γ and ν from TeV blazars

Matteo Cerruti
CNRS, LPNHE, Paris

CAVEAT

Extremely biased talk!

Towards TeV sources (as in title)

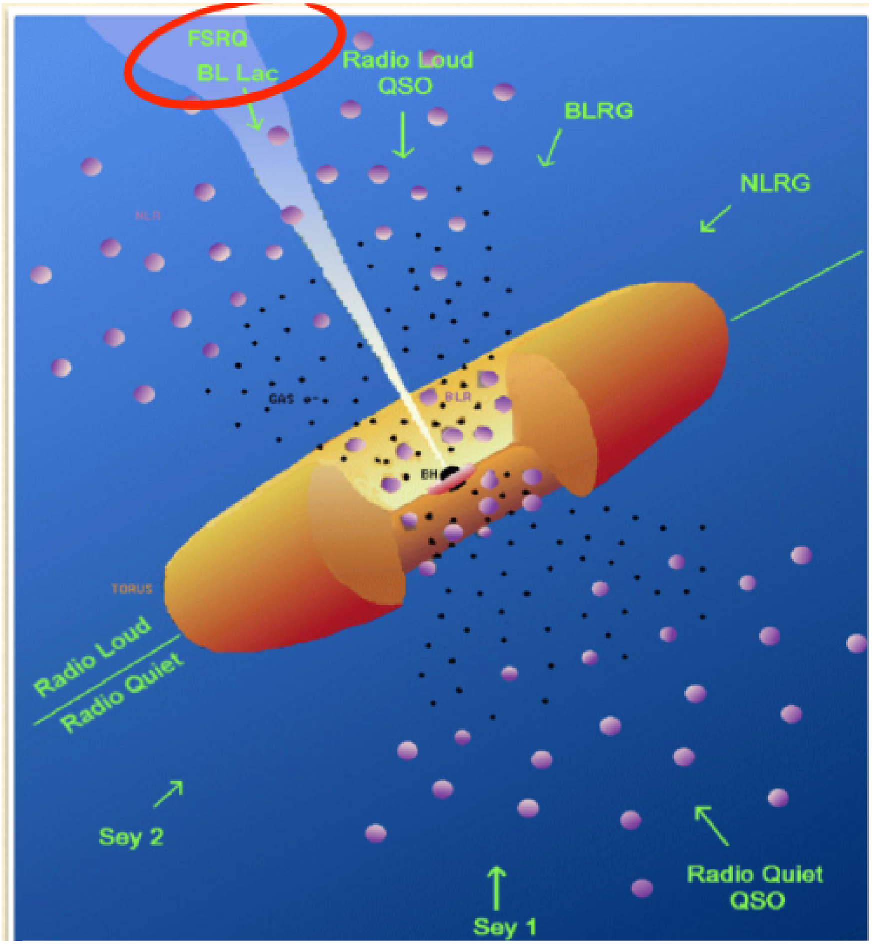
Only focused on stationary states, no flares!
Only focused on emission AT the source, no UHECR propagation!

For further details, see these publications

- Cerruti et al. 2015 2015MNRAS.448..910C
- Zech et al. 2017 (CTA internal-reviewed paper) 2017A&A...602A..25Z
- Cerruti et al. 2017 (Gamma 2016 proceedings) 2017AIPC.1792e0027C
- Cerruti et al. 2017 (in press in A&A) 2017arXiv170700804C

Collaborators: Wystan Benbow, Catherine Boisson, Xuhui Chen, Jon Dumm, Gabriel Emery, Lucy Fortson, David Guarin, Susumu Inoue, Jean-Philippe Lenain, Daniel Mazin, Thibaud Richard, Karlen Shahinyan, Andreas Zech

BLAZARS



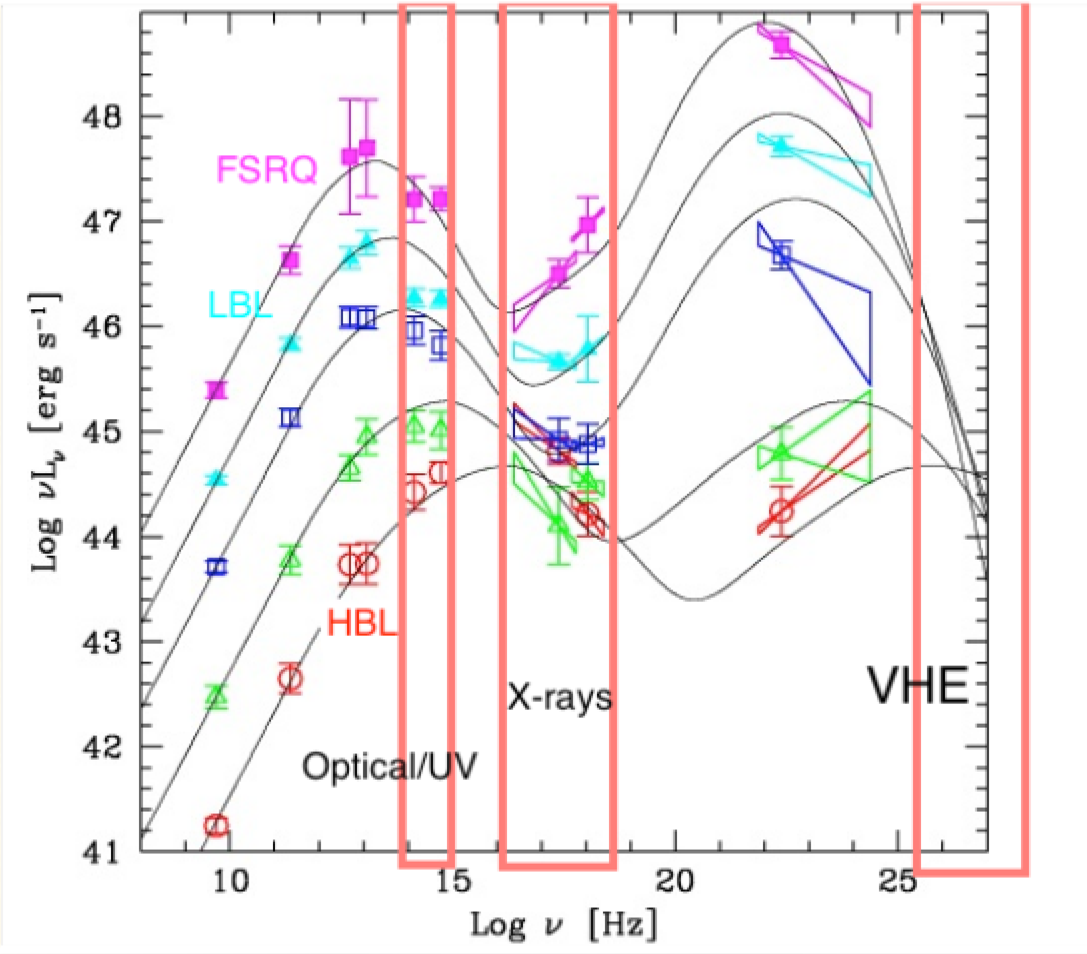
Blazar : radio-loud AGN whose relativistic jet points in the direction of the observer

→ emission from the jet dominates over any other AGN component (the disk, the BLR, the X-ray corona,…)

→ non-thermal emission from radio to gamma-rays, and extreme variability

- Flat-Spectrum-Radio-Quasars: optical spectrum with broad emission lines
- BL Lacertae objets : optical spectrum featureless

BLAZARS



Fossati et al. 1998

Spectral energy distribution (SED) two distinct components

FSRQs show a peak in IR

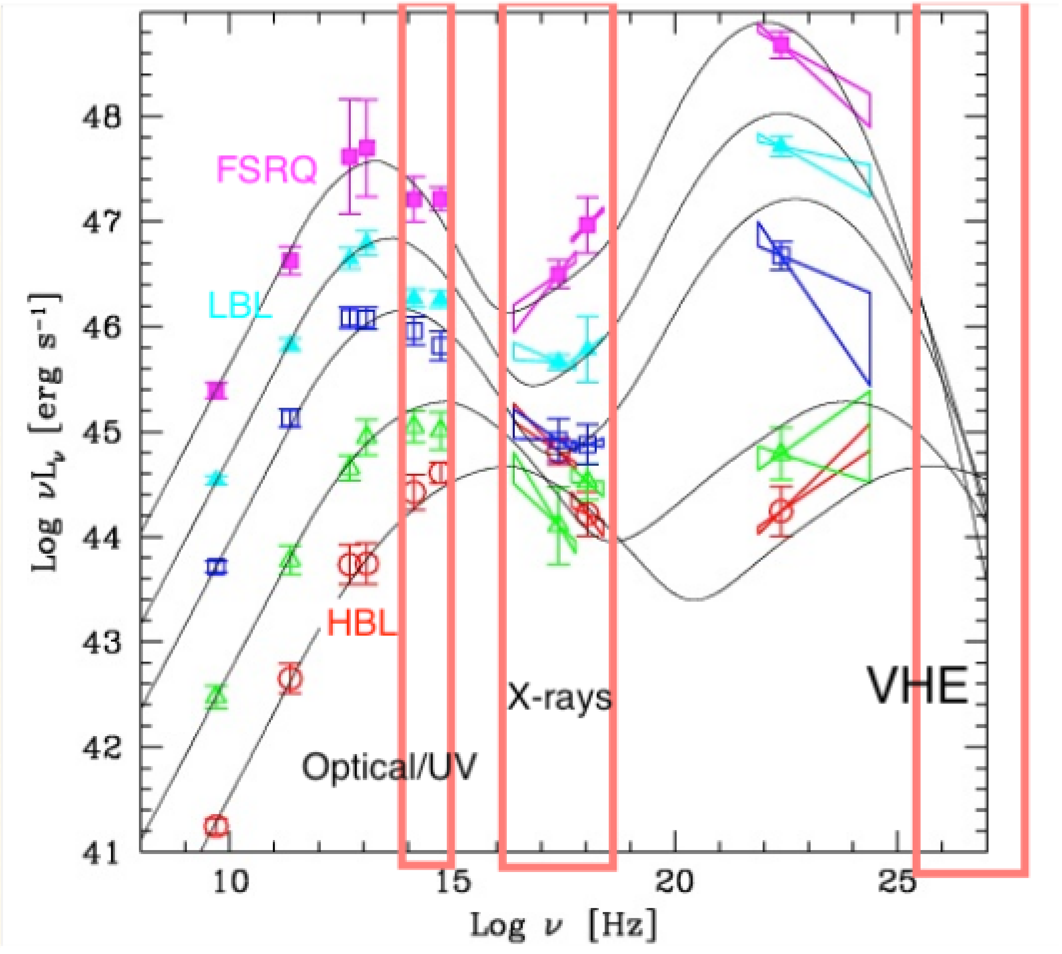
BL Lac objects are classified in:

- peak in optical : Low-frequency peaked (LBLs)

- peak en UV/X : High-frequency peaked (HBLs)

- peak >10 KeV : Ultra-high-frequency peaked (UHBLs)

BLAZARS



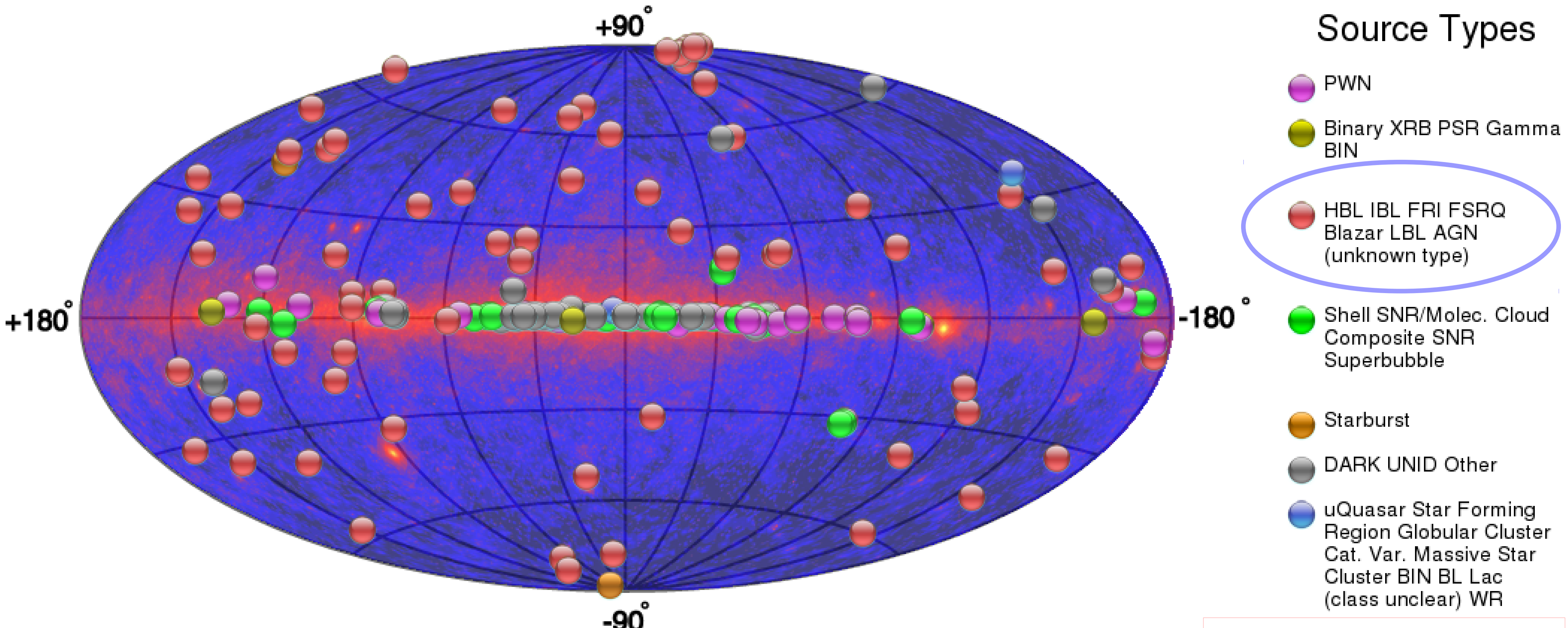
Fossati et al. 1998

In whichever band you observe, you 'select' a blazar with a given peak frequency

→ Radio blazar catalogs and X-ray blazar catalogs don't 100% overlap!

At TeV energies we are dominated by ***high-frequency-peaked blazars***

THE TeV SKY

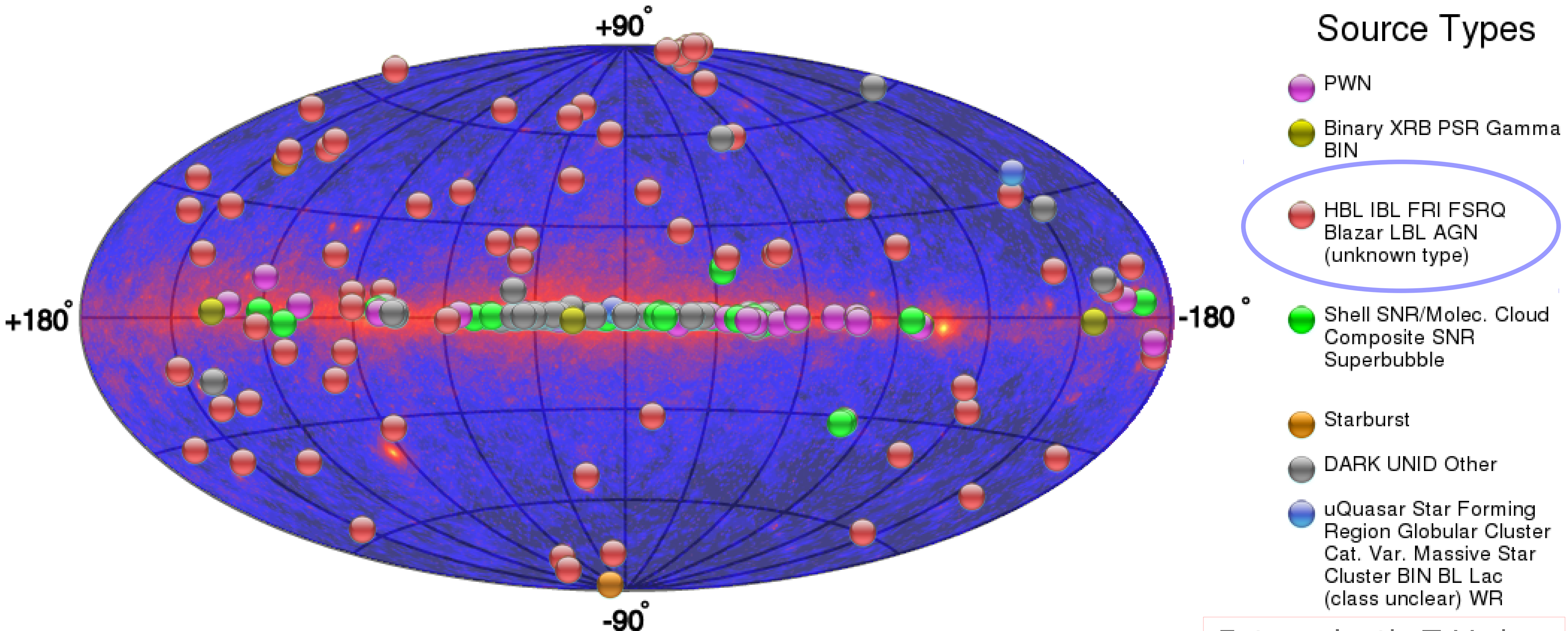


From TeVCAT

Extragalactic TeV sky:

2 starburst galaxies
4 radio-galaxies
66 blazars

THE TeV SKY



From TeVCAT

Extragalactic TeV sky: of these 66 blazars
- 49 are HBLs
- 11 are I/LBLs
- 6 are FSRQs

TeV BLAZAR MODELING

Leptonic vs Hadronic:

Low energy bump IS synchrotron emission by leptons

High energy bump?

- leptonic scenario: inverse Compton scattering
  Same electrons producing synchrotron
  + their own synchrotron radiation (SSC)
  + an external photon field (EIC)

General consensus on the fact that HBLs → SSC
LBLs , FSRQs → EIC

- hadronic scenario: proton synchrotron and/or emission by secondaries produced in p+γ interactions

HADRONIC BLAZAR MODELING IS MULTI-MSN

TeV BLAZAR MODELING

Hadronic modeling of FSRQs:

Major problem is energetic
we need energy in protons which is higher than Eddington luminosity

Several authors came to the same conclusion:
Sikora et al. 09, Zdziarski and Bottcher 15,
Petropoulou and Dimitrakoudis 15,
+++

N.B. Hadronic models can still be ok for flares!

TeV BLAZAR MODELING

Hadronic modeling of FSRQs:

w ton

Always check energy budget of hadronic models

Sometimes in the literature you can find $L=10^{4\text{-}5}\ L_{Edd}$

N.B. Hadronic models can still be ok for flares!

TeV BLAZAR MODELING

Hadronic modeling can still work for HBLs and UHBLs with reasonable energy budget (i.e. at most $L \sim L_{Edd}$)

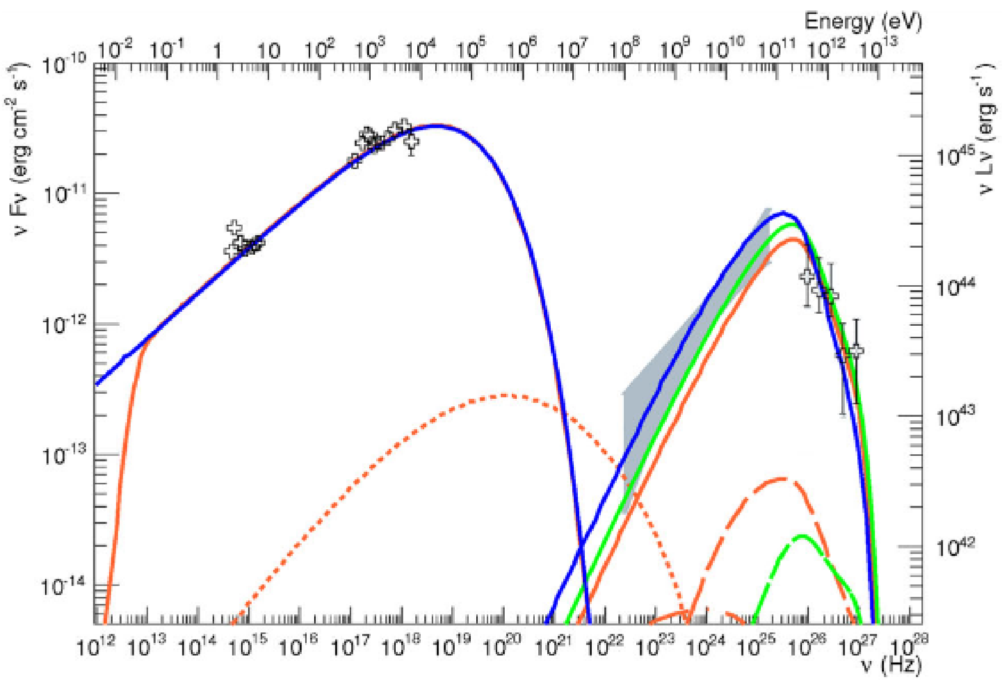
UHBLs, interesting observing properties:

* high-frequency SED peak in TeV band
* NOT flaring!
* if modelled with SSC scenario, they face some issues
  - Doppler factor is higher than for ‚standard' HBLs
  - they require a high value of E_{min} for electrons

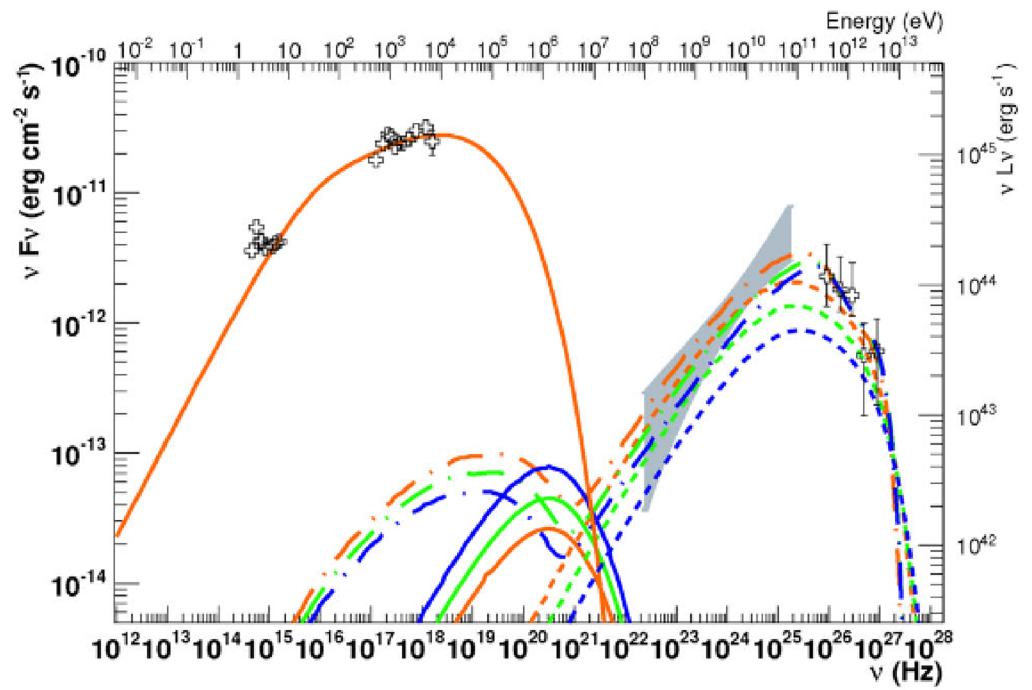
TeV UHBLs MODELING

Hadronic modeling of RGB J0710+591 (typical UHBL)

$\delta = 30$



Proton-synchrotron scenario
$\gamma_{p,Max} = 10^{9\text{-}10}$
$L = 10^{45\text{-}47}$ erg s^{-1}

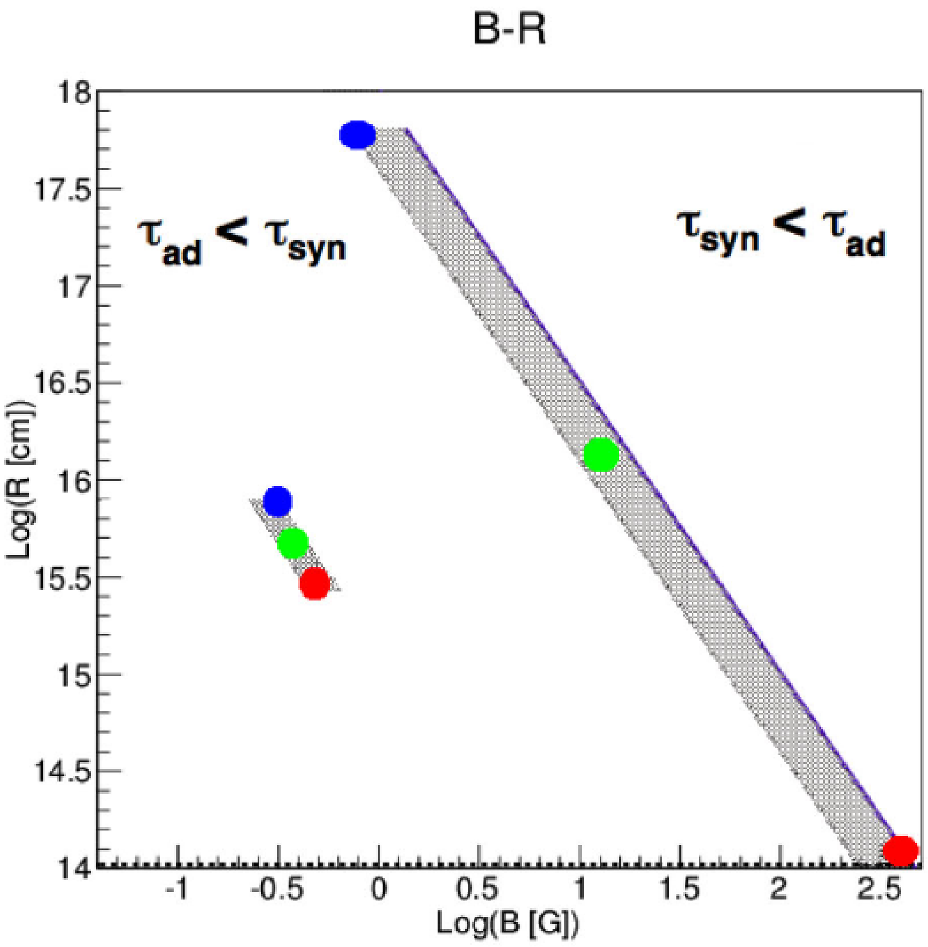


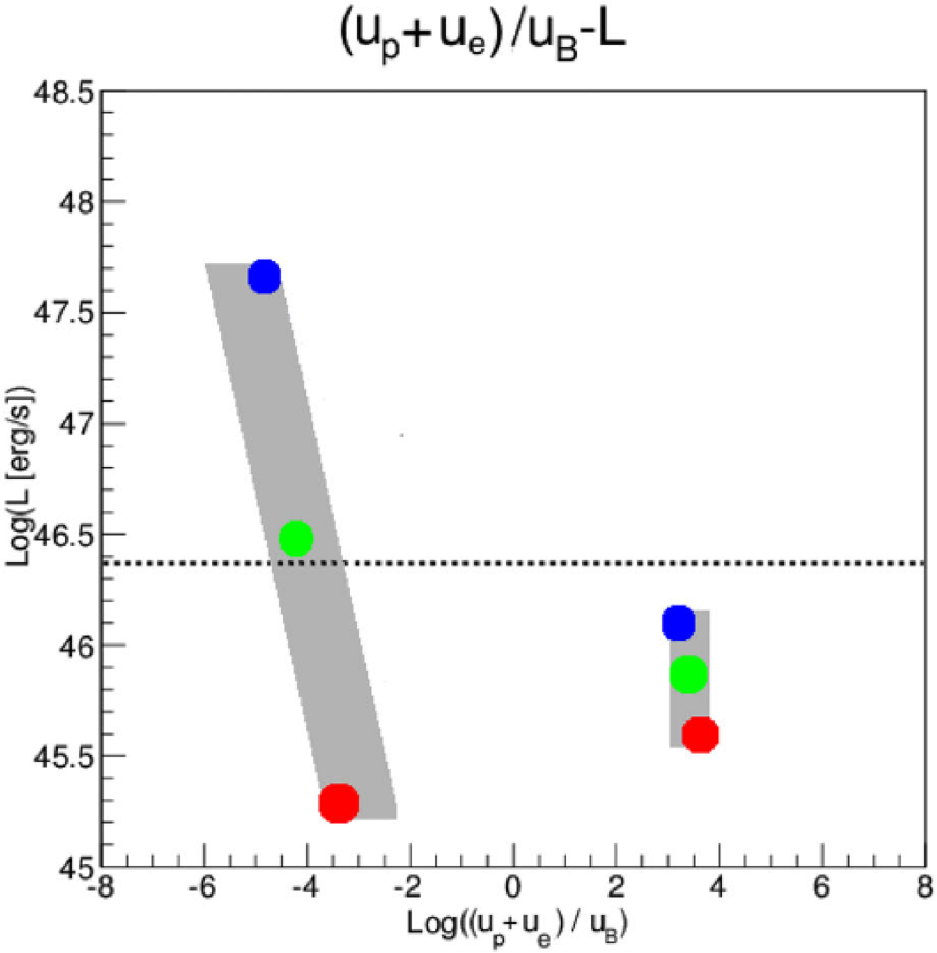
Lepto-hadronic scenario
$\gamma_{p,Max} = 10^{8}$
$L = 10^{46}$ erg s^{-1}

Cerruti et al. 2015 2015MNRAS.448..910C

TeV UHBLs MODELING

Hadronic modeling of RGB J0710+591 (typical UHBL)





Cerruti et al. 2015 2015MNRAS.448..910C

TeV UHBLs MODELING

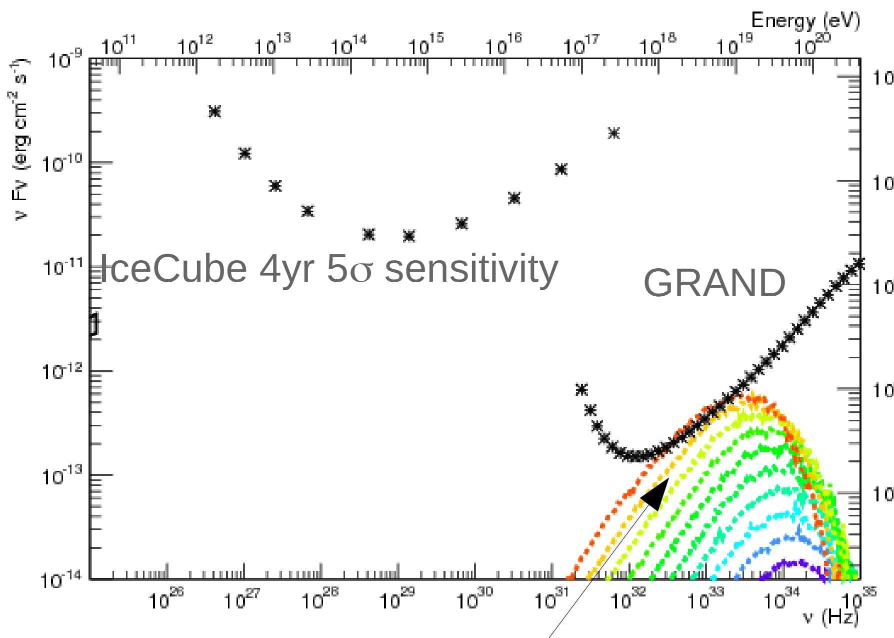
Hadronic modeling is a generic name for a broad family of solutions with VERY different parameters for the jet/particles and VERY different radiative processes

Lepto-hadronic solutions exist!

Hadronic parameter space is HUGE
A single hadronic solution is NOT representative

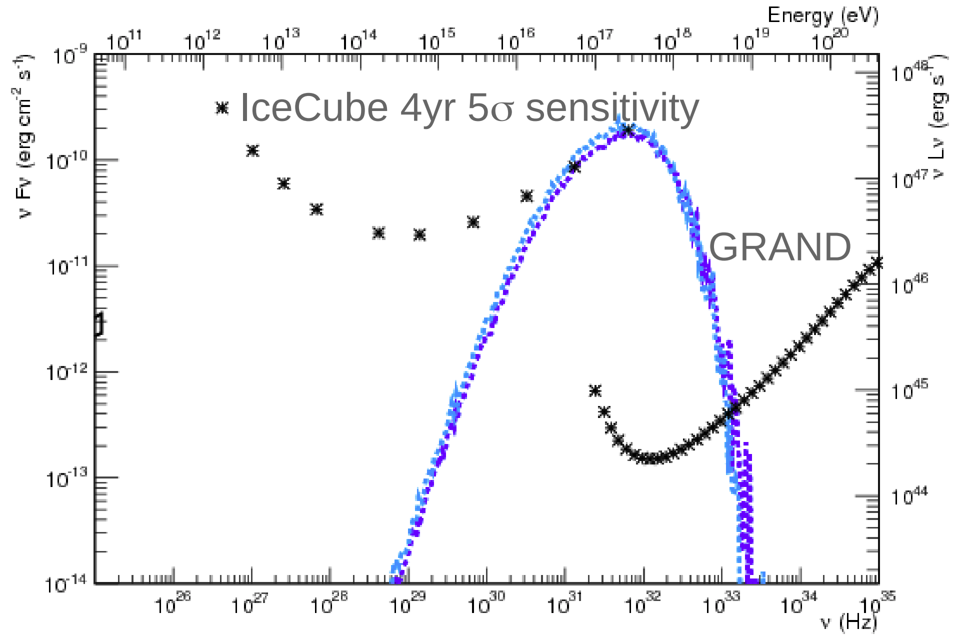
ν from TeV UHBLs

Proton-synchrotron scenario



The smaller and dense the emitting region, the higher the neutrino flux

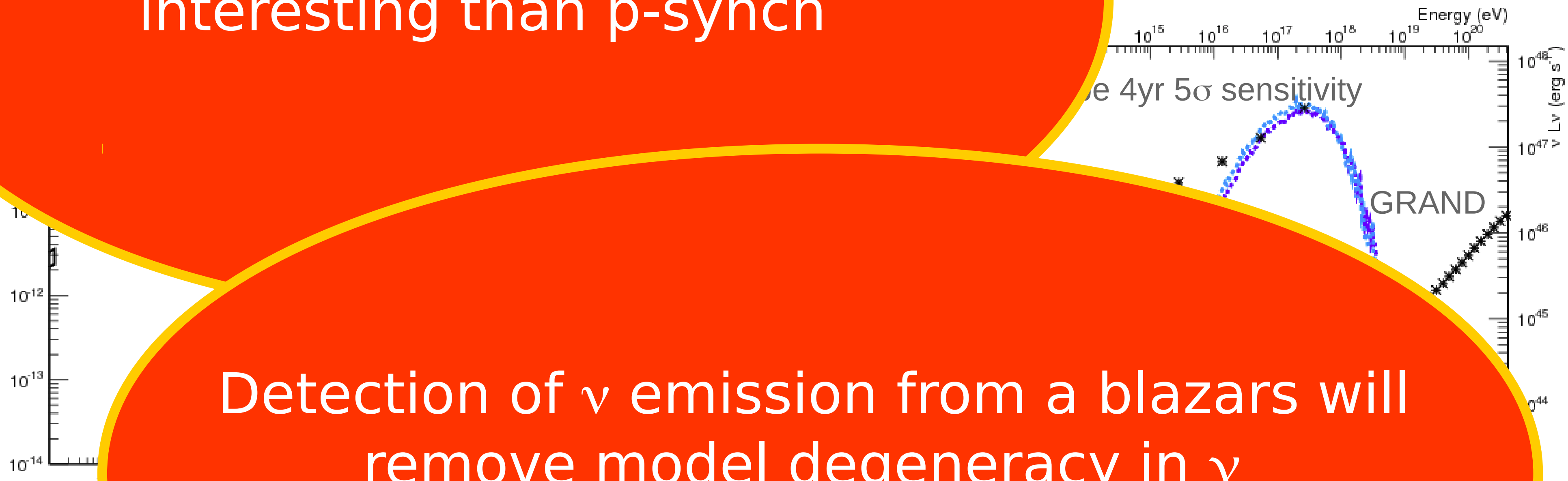
Lepto-hadronic scenario



ν from TeV UHBLs

Lepto-hadronic solutions are much more interesting than p-synch

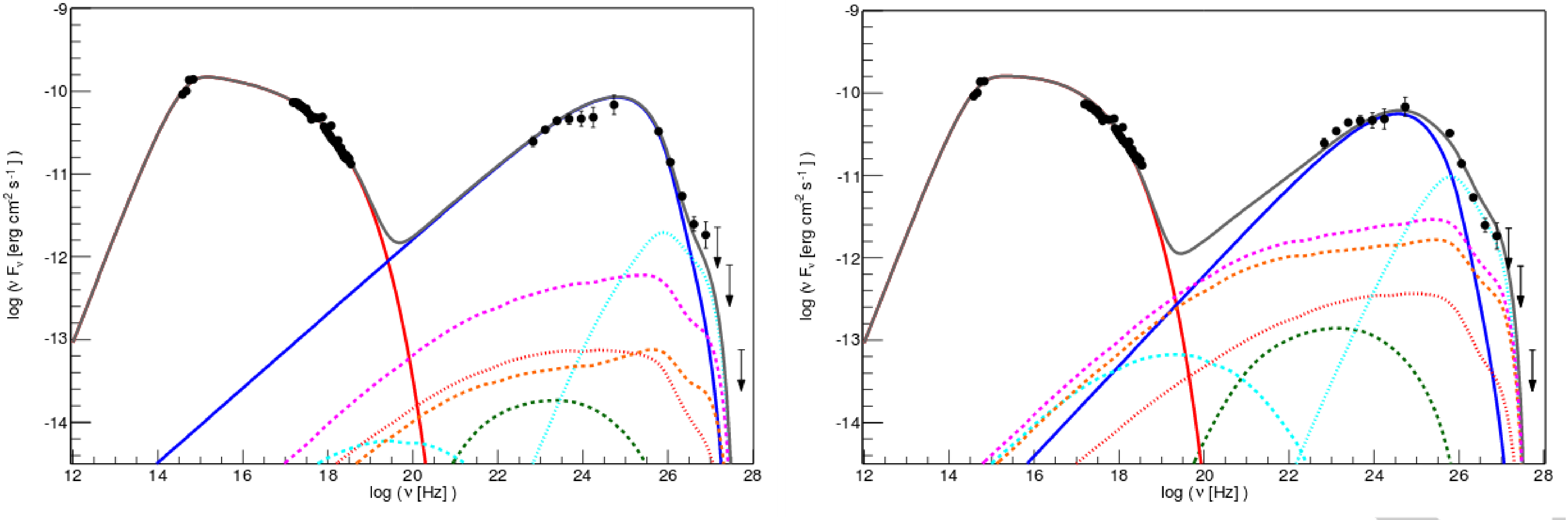
adronic scenario



Detection of ν emission from a blazars will remove model degeneracy in γ
→ constraints on jet physics & accelerator

TeV HBLs MODELING

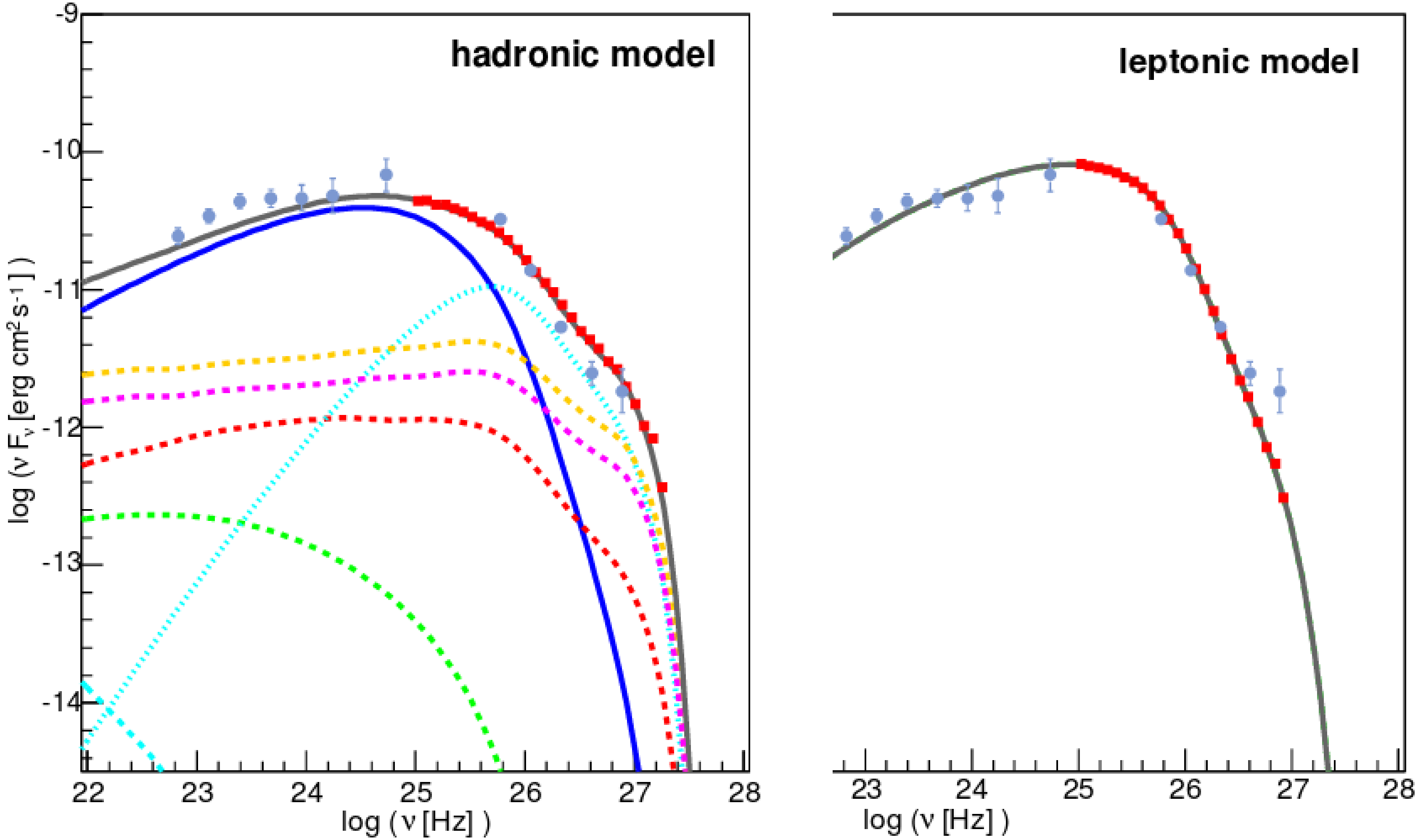
What CTA will see from the brightest HBLs?



Two different hadronic models of PKS 2155-304,
showing the emergence of the cascade bump

Zech, Cerruti & Mazin, 2017 2017A&A...602A..25Z

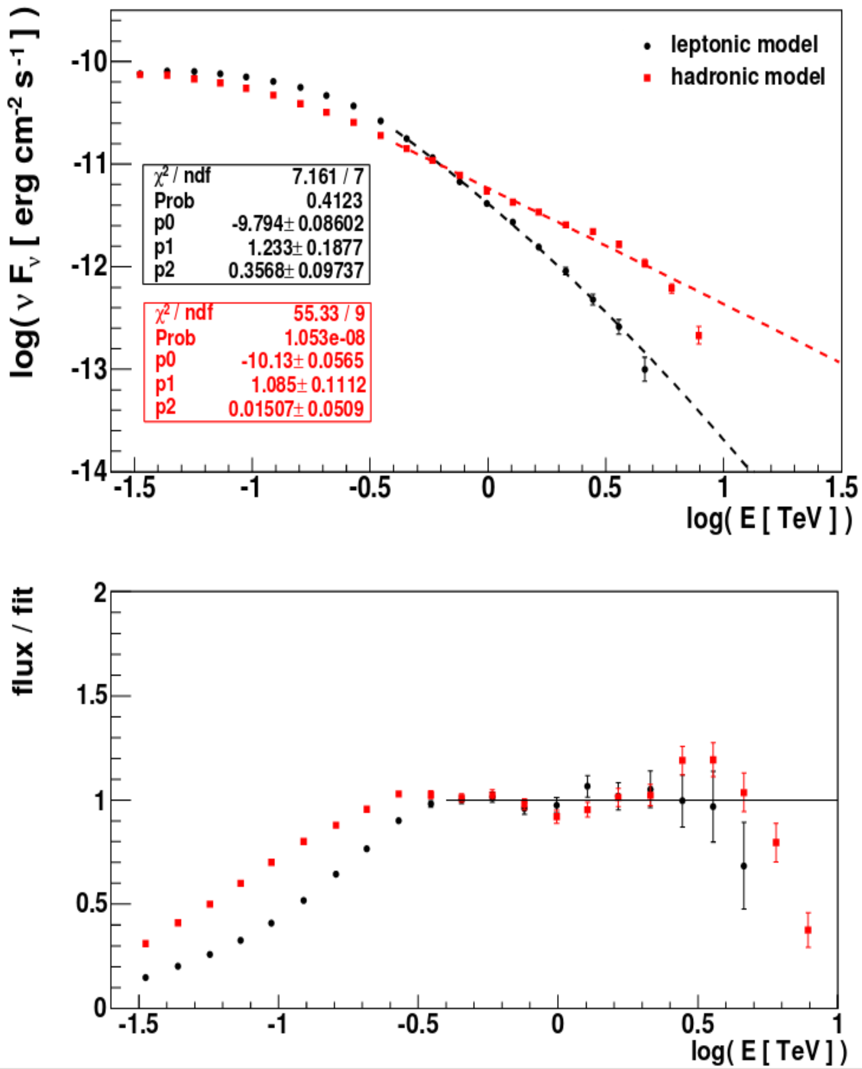
TeV HBLs MODELING

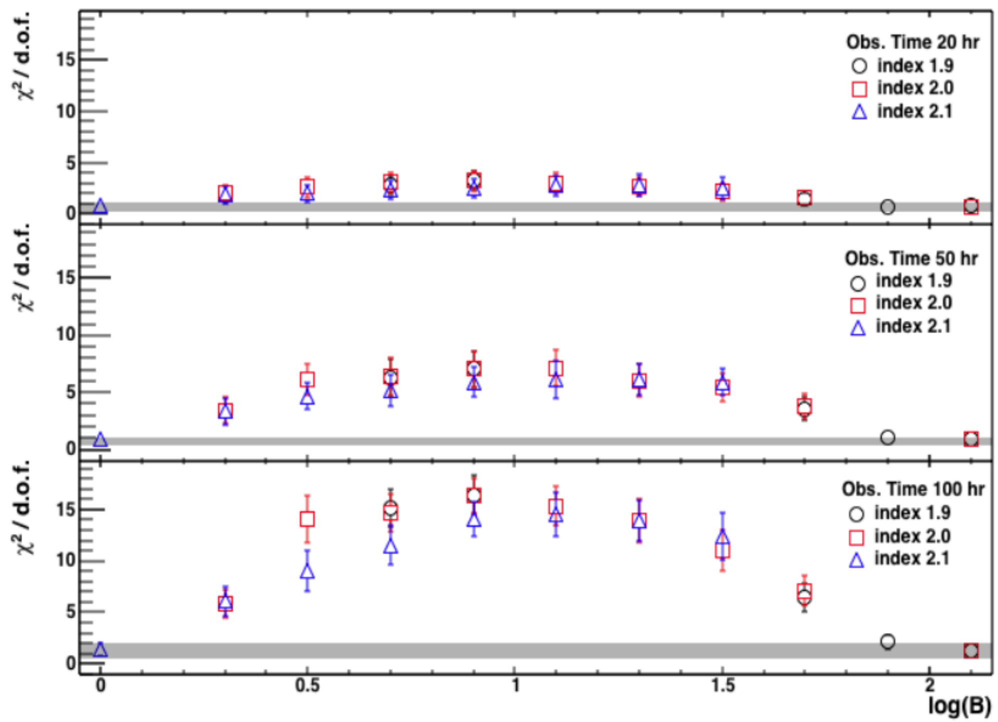


In red, simulated CTA spectra for leptonic and hadronic models

Zech, Cerruti & Mazin, 2017 2017A&A...602A..25Z

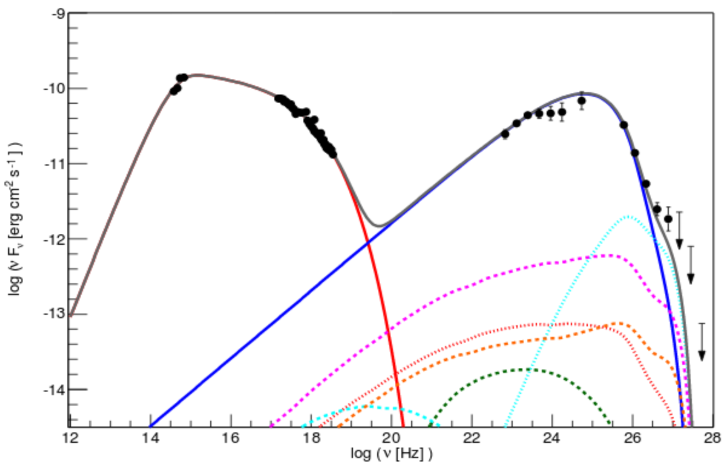
TeV HBLs MODELING

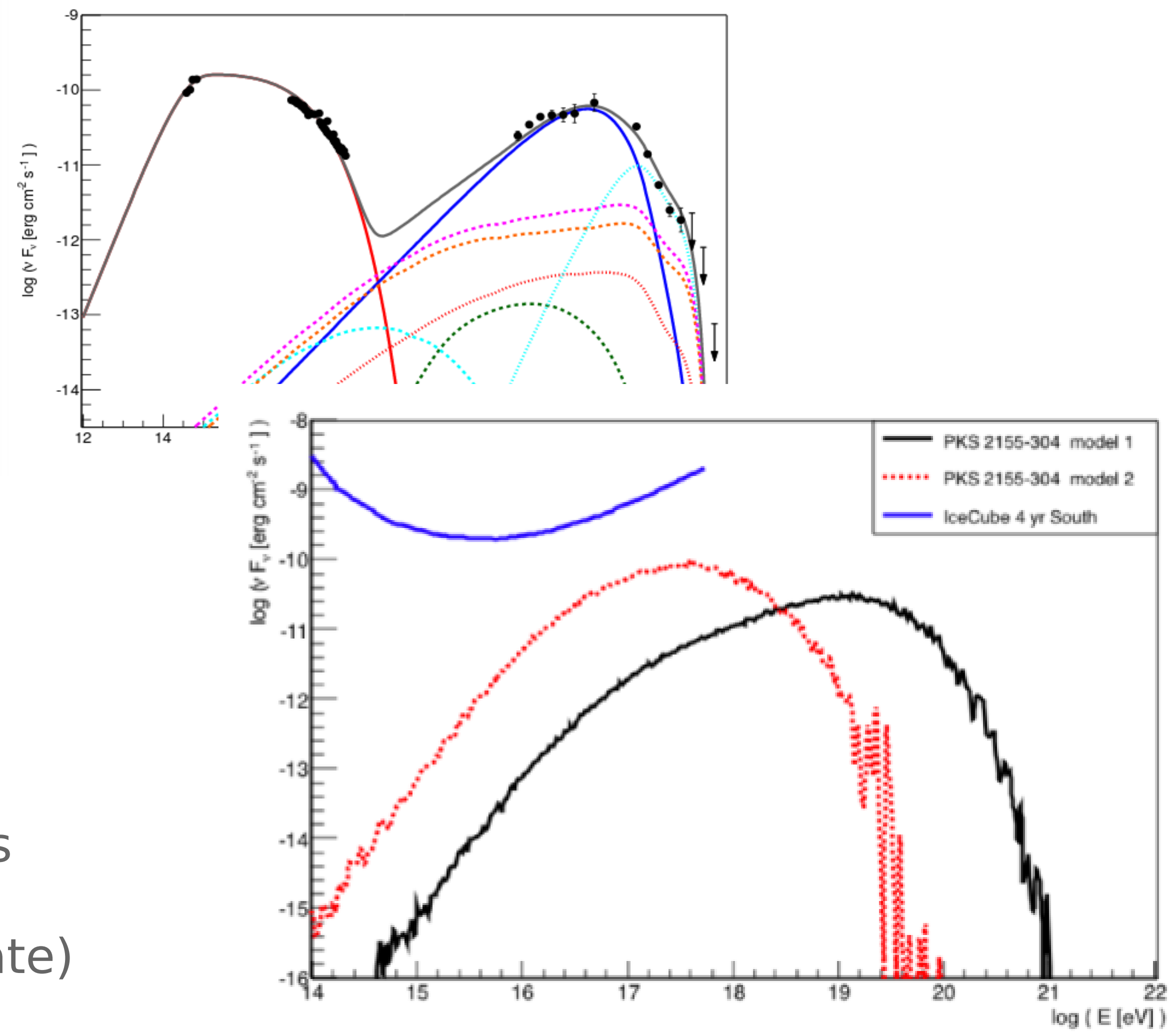




Detectability of the cascade bump estimated by fitting the CTA spectrum with a log-parabolic model and comparing leptonic and hadronic results

ν FROM TeV HBLs





Same model as before:

associated neutrino flux, and comparison with IceCube sensitivity to point-like sources

→ still too faint (for the low-state)

Zech, Cerruti & Mazin, 2017 2017A&A...602A..25Z

TeV HBLs MODELING

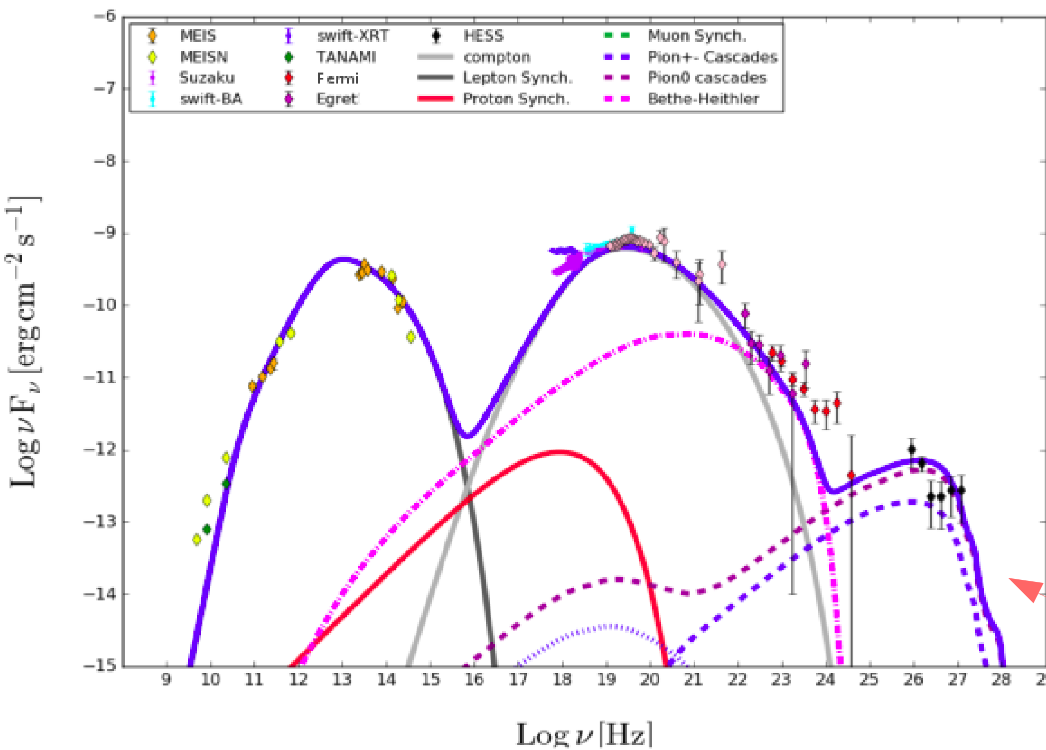
If Gamma emission is hadronic
CTA WILL observe a hardening

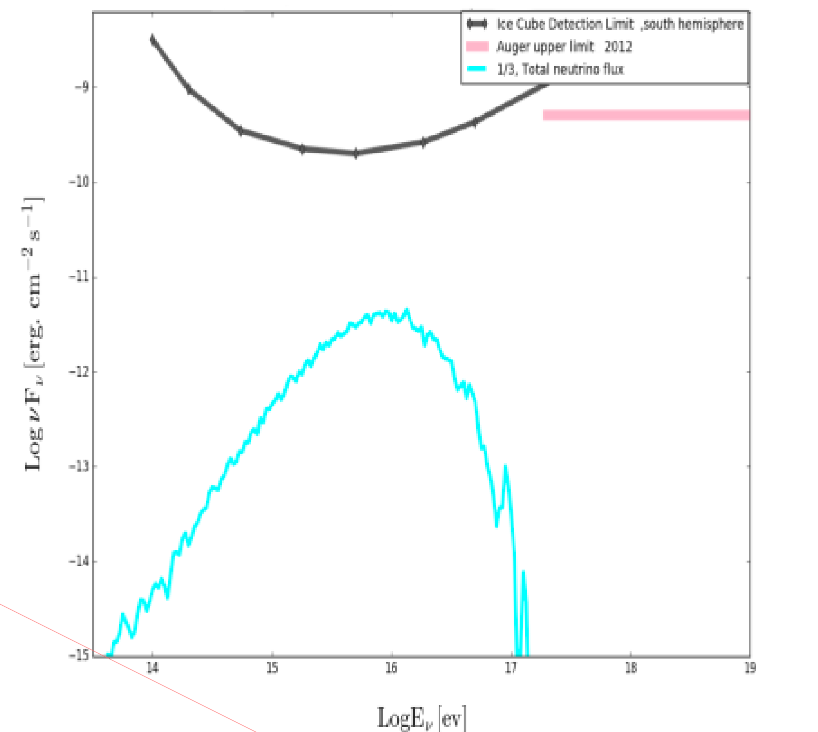
If CTA observes a hardening,
simple SSC model will be excluded

...if CTA doesn‘t observe a hardening, a SIGNIFICANT part of the hadronic model parameter space is excluded!

TeV RADIO-GALAXIES MODELING

Centaurus A



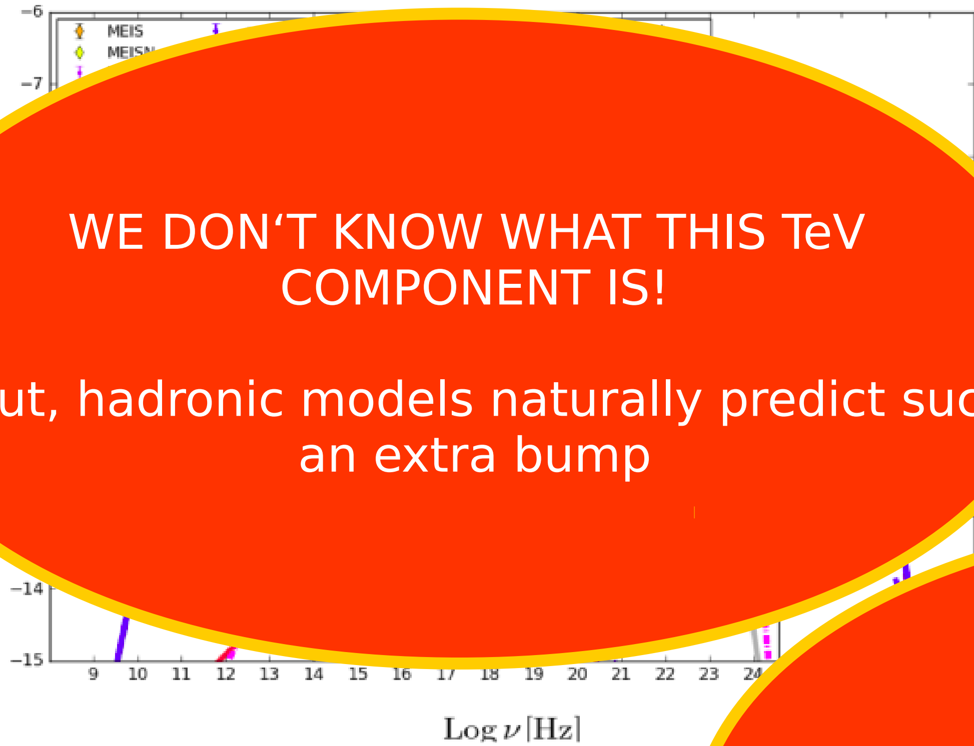


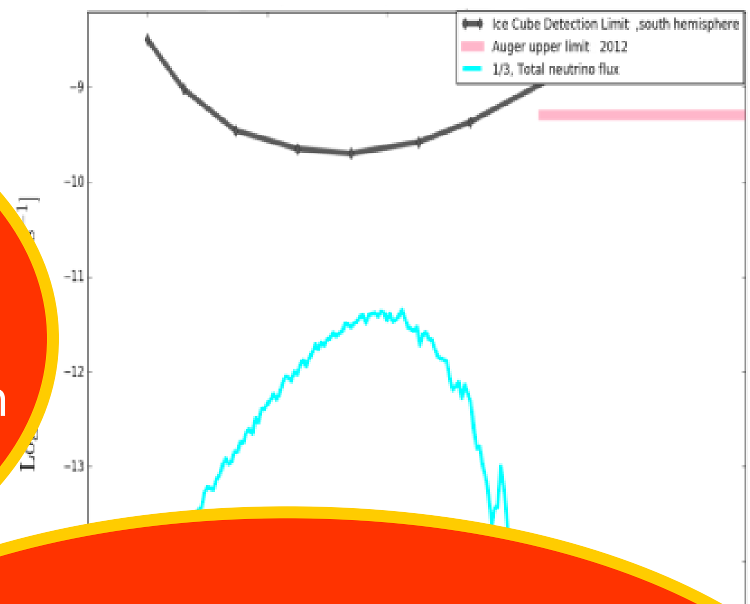
This is the ONLY γ-ray AGN for which we see a third SED component

Cerruti et al. 2017 2017AIPC.1792e0027C

TeV RADIO-GALAXIES MODELING

Centaurus A





WE DON'T KNOW WHAT THIS TeV COMPONENT IS!

...but, hadronic models naturally predict such an extra bump

This is the ONLY γ-ray AGN f

Neutrino flux still two orders of magnitudes lower than IceCube sensitivity

Cerruti et al. 2017 2017

CONCLUSIONS

γ and ν from hadronic modeling of TeV blazars

FSRQs face energy problem: always check energy budget of hadronic models

(U)HBLs are interesting targets for such studies
→ different solutions! P-synch / lepto-hadronic
→ lepto-hadronic is more interesting for ν

CTA will be able to detect hadronic signatures in HBLs, or exclude a significant part of the parameter space

Hadronic models naturally explain the TeV emission from Centaurus A (not a lot of ν)