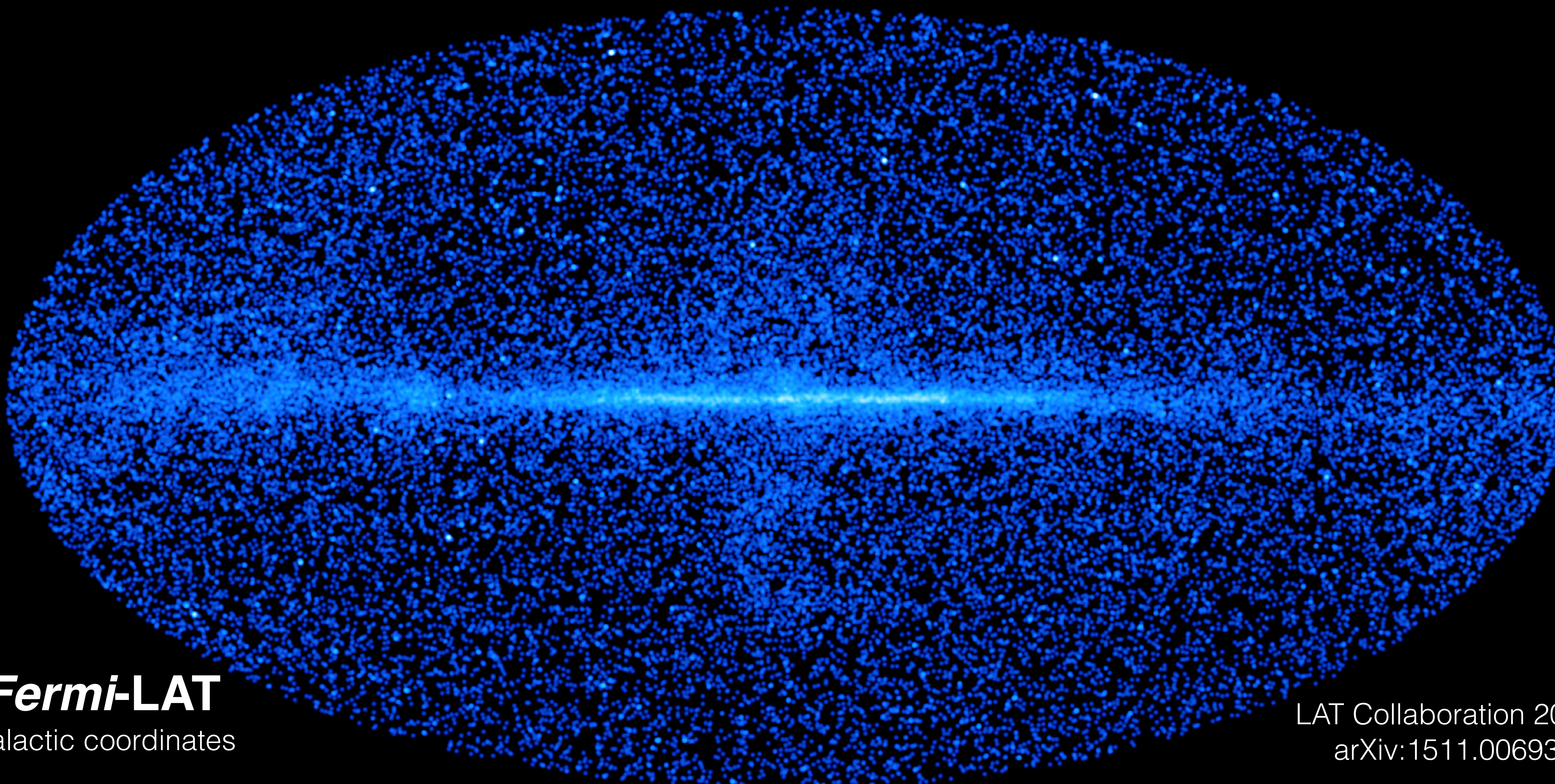
Gamma-ray Detected Starbursts: Luminosity Scaling Relations



Gamma-ray Detected Starbursts: Spectra

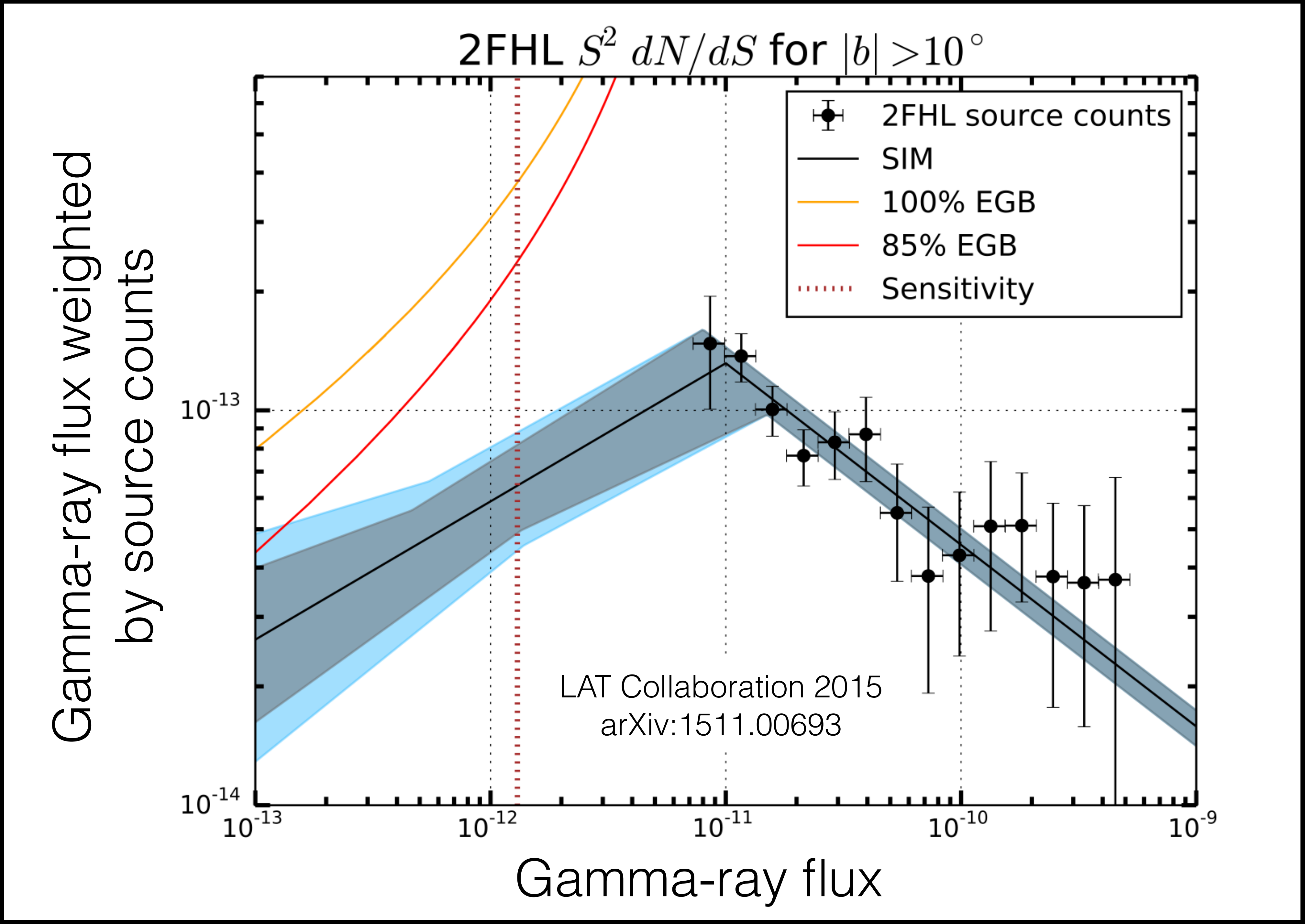
	Spectral Index	Energy Range (GeV)	Reference
M82	2.21 ± 0.06 2.5 ± 0.6	0.1 - 100 700 - 5 x 10	3FGL Acciari et al. 2009
NGC 253	2.34 ± 0.03	0.2 - 3 x 10	Abramowski et al. 2012
NGC 4945	2.43 ± 0.07	0.1 - 100	3FGL
NGC 1068	2.32 ± 0.10	0.1 - 100	3FGL
NGC 2146	2.37 ± 0.15	0.1 - 100	3FGL
Arp 220	2.35 ± 0.16	0.2 - 100	Peng et al. 2016

Resolving the High-energy Extragalactic Gamma-ray Background (EGB)



>50 GeV, 6.7 years, ~60000 events, ~0.1 deg angular resolution
2FHL catalog includes 360 sources
At high Galactic latitude, ~97% blazars

Resolving the High-energy Extragalactic Gamma-ray Background (EGB)



→ ***Blazars account for 86^{+16}_{-14}% of total EGB above 50 GeV***

Cumulative Gamma-ray and Neutrino Emission of Star-forming Galaxies

Two approaches:

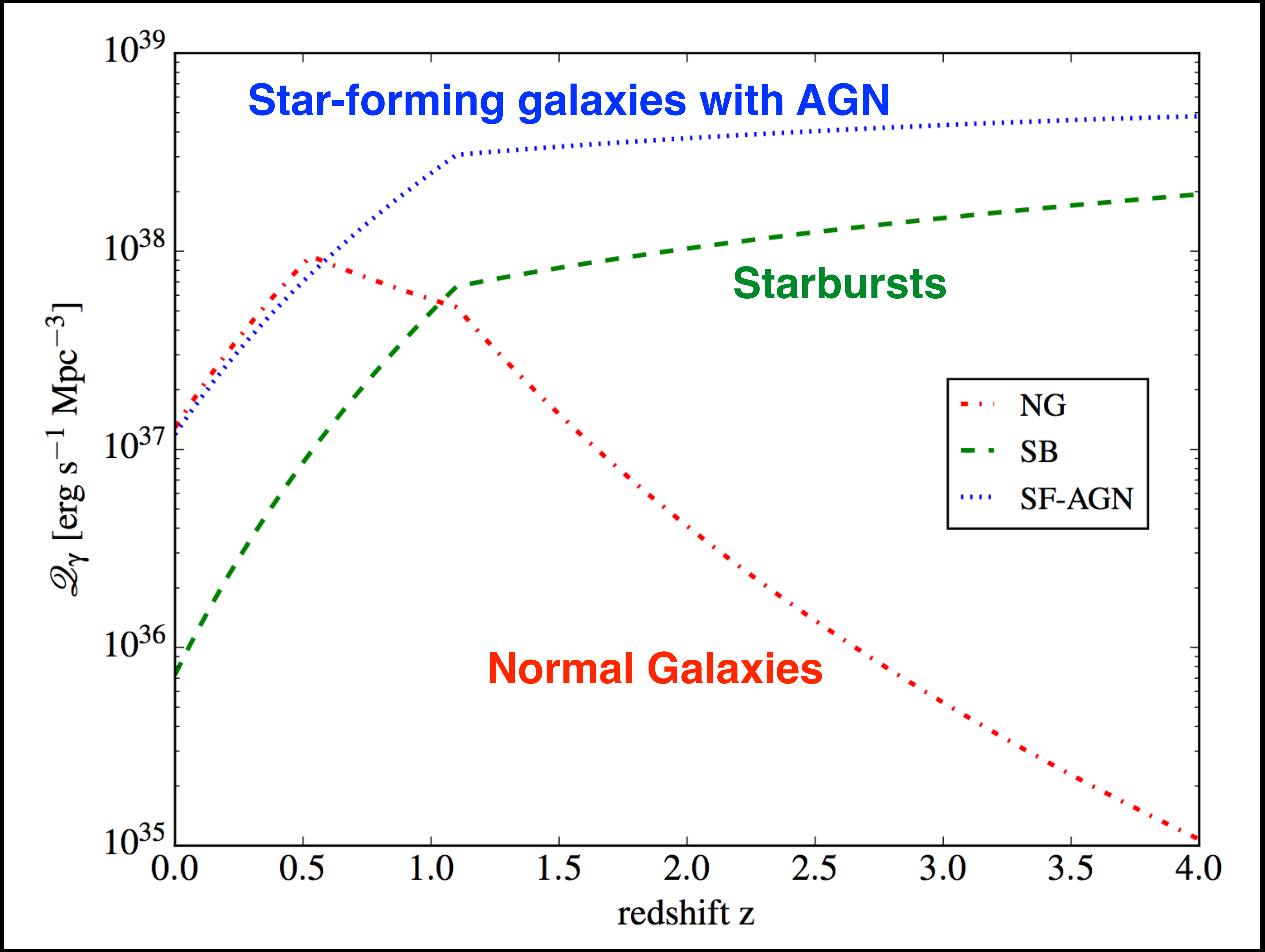
1. "Realistic" star-forming galaxy population model

- IR-gamma-ray luminosity scaling relation
- IR galaxy luminosity function from *Herschel*
- Multiple galaxy sub-classes: normal, starburst, star-forming w/ AGN
- Tamborra, Ando, & Murase 2014

2. Generic calorimeter model

- Cosmic star formation history
- Choose broken power law emission spectrum to fit IceCube diffuse intensity with minimal EGB contribution
- Murase, Ahlers, & Lacki 2013

"Realistic" Galaxy Population Model: Evolution of Emissivity Density



Three populations

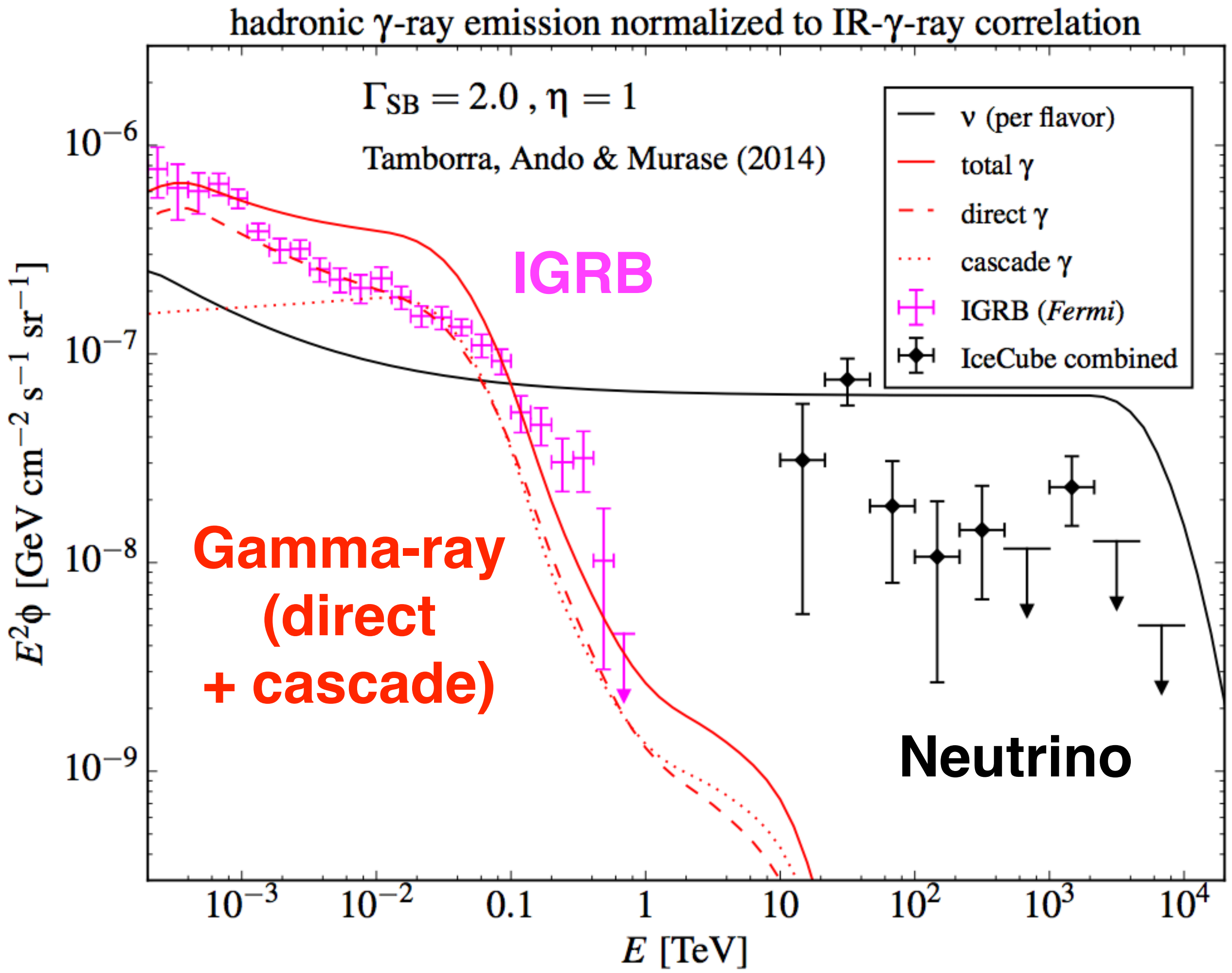
Starbursts:
Spectral index Γ_{SB}

Normal galaxies:
Spectral index $\Gamma_{SB} + \delta$
w/ $\delta = 0.5$

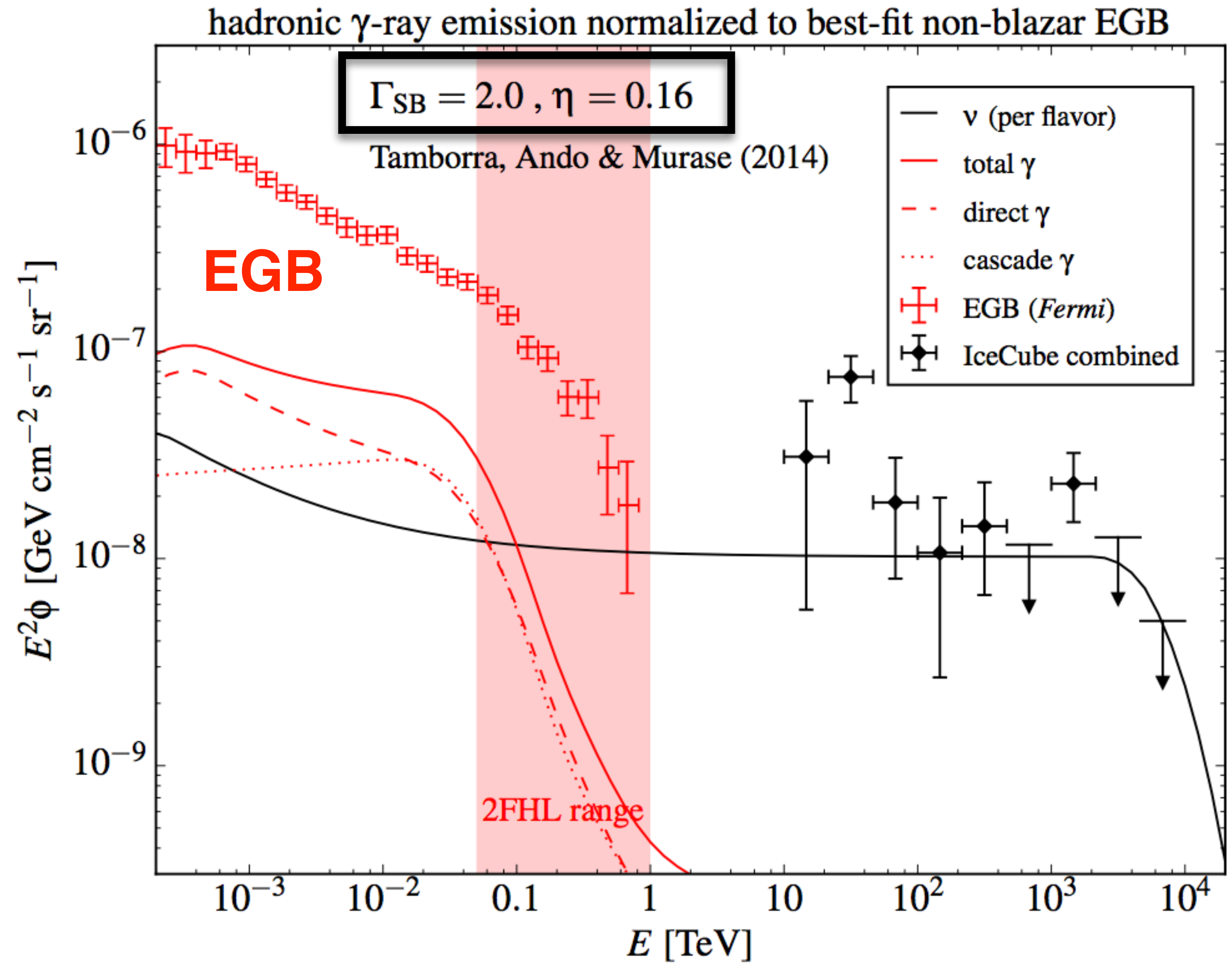
SFGs w/ AGN:
Mix of starbursts and normal galaxies

"Realistic" Galaxy Population Model: Cumulative Emission

Normalized to IR-gamma-ray scaling relation



Normalized to non-blazar EGB (0.05 - 1 TeV)

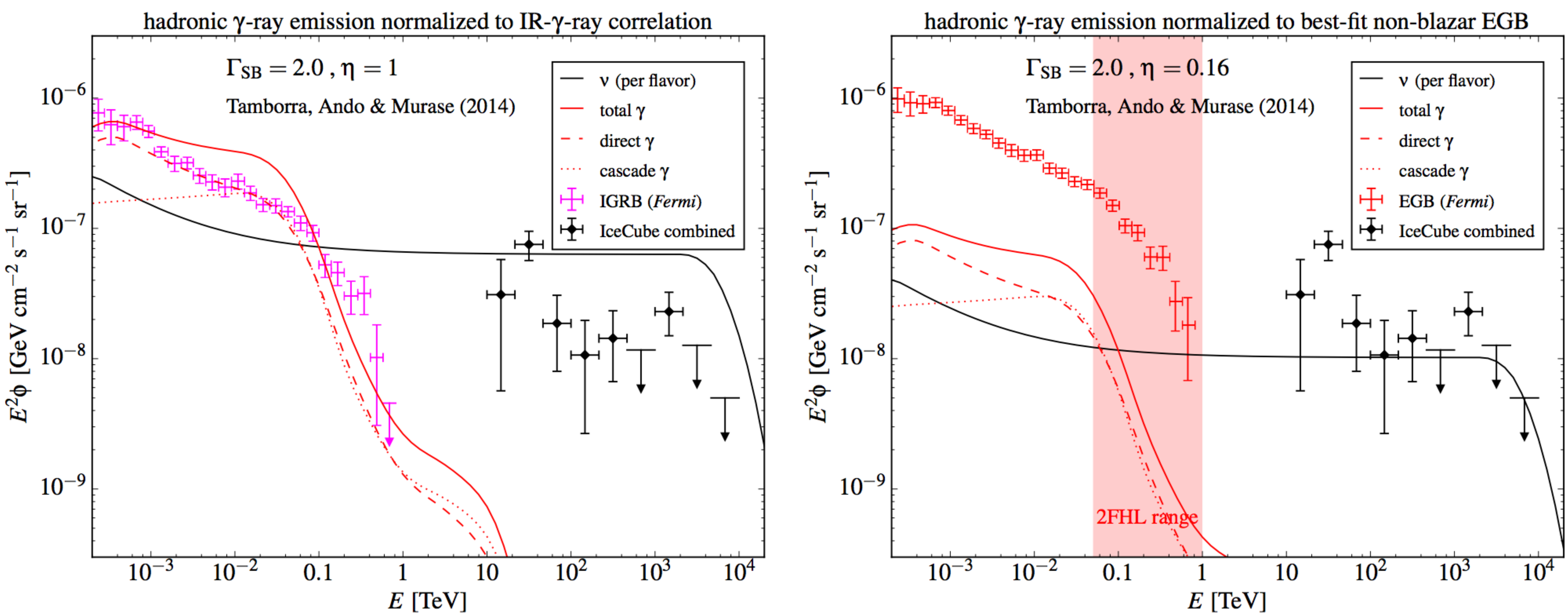


Spectral index for starbursts = 2.0

“Realistic” Galaxy Population Model: Cumulative Emission

Normalized to IR-gamma-ray scaling relation

Normalized to non-blazar EGB (0.05 - 1 TeV)

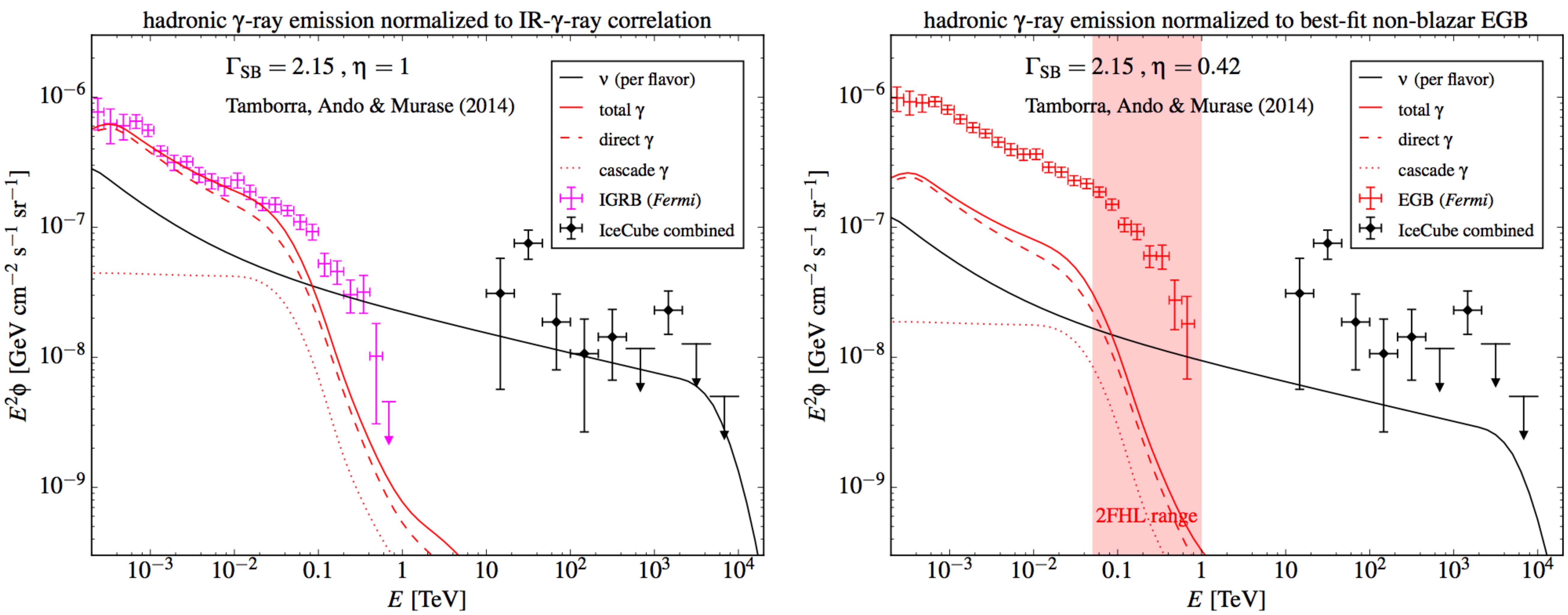


Spectral index for starbursts = 2.0

"Realistic" Galaxy Population Model: Cumulative Emission

Normalized to IR-gamma-ray scaling relation

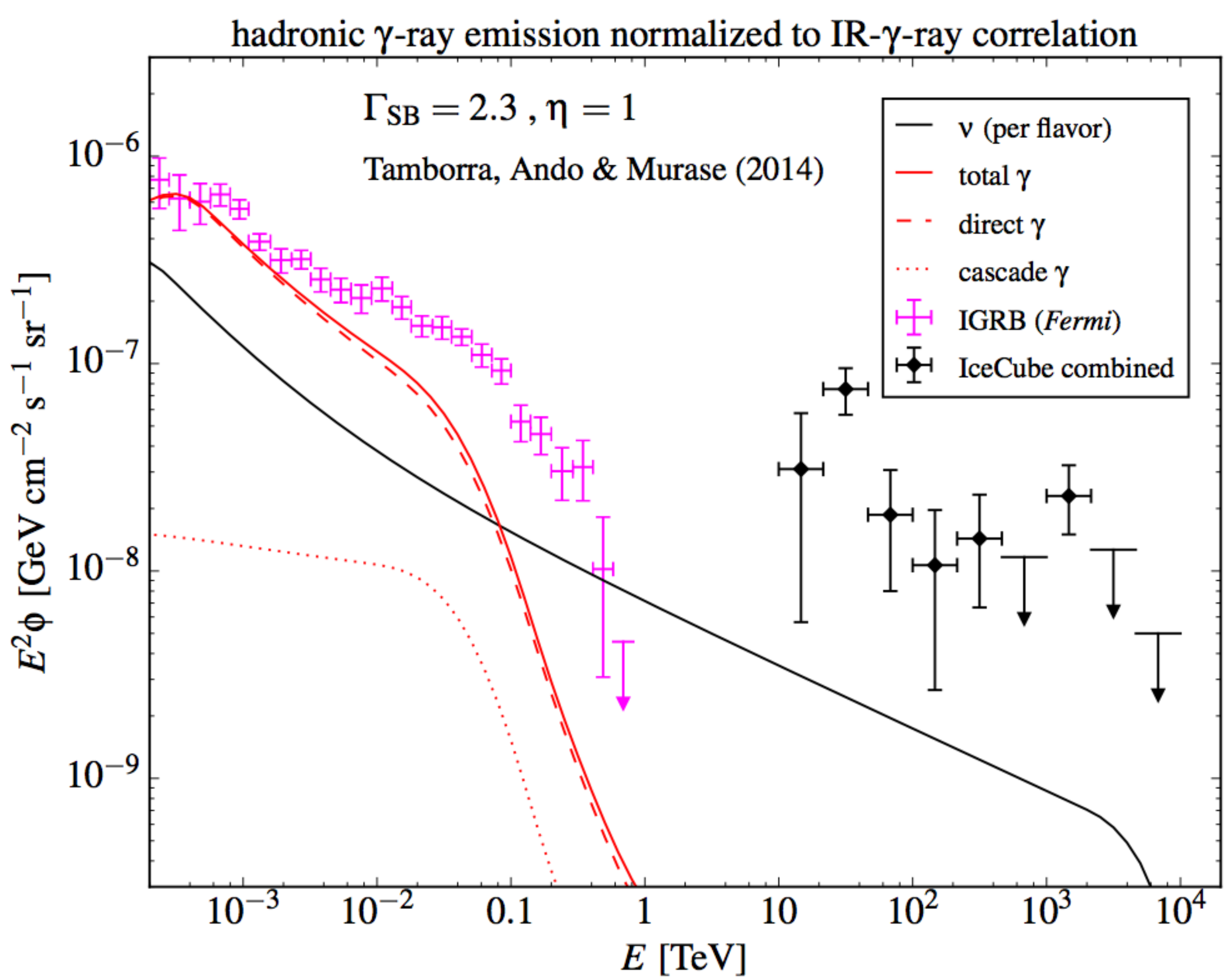
Normalized to non-blazar EGB (0.05 - 1 TeV)



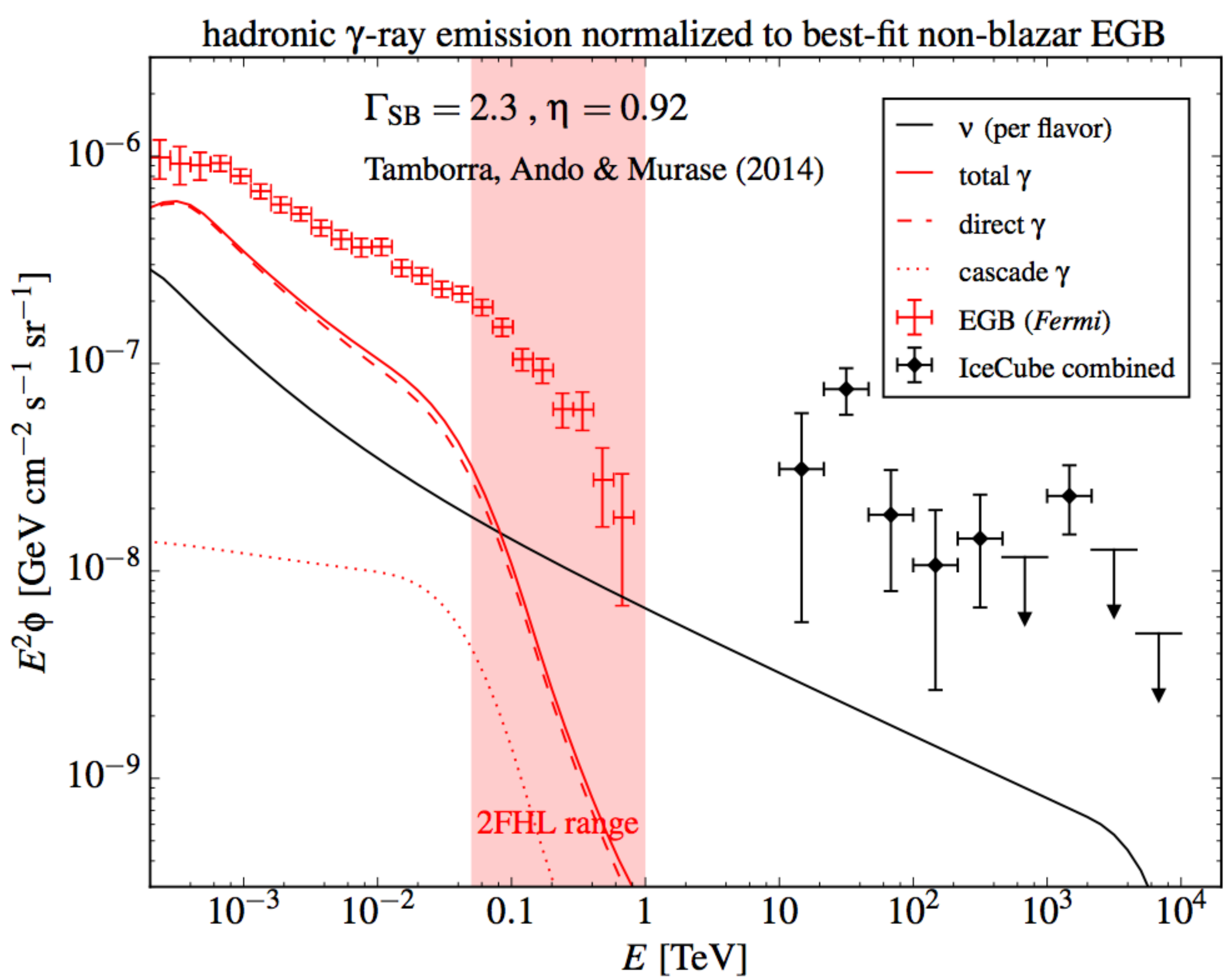
Spectral index for starbursts = 2.15

"Realistic" Galaxy Population Model: Cumulative Emission

Normalized to IR-gamma-ray scaling relation

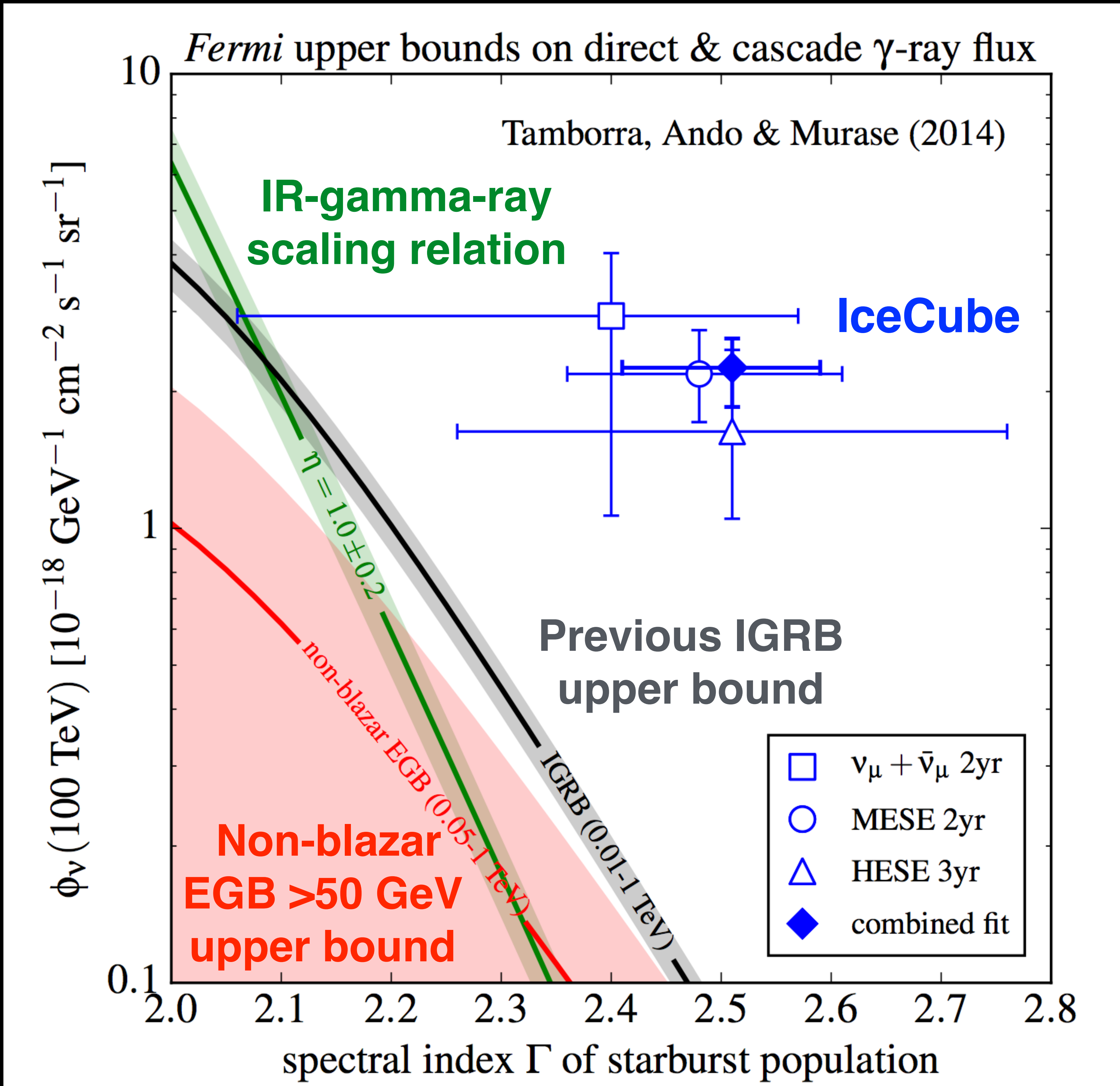


Normalized to non-blazar EGB (0.05 - 1 TeV)

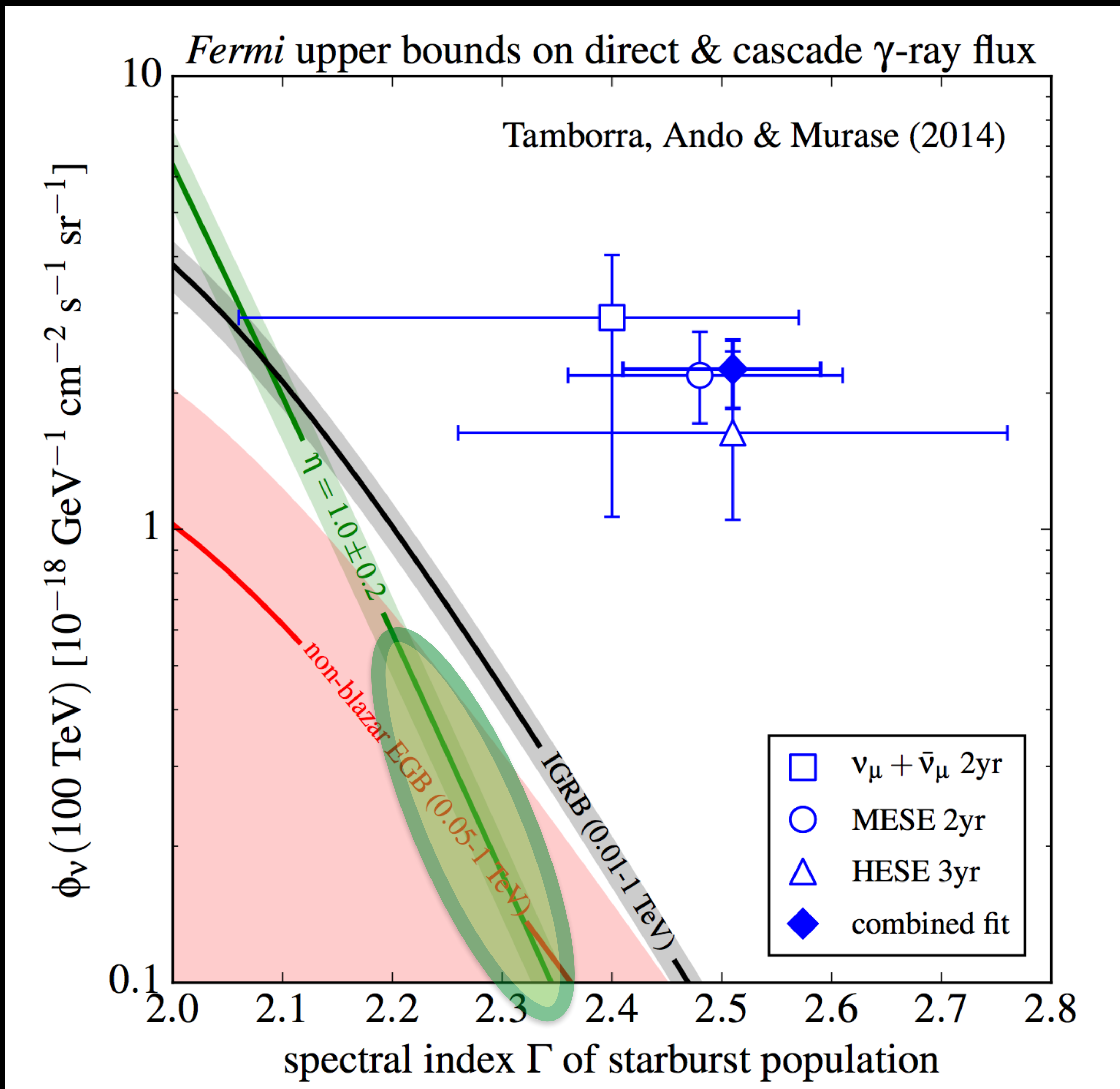


Spectral index for starbursts = 2.3

“Realistic” Galaxy Population Model: Parameter Space Constraints



"Realistic" Galaxy Population Model: Parameter Space Constraints



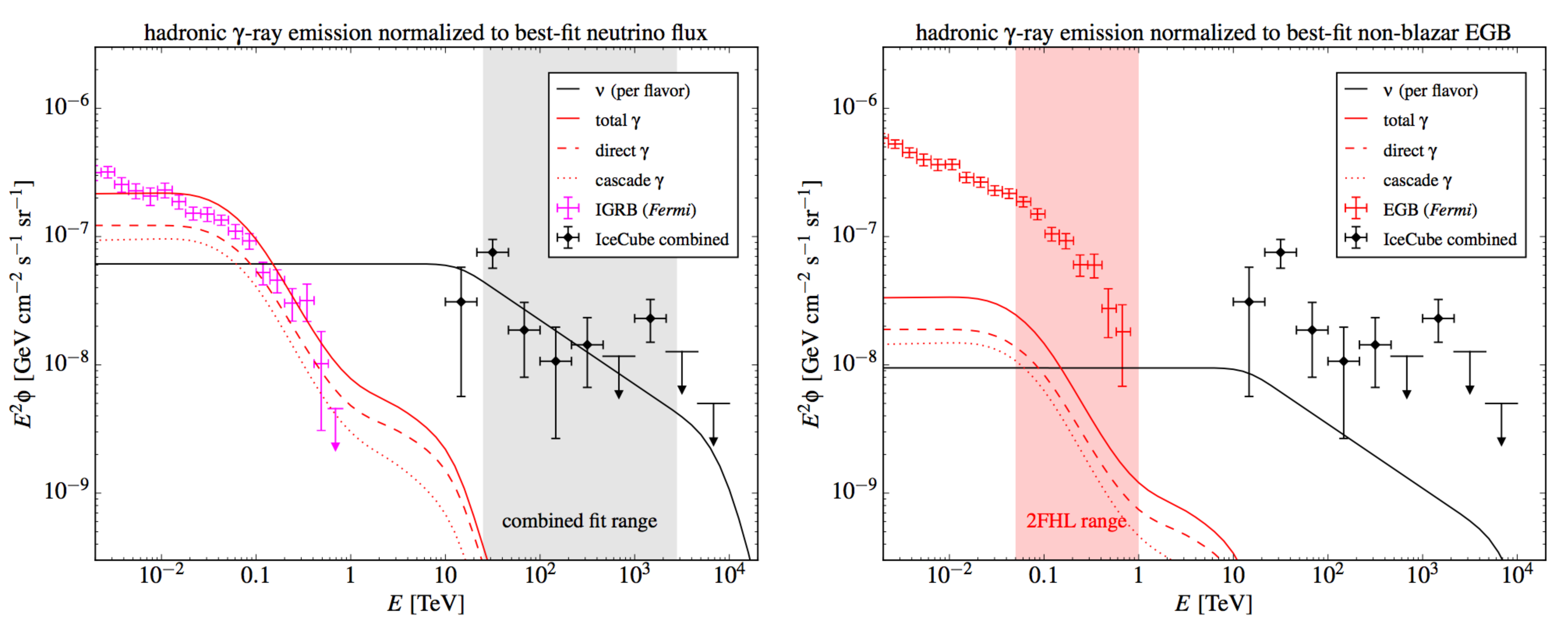
Region of parameter space compatible with all available gamma-ray data

- ✓ IR-gamma-ray scaling relation
- ✓ Non-blazar EGB
- ✓ Spectra of detected starbursts

…but undershoots IceCube signal by about an order of magnitude

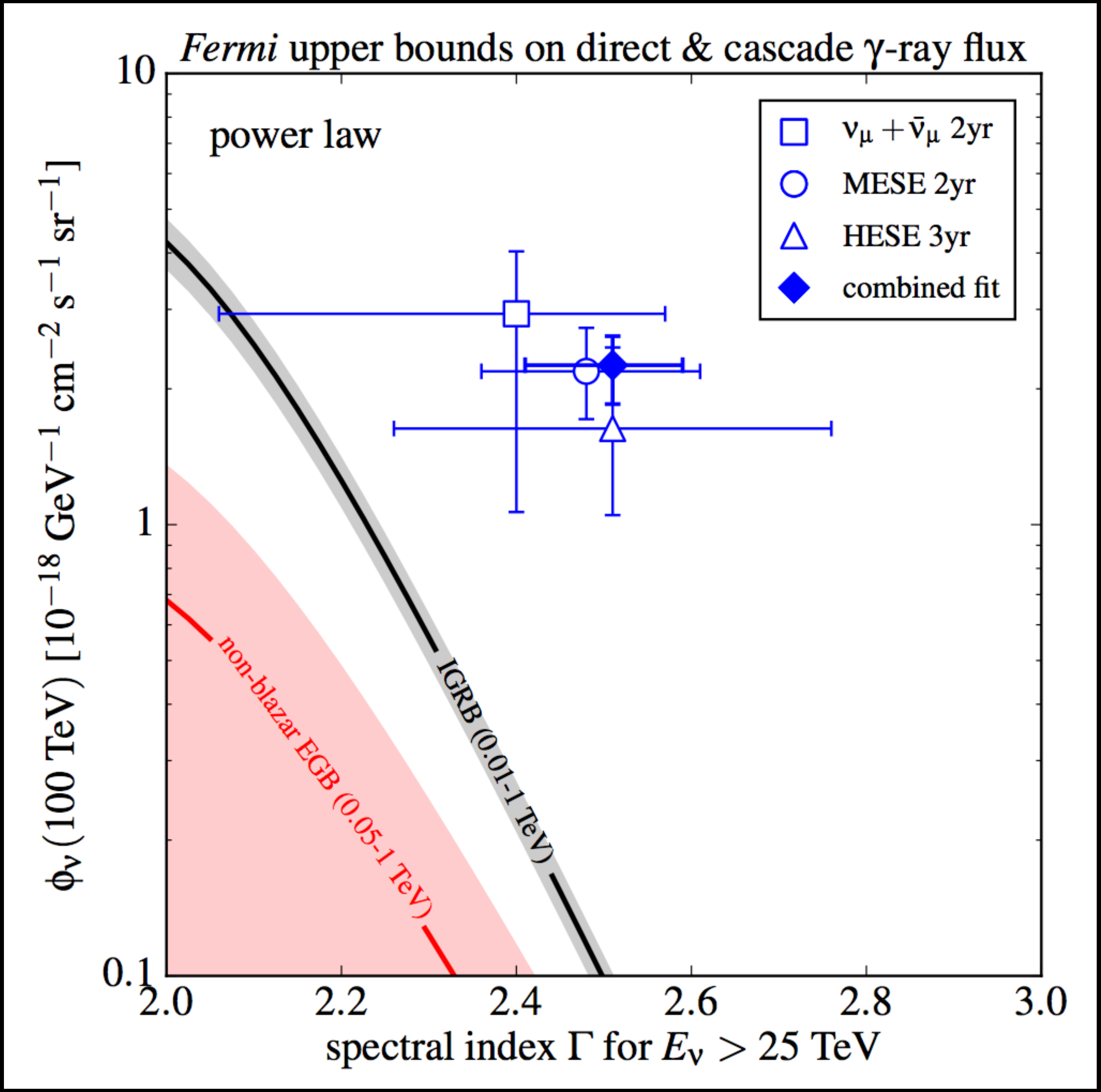
Generic Calorimeter Model: Cumulative Emission

Normalized to best-fit IceCube neutrino flux | **Normalized to non-blazar EGB (0.05 - 1 TeV)**



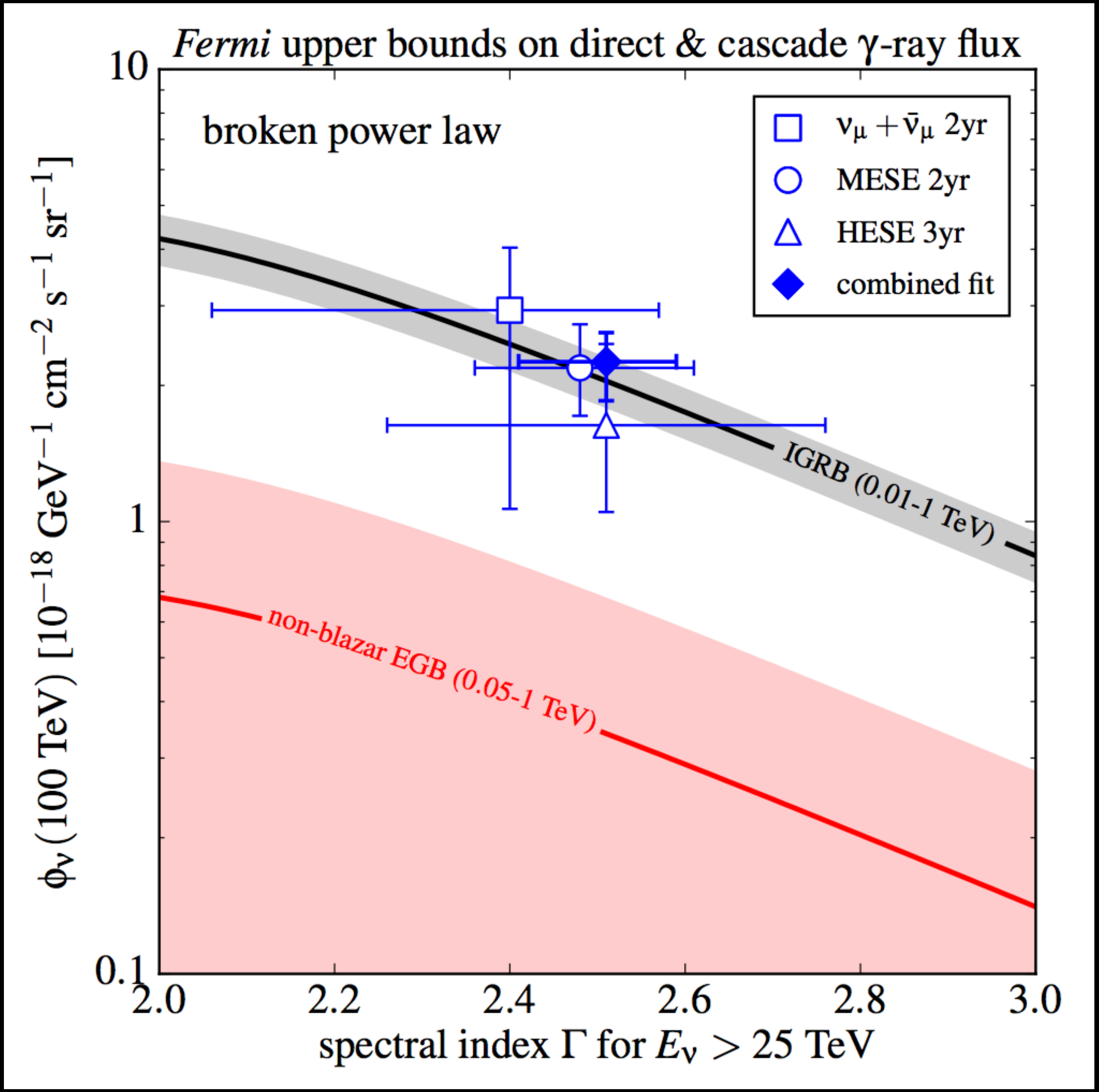
Break at 25 TeV to minimize EGB contribution

Generic Calorimeter Model: Parameter Space Constraints



Unbroken power law spectral model

Generic Calorimeter Model: Parameter Space Constraints



Broken power law spectral model

General Considerations

Conservative analysis in several respects:

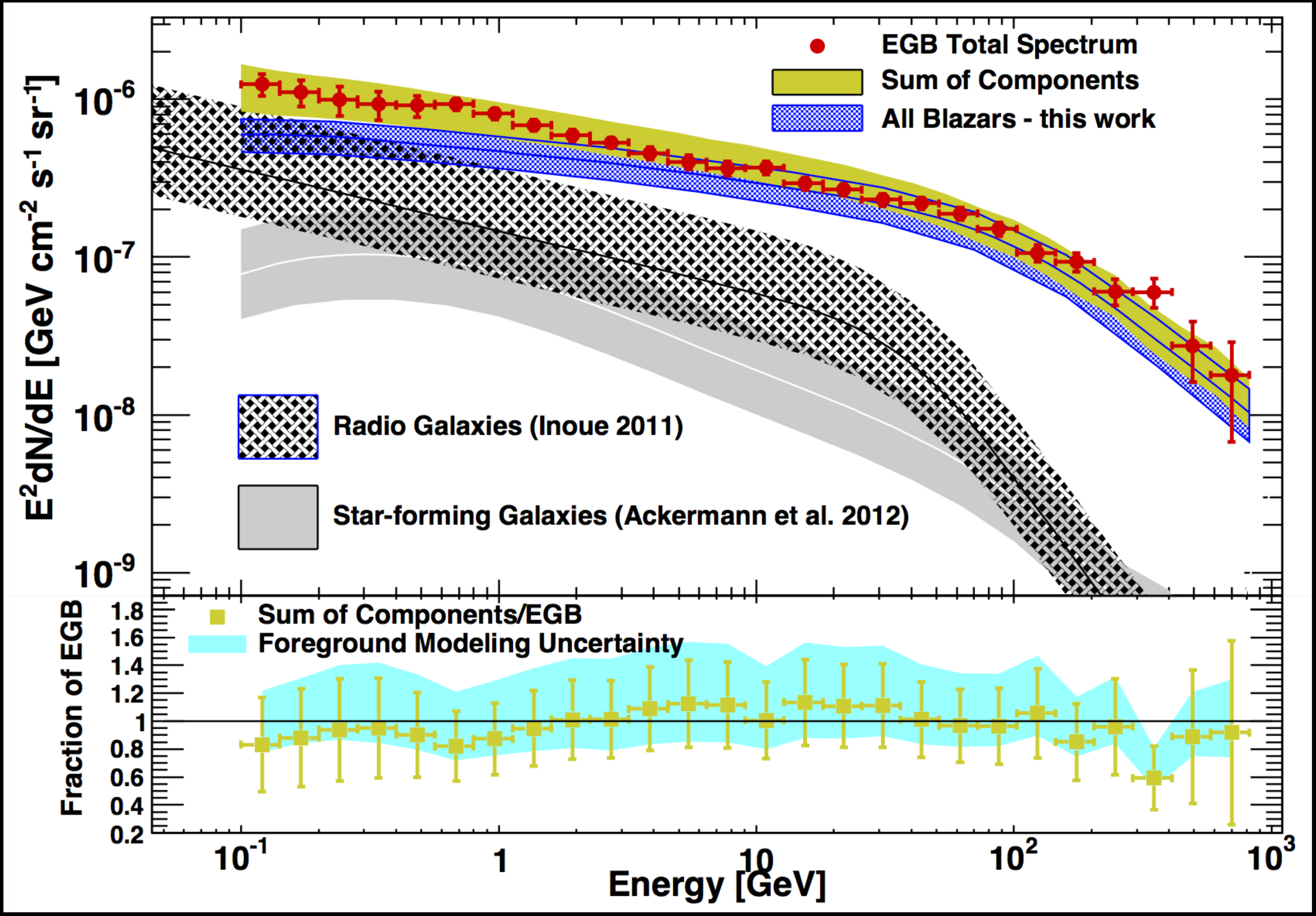
- Broken power law spectrum in generic calorimeter model tuned to fit IceCube data with a minimal EGB contribution; realistic model includes normal galaxies with softer spectra

- Attributed all gamma-ray emission in star-forming galaxies to hadronic processes

- Assumed that star-forming galaxies saturate non-blazar EGB, even though comparable contributions are expected from other extragalactic source classes, e.g., mis-aligned AGN (Inoue 2011, Di Mauro et al. 2014, Hooper et al. 2016)

General Considerations

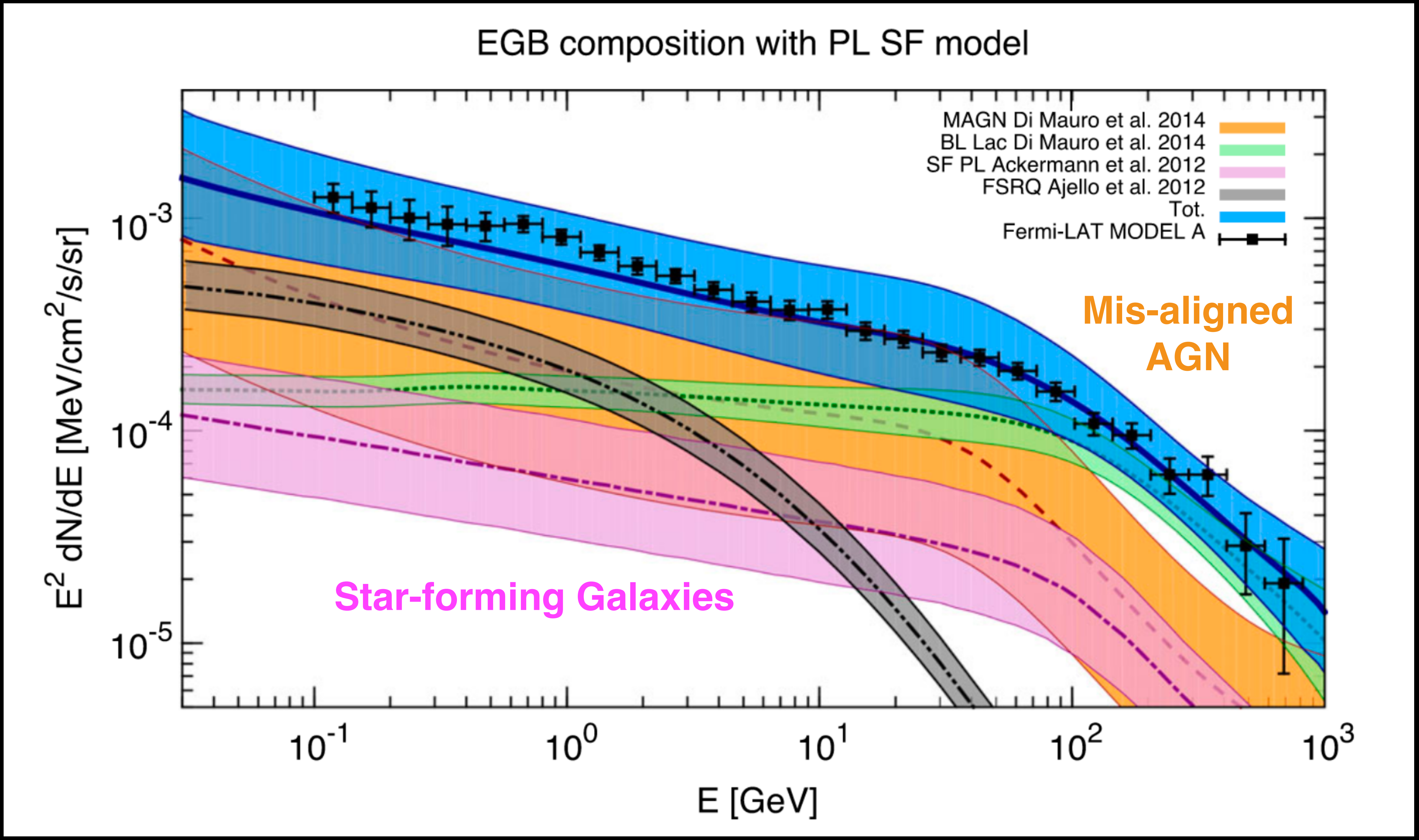
Comparable contributions expected from mis-aligned AGN



Ajello et al. 2015

General Considerations

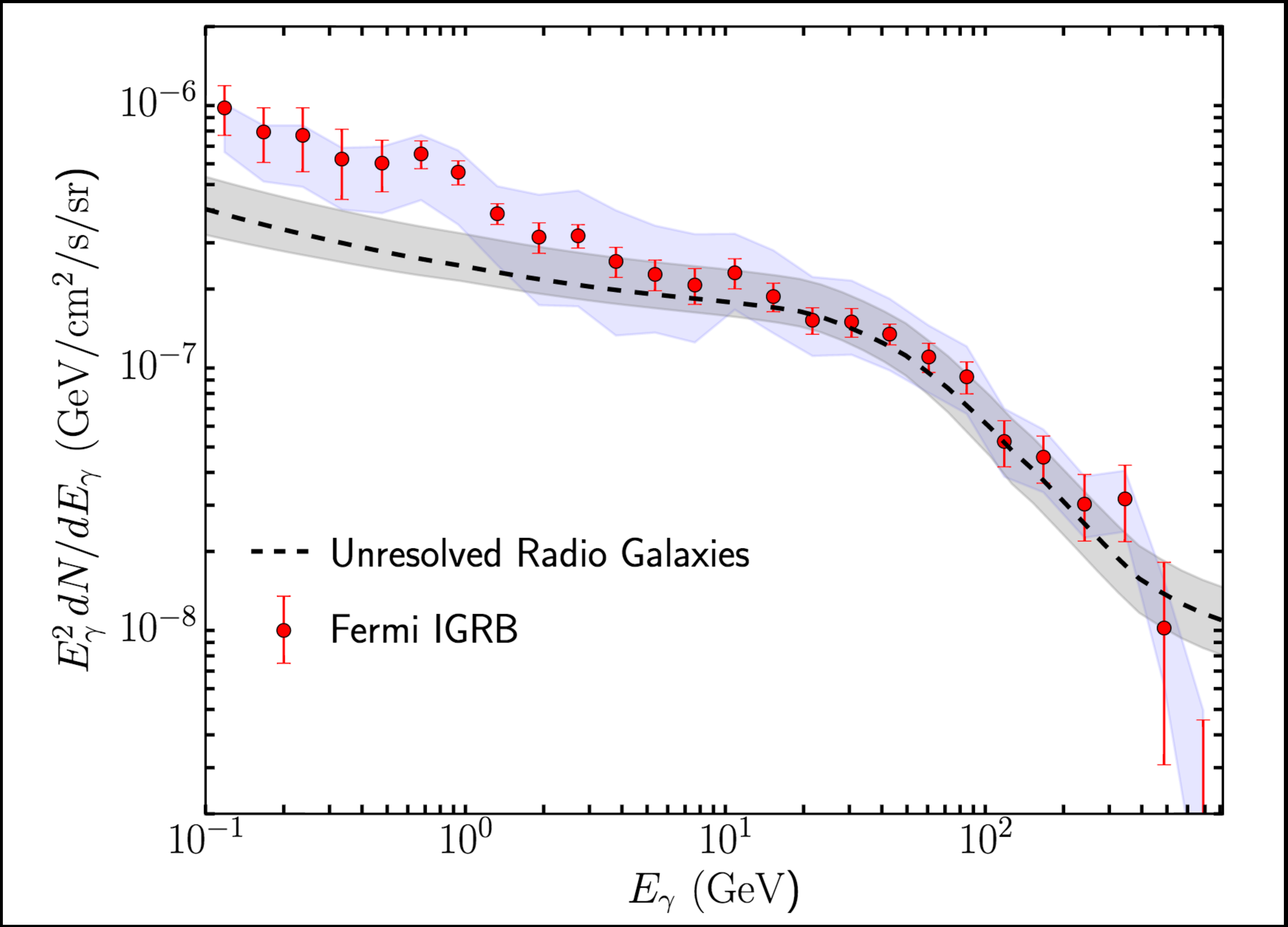
Comparable contributions expected from mis-aligned AGN



Di Mauro & Donato 2015

General Considerations

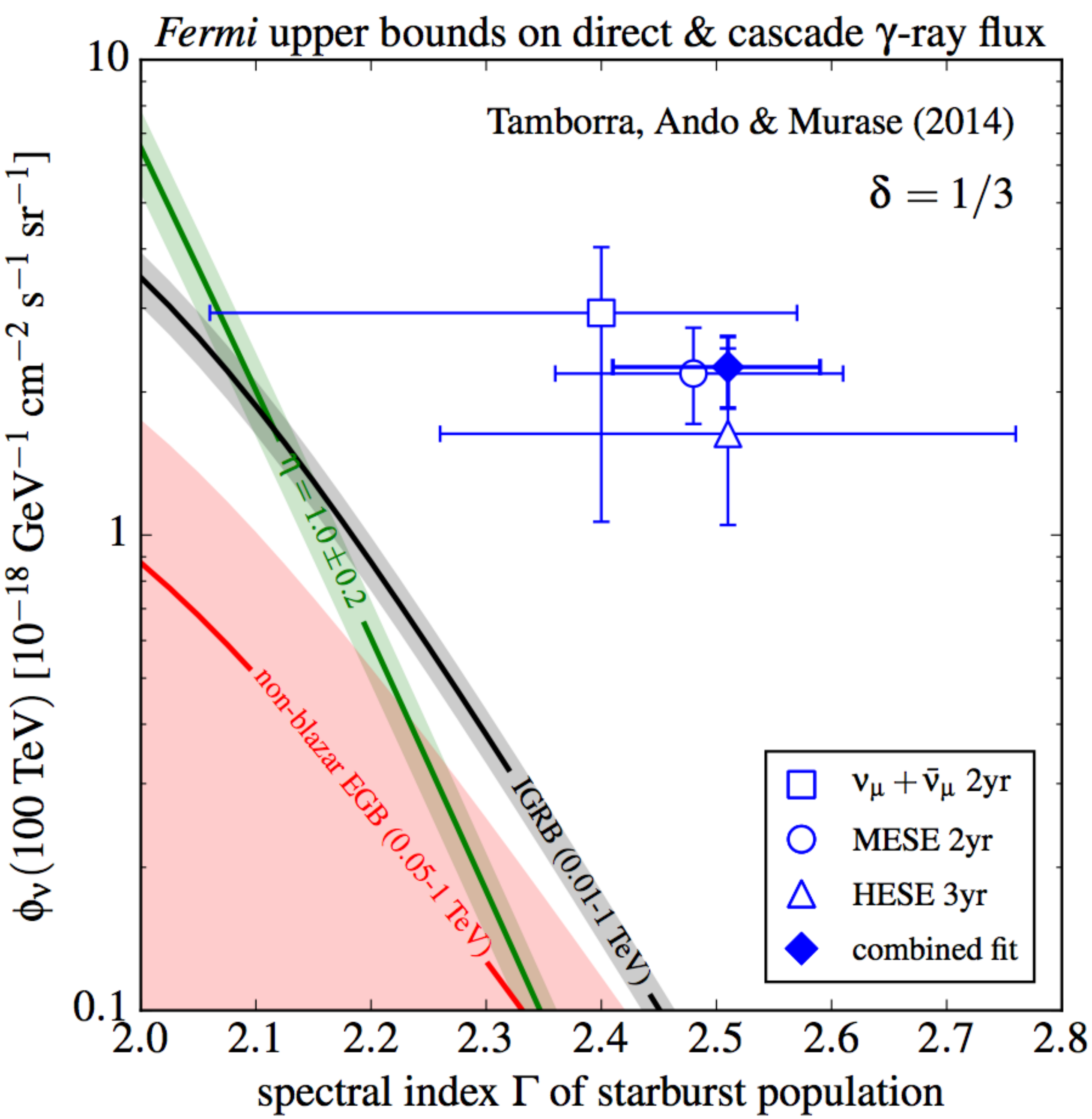
Comparable contributions expected from mis-aligned AGN



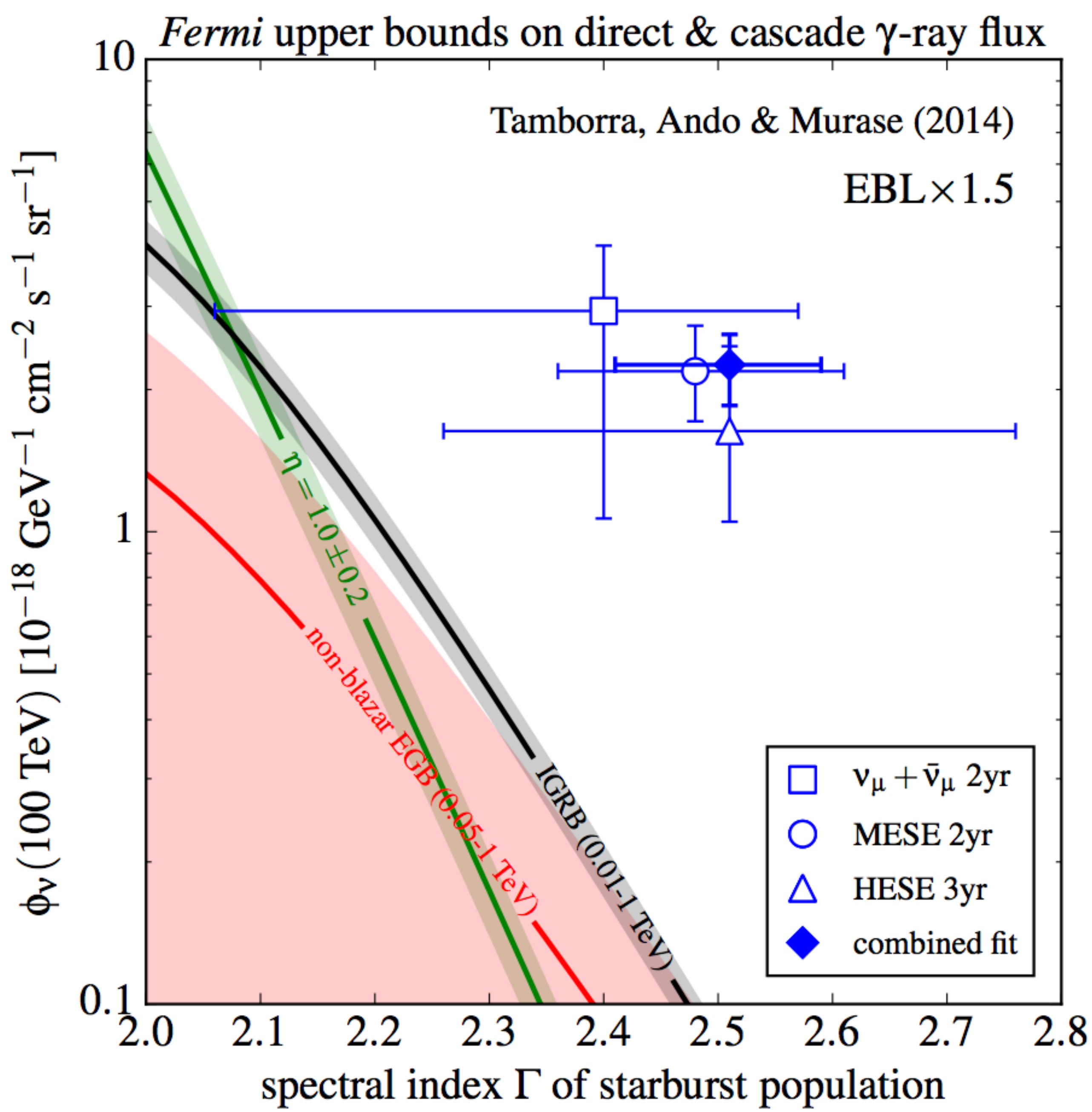
Hooper et al. 2016
arXiv:1604.08505

Model Variations:
Realistic Galaxy Population Model

Reduce spectral softening due to diffusion



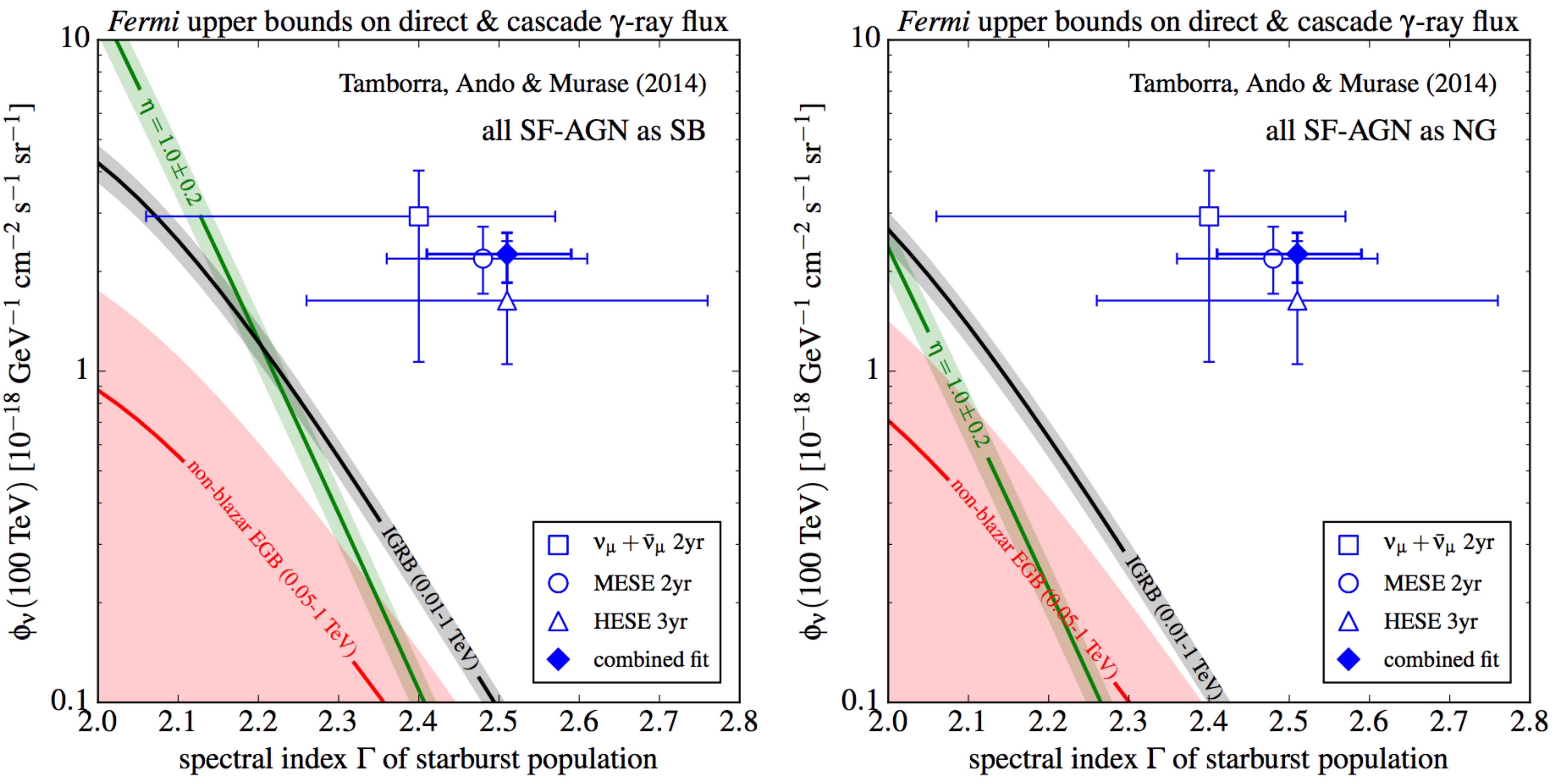
Maximum EBL density allowed by gamma-ray observations of blazars



Model Variations:
Realistic Galaxy Population Model

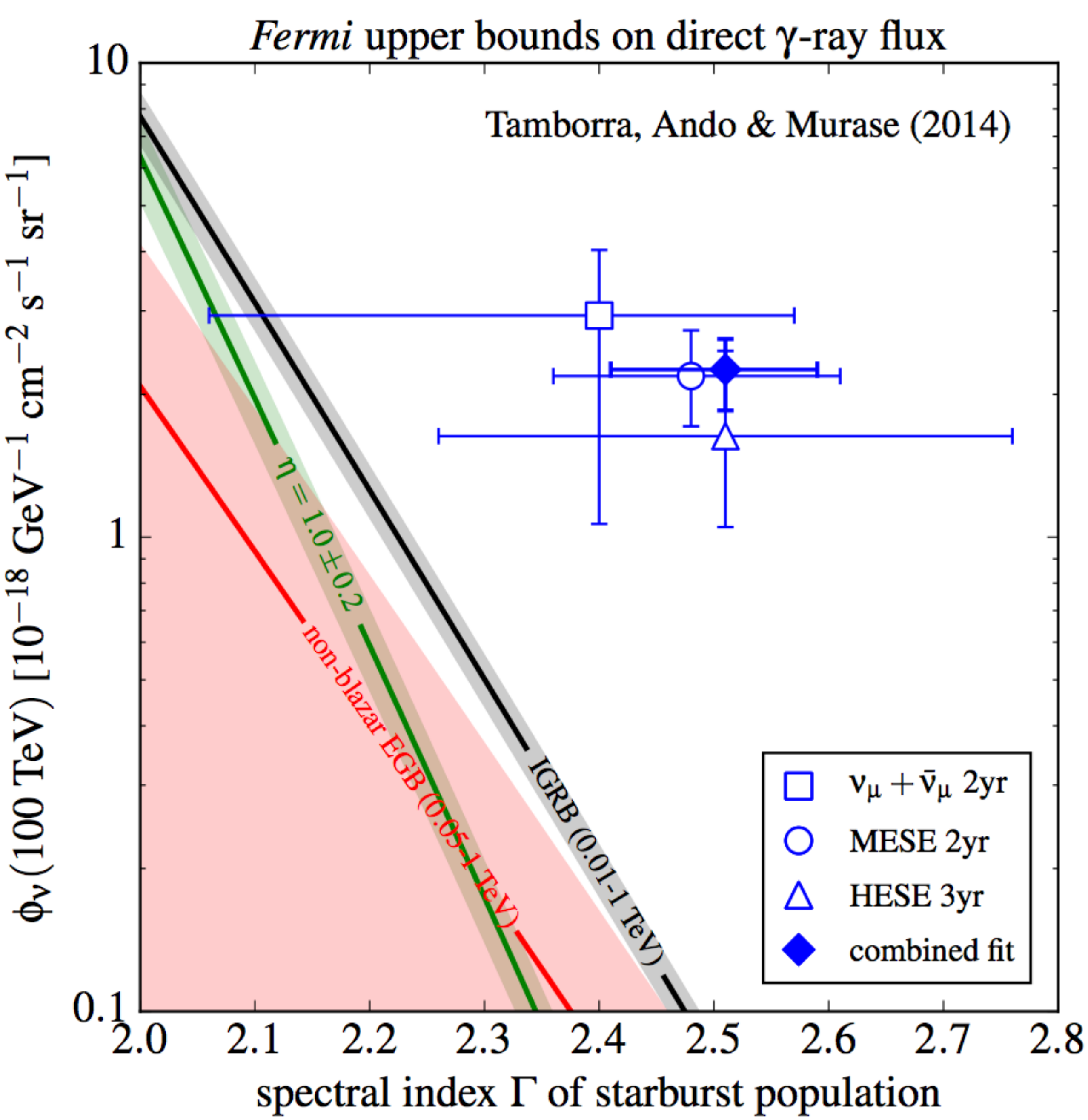
Assign hard spectral index to all star-forming galaxies with AGN

Assign soft spectral index to all star-forming galaxies with AGN

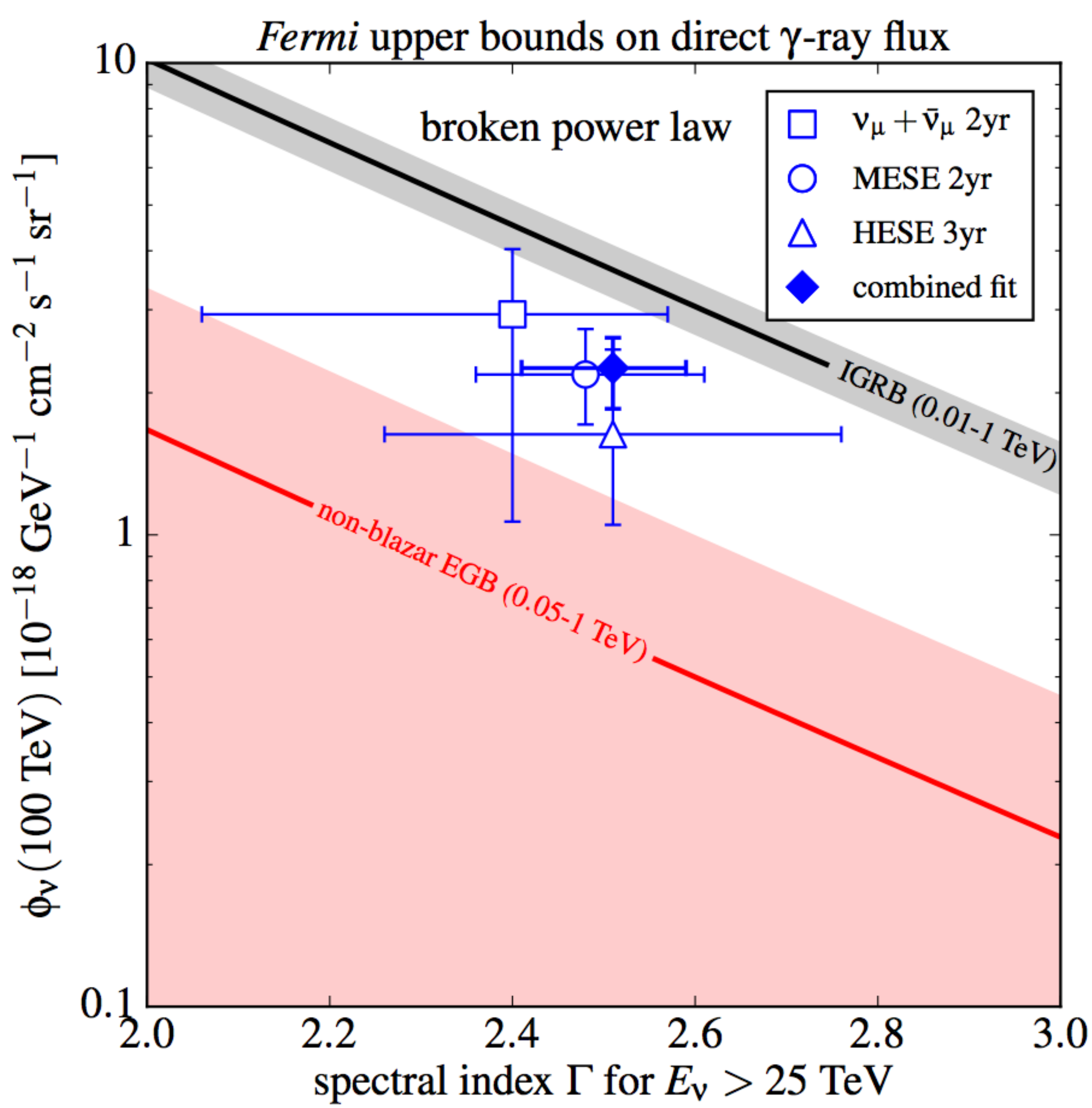


Model Variations:
Consider Only Direct Gamma-ray Emission

“Realistic” galaxy population model



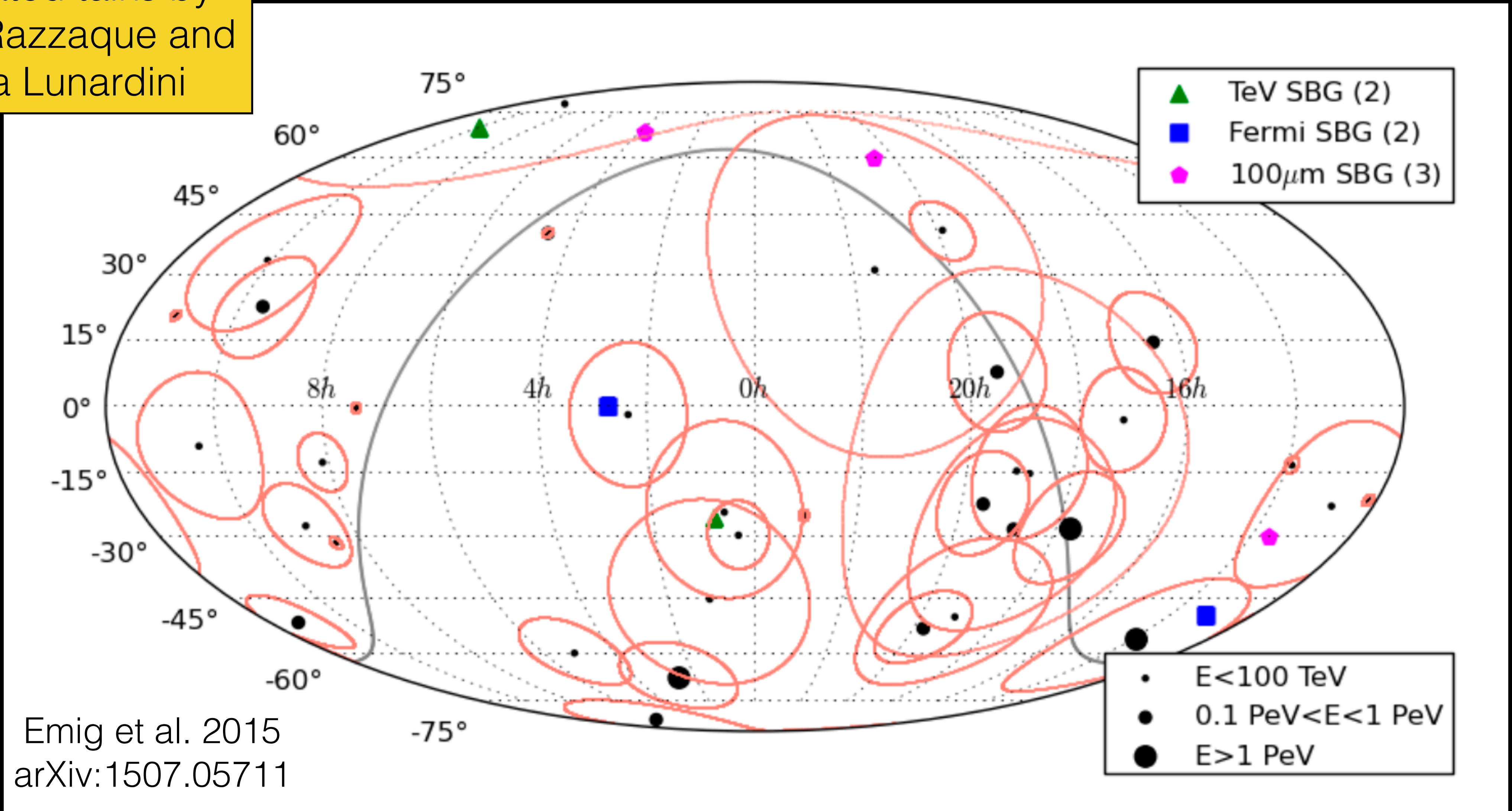
Generic calorimeter model



IceCube Events from Local Starbursts?

Some indication of a spatial correlation between IceCube high-energy contained (HESE) events and nearest starburst galaxies

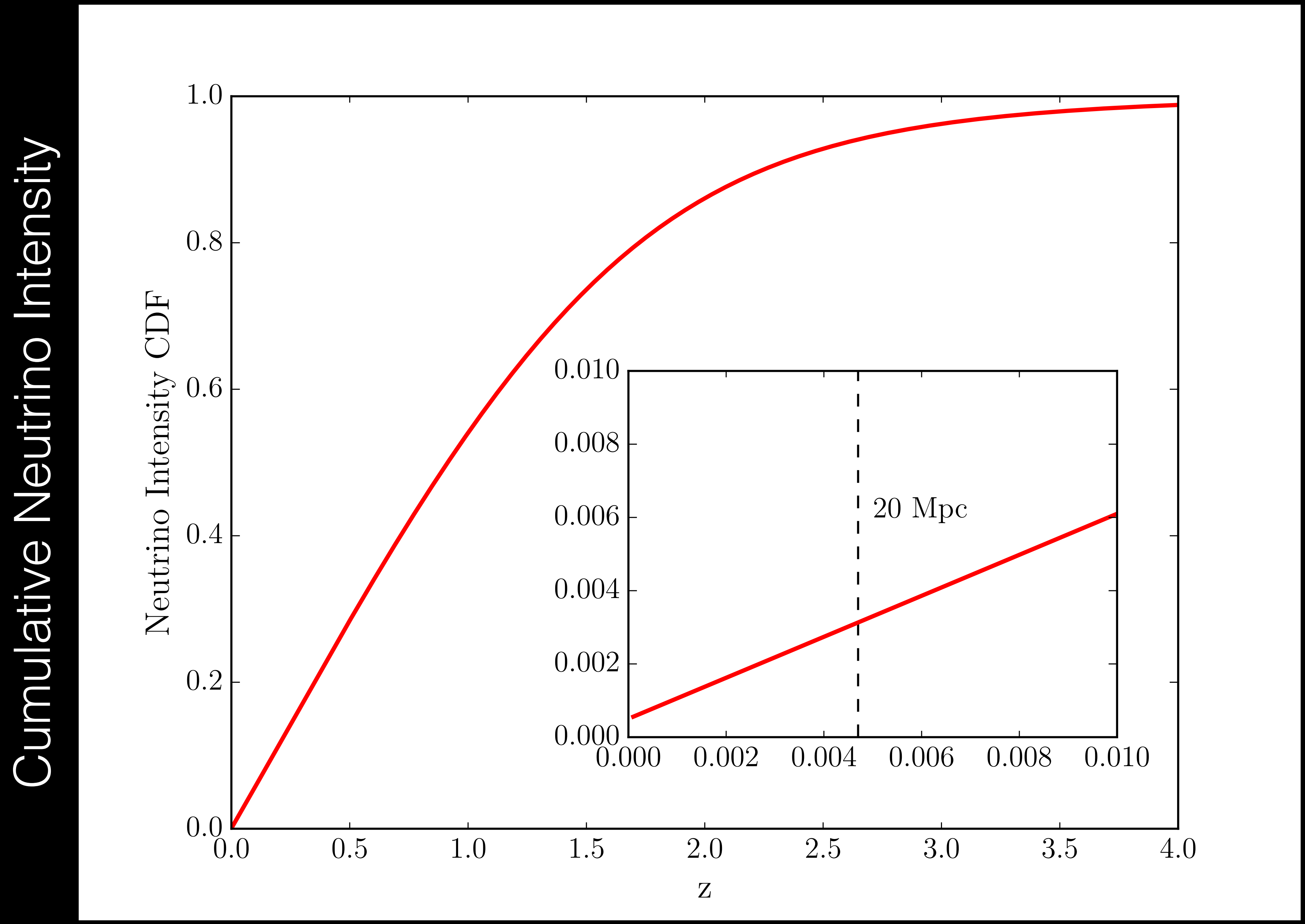
See related talks by Soebur Razzaque and Cecilia Lunardini



Emig et al. 2015
arXiv:1507.05711

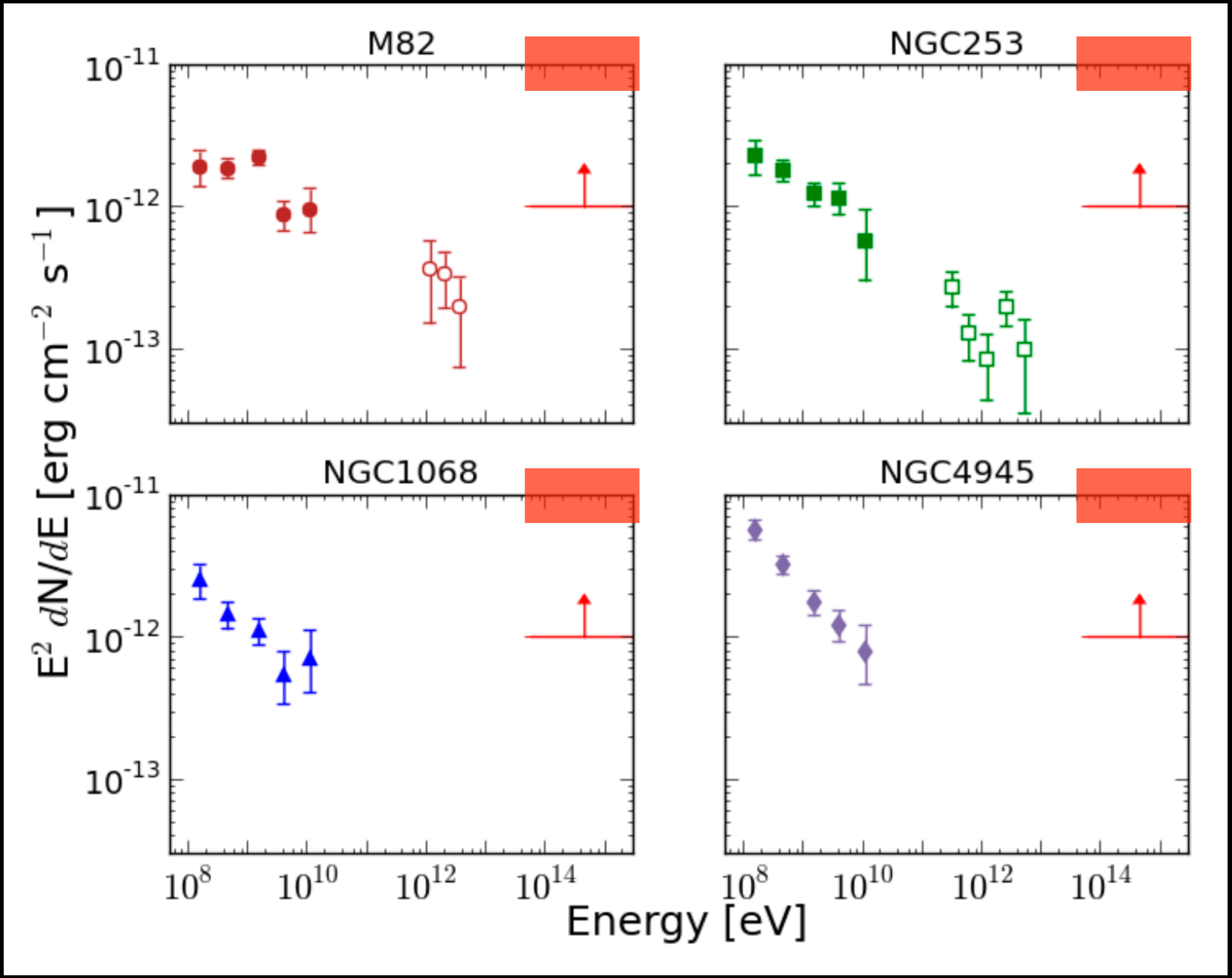
Is an association between IceCube HESE events and the nearest starburst galaxies plausible?

IceCube Events from Local Starbursts?



Following cosmic star formation history,
and assuming homogeneity, expect ~0.3% of total neutrino intensity to come from all starbursts within 20 Mpc

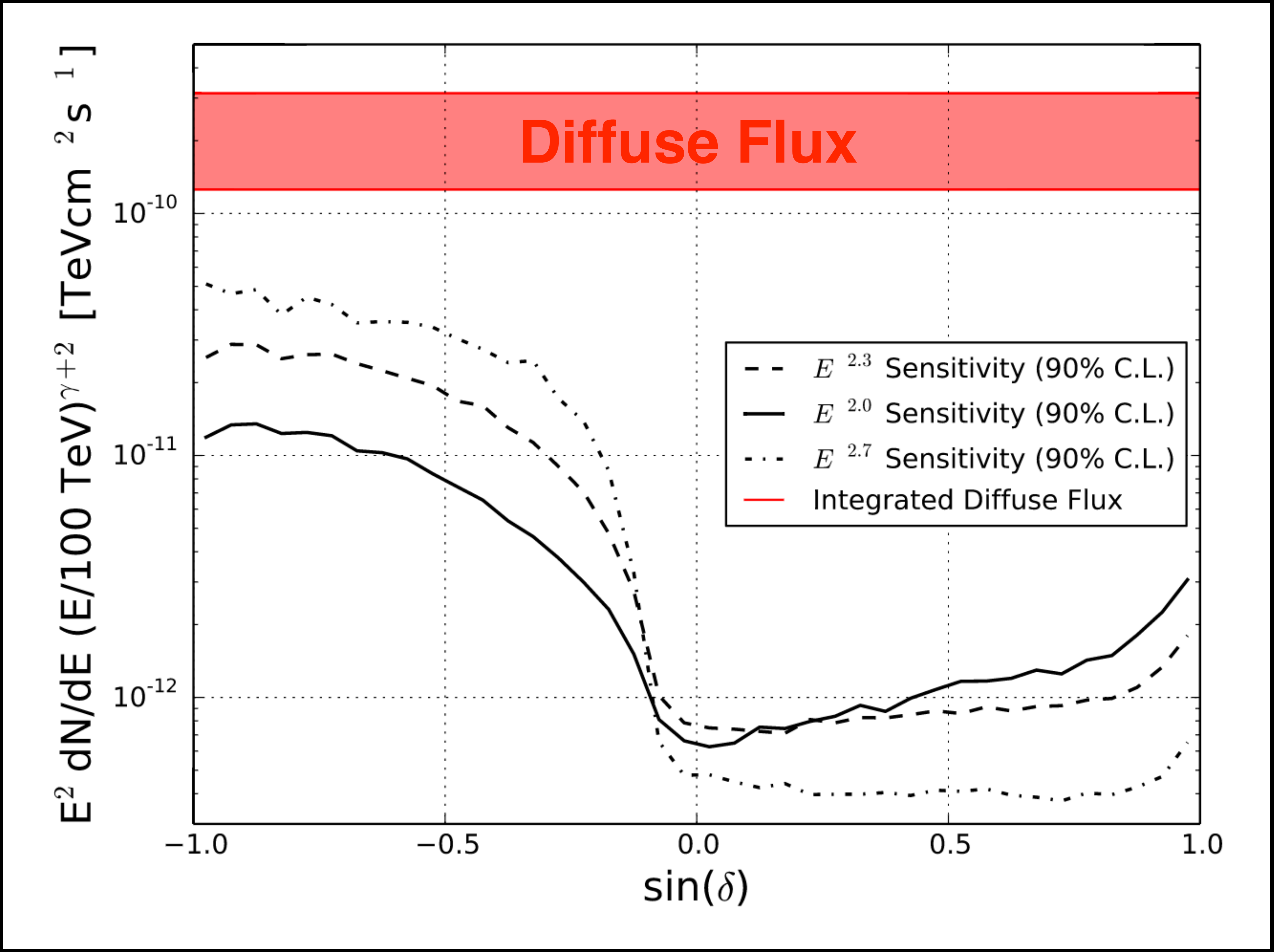
IceCube Events from Local Starbursts?



Emig et al. 2015
arXiv:1507.05711

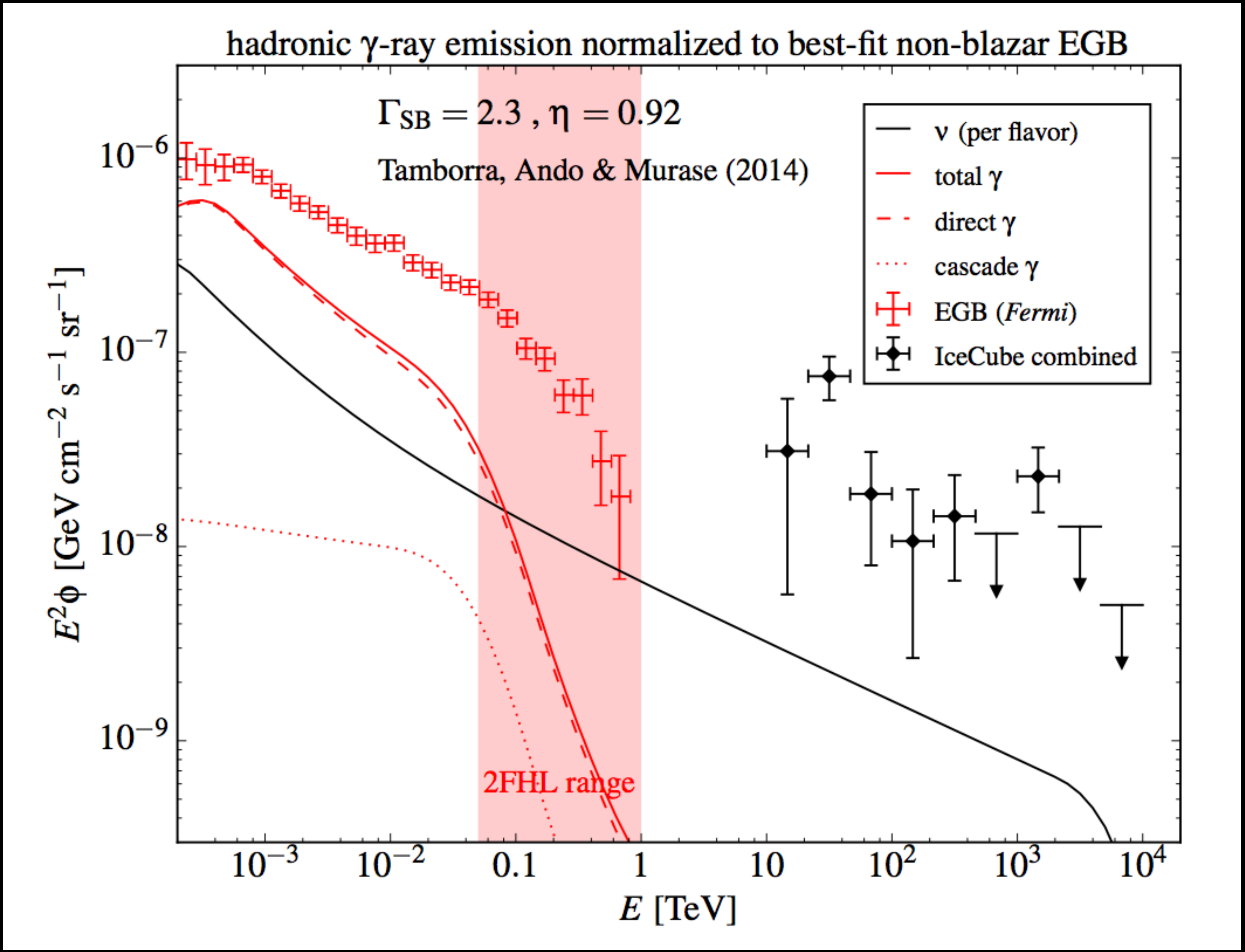
"For a neutrino spectrum of the form E^{-2} the neutrino flux required to produce one event in IceCube, $\phi_{(1)}$, is such that $E^2\ \phi_{(1)} \sim 10^{-11}$ erg cm^{-2} s^{-1}, nearly independently of the energy of the specific neutrino event considered, and with a Poissonian error of a factor of a few."

IceCube Events from Local Starbursts?



Jacob Feintzeig PhD Thesis

Scenario Compatible with Available Gamma-ray Data



Implications

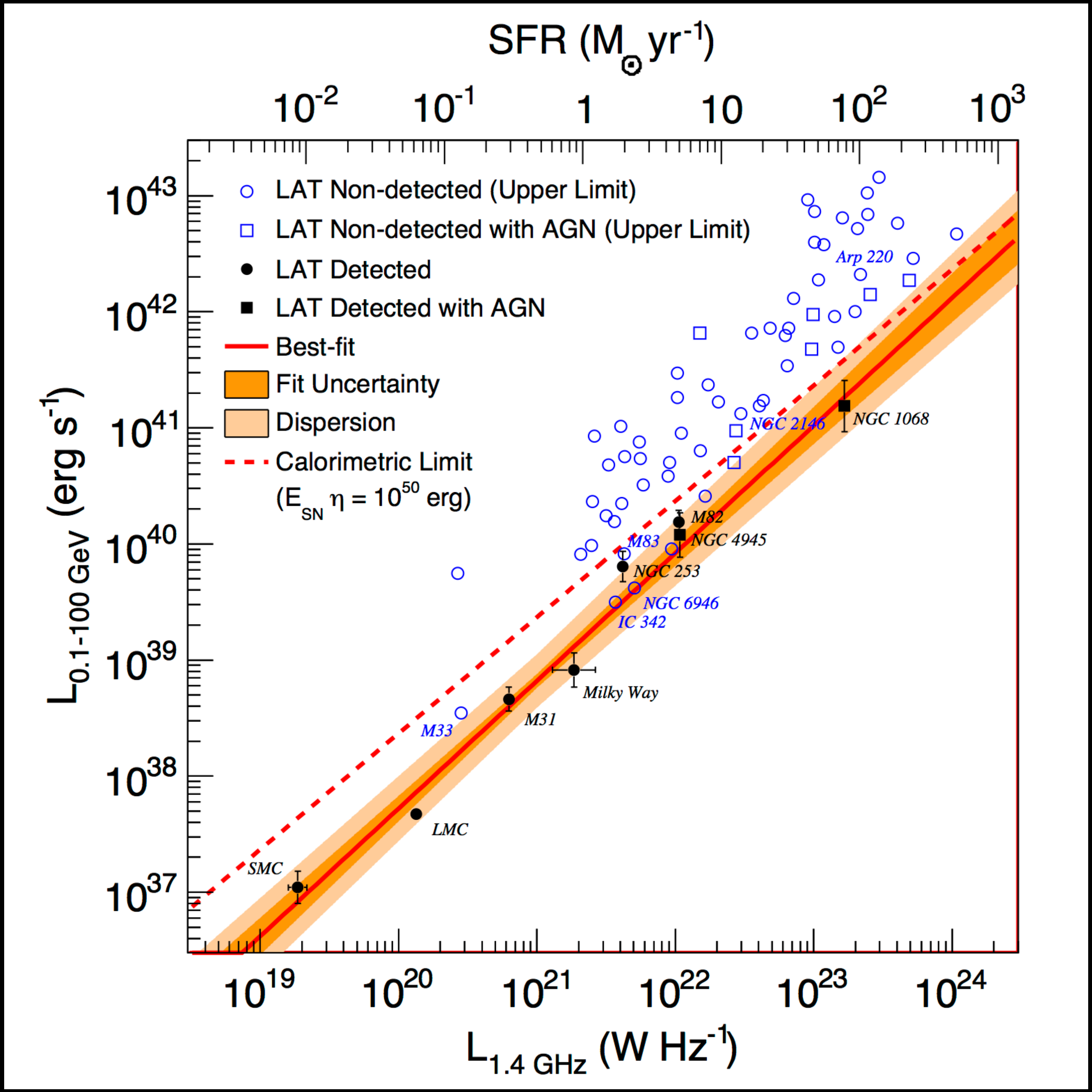
Where do the IceCube neutrinos come from??

1. **Several prominent extragalactic source classes are tightly constrained: gamma-ray blazars, GRBs, *and now starbursts***
   - Gamma rays do not escape neutrino sources?
   - Galactic contribution to IceCube signal? Unknown systematic?

2. **Potentially good news for those searching for the first individual high-energy neutrino sources**
   - Starbursts would be very challenging to detect individually (faint, no variability on timescale of experiment)
   - Other source classes may provide easier handles for detection

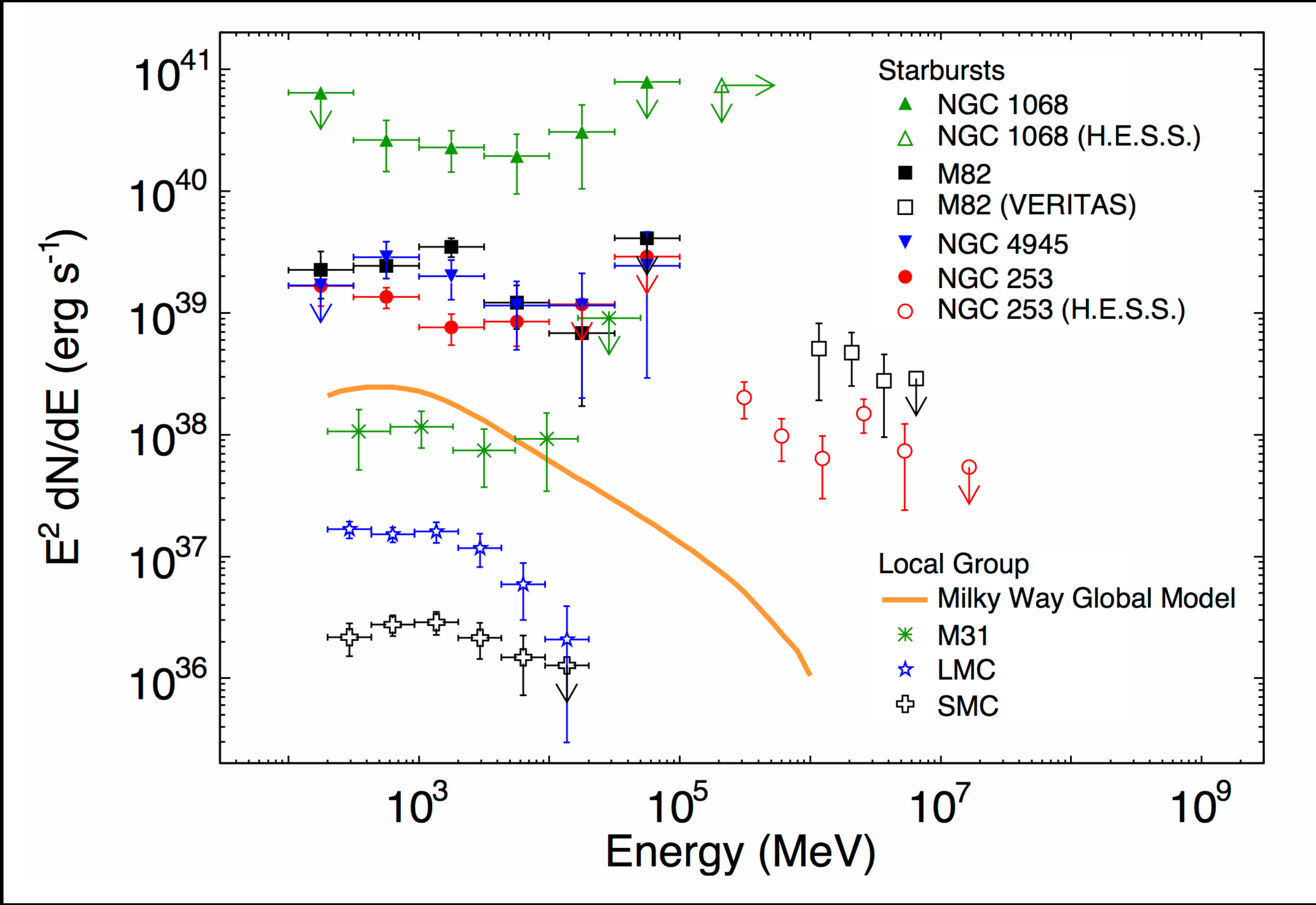
arXiv:1511.00688
Look for an updated version soon…

Gamma-ray Detected Starbursts: Luminosity Scaling Relations



Ackermann et al. 2012

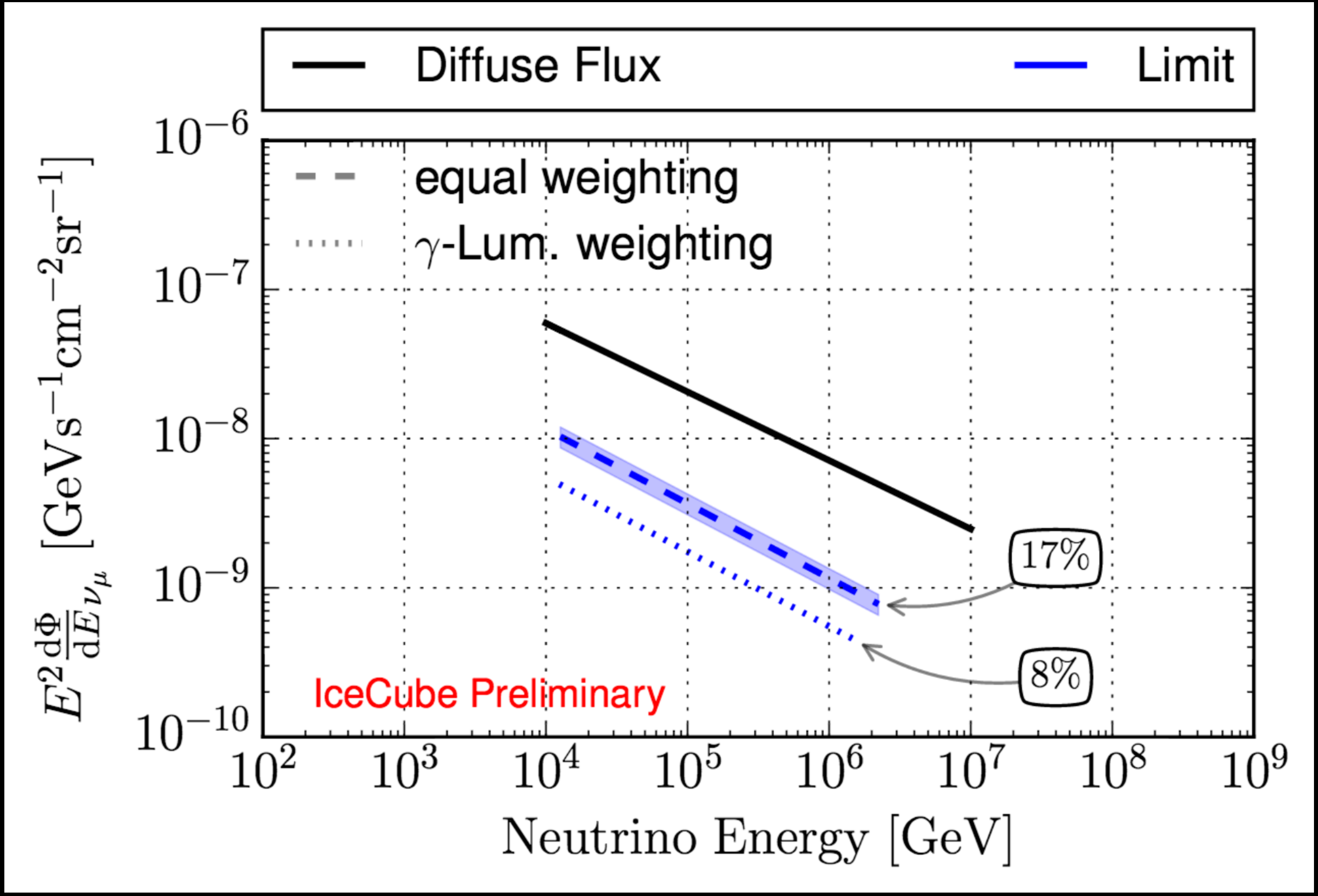
Gamma-ray Detected Star-forming Galaxies: Spectra



Ackermann et al. 2012

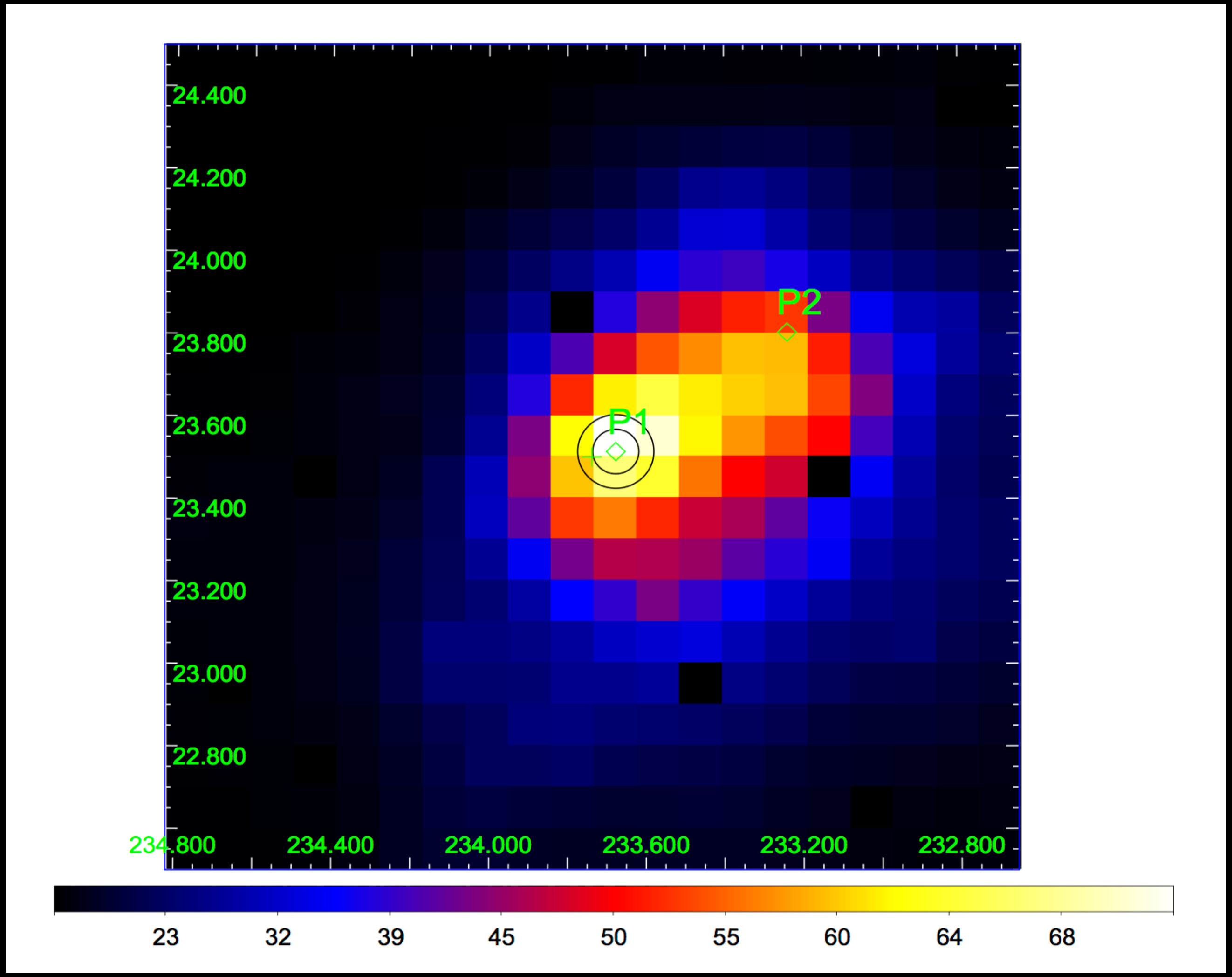
Constraints on the Neutrino Emission of Gamma-ray Blazars

Glusenkamp et al. (IceCube) 2015
arXiv:1502.03104



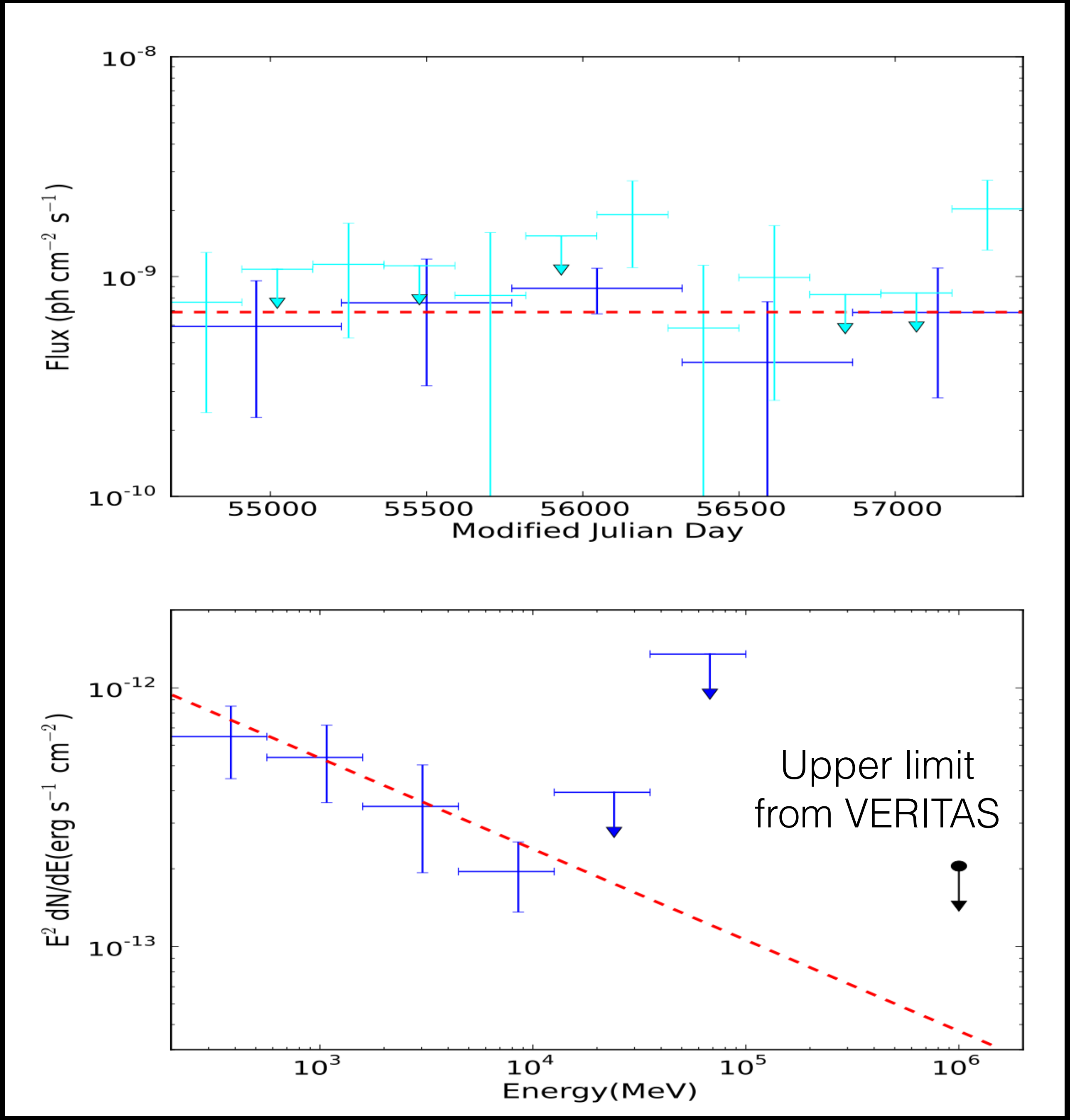
Note: In gamma-ray weighting scheme, ~60% of the total blazar EGB contribution is resolved into 2LAC sources, so place an upper bound of 8% / 0.6 = ~13% on the total contribution of all gamma-ray blazars to IceCube signal

Arp 220 Gamma-ray Detection with *Fermi*-LAT

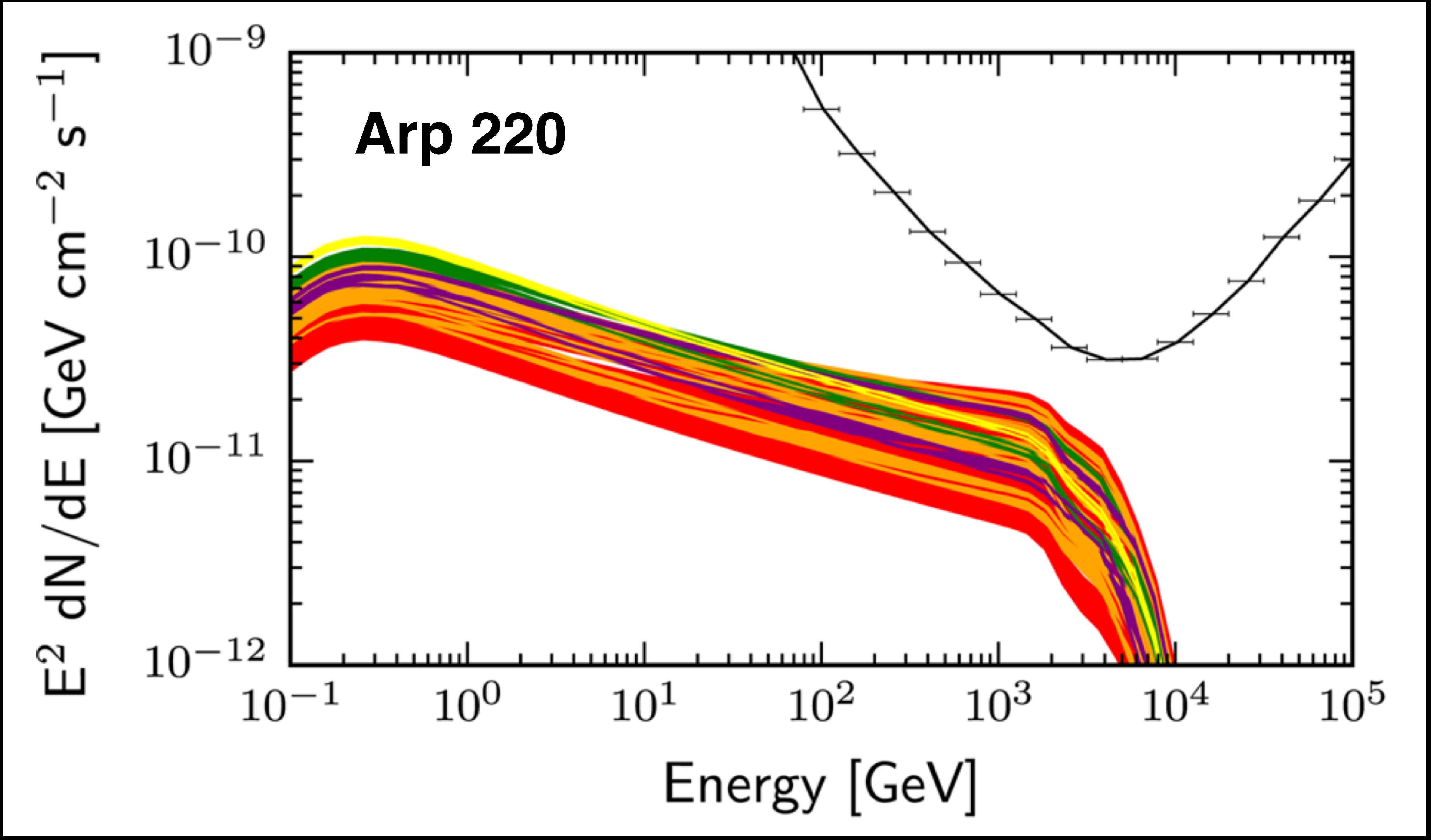


Peng et al. 2016
arXiv:1603.06355

see also
Griffin et al. 2016
arXiv:1603.06949

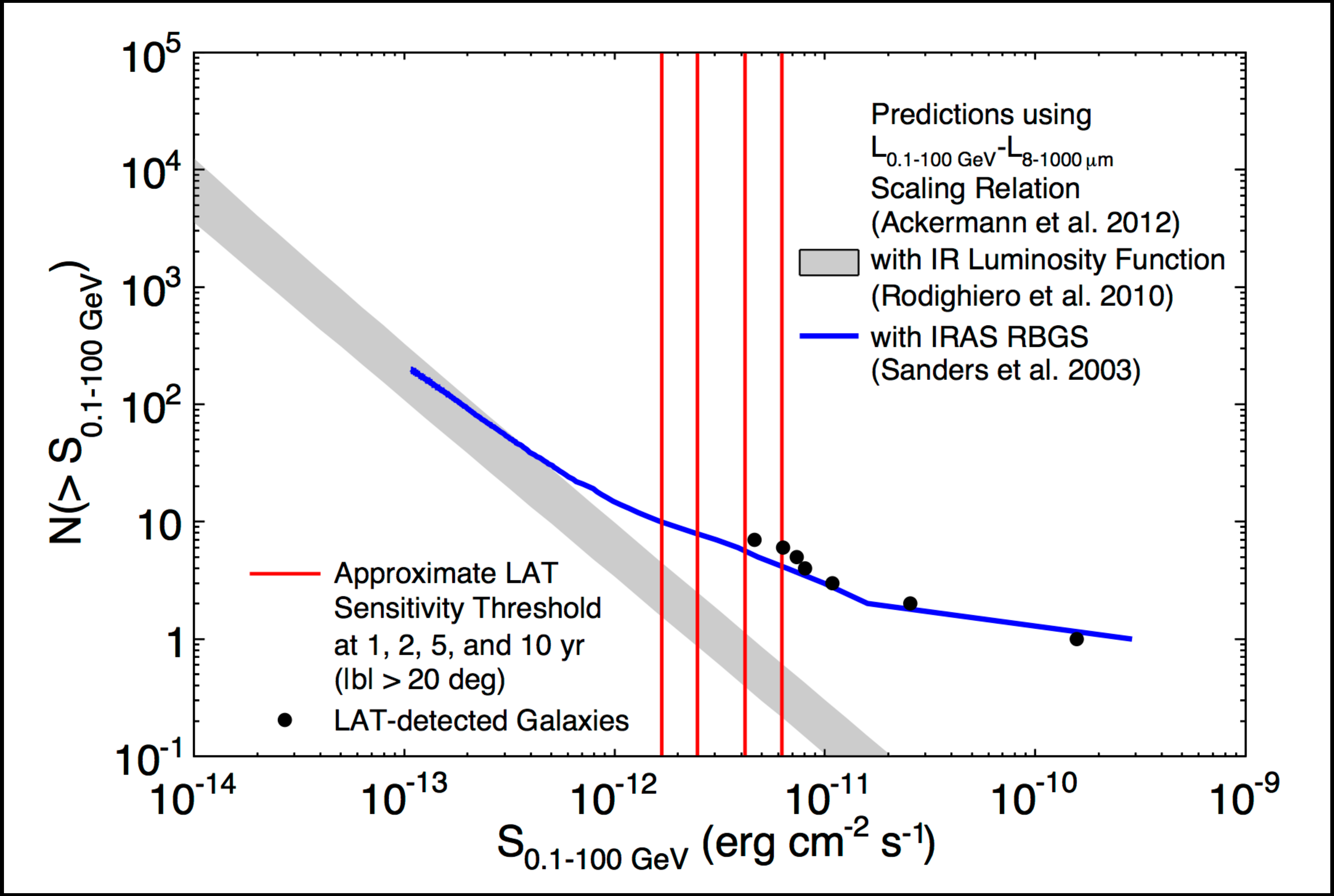


Gamma-ray Opacity within Starbursts



Yoast-Hull, Gallagher, & Zweibel 2015

Local Enhancement?



Local Enhancement?