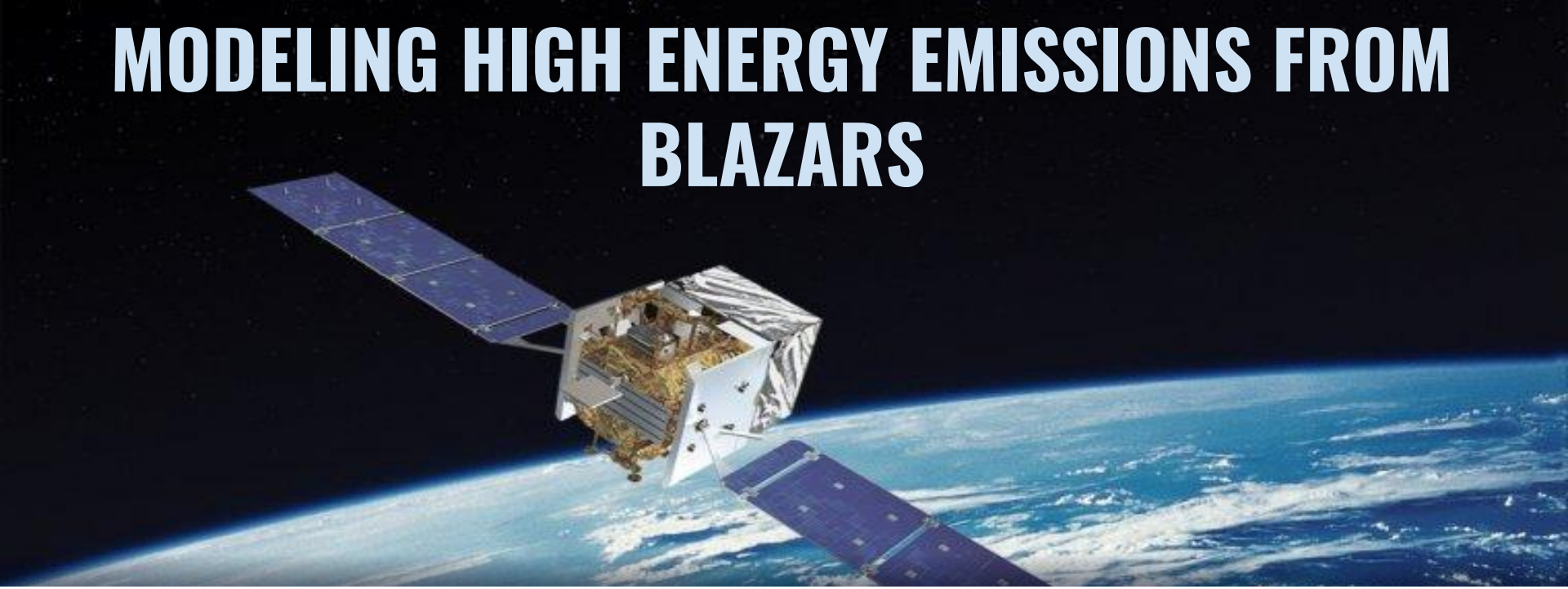
MODELING HIGH ENERGY EMISSIONS FROM BLAZARS



Durham University

Alberto Rosales de Leon

Fermi Summer School

May-June, 2019

Durham University, Gamma-ray Group

Founded in 1832 is the 3rd oldest university in Englad

Norman Architecture

Castle (built in 1072)

Cathedral (built in 1080)

Durham's Catedral/Castle was created a UNESCO World Heritage Site in 1986.

Number Students: 18,385*

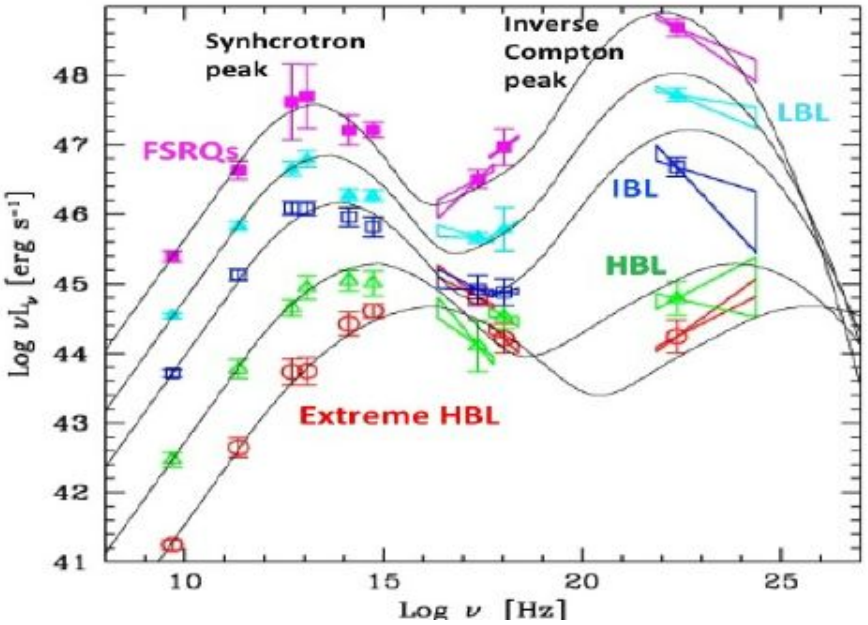
Postgraduates: 4,720*

*2017

Blazars

Blazars: AGN sub-class, substantial variability spectrum, relativistic jet in line of sight

Spectral Energy Distribution - SED: Double peak structure in the ν - νFν plane. Non thermal spectra



Blazar Sequence [Fossati et al. 1998]

1st Peak - Synchrotron Radiation

2nd Peak - Synchrotron Self-Compton (SSC)

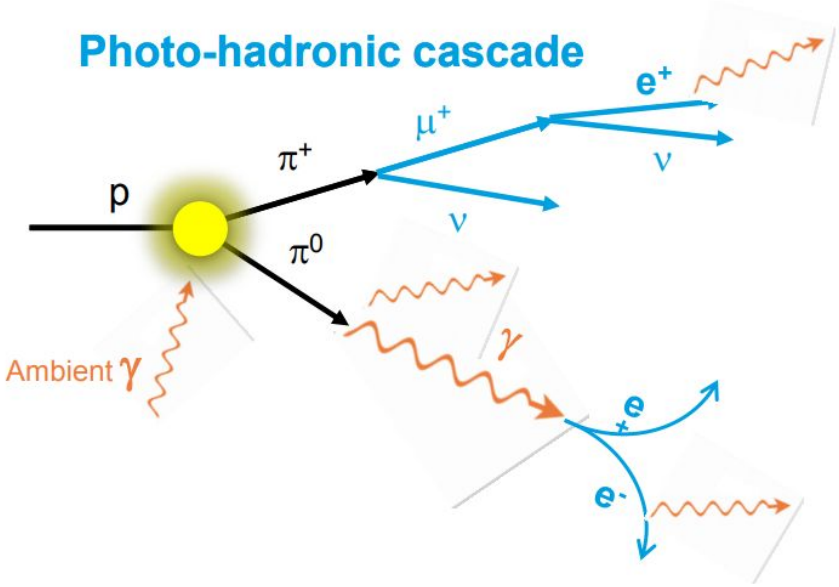
Hadronic components ?

Blazars → FSRQs

Blazars → BL Lac

- LBL $\nu_{sy} < 10^{14}$ Hz
- IBL $10^{15} < \nu_{sy} < 10^{14}$ Hz
- HBL $\nu_{sy} > 10^{15}$ Hz
- UHBL $\nu_{sy} > 10^{17}$ Hz

Hadronic scenario: neutrinos + gamma-rays



electrons and protons accelerated to HE:

$$E_p \gtrsim 10^{17} eV$$

$$p\gamma \rightarrow p\pi^0 + n\pi^+$$

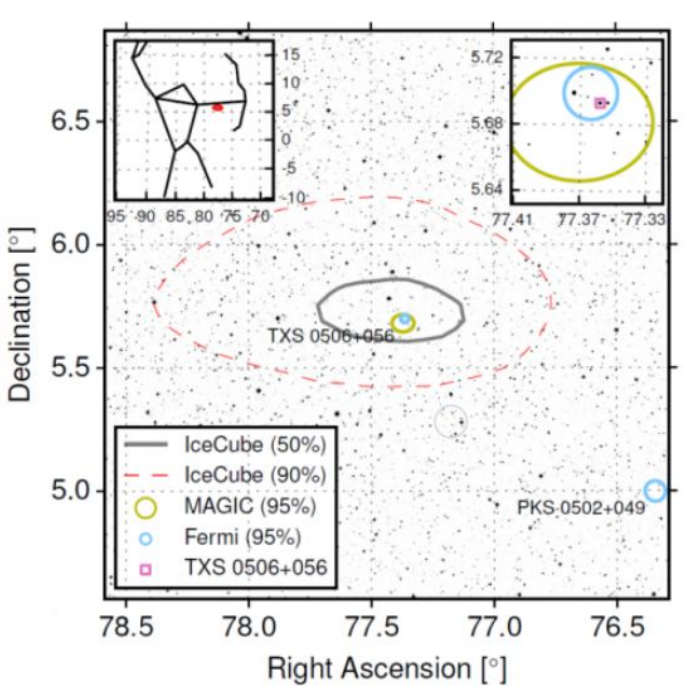
$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \nu_\mu + \bar{\nu}_\mu$$

$$\pi^0 \rightarrow \gamma\gamma$$

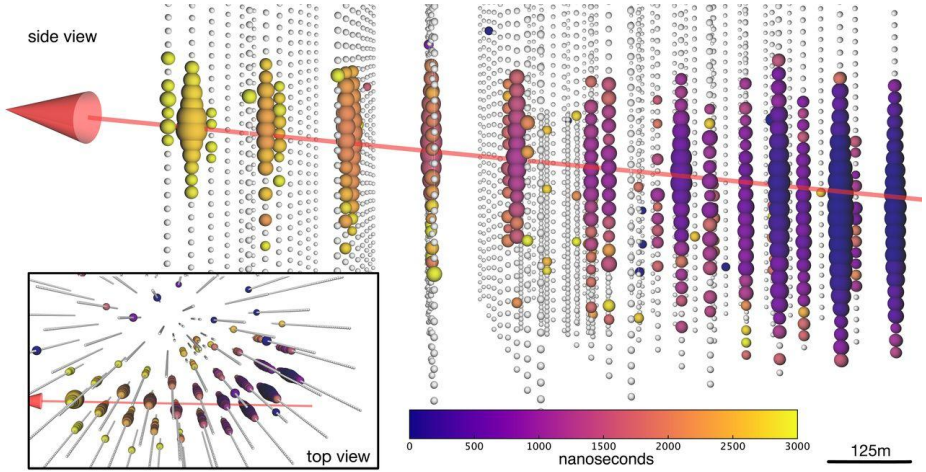
proton-synchrotron
photo-pion production
synchrotron from sub-products
synchrotron pair cascades
Bethe-Heitler pair production

$$p + \gamma \rightarrow p + e^+ + e^-$$

TXS 0506+056



Science 361, eaat1378 (2018)



In 2017 the IceCube collaboration detected a muon neutrino event with a reconstructed energy of 290 TeV during a flaring period of the source TXS-0506+056 at a significance level of 3σ.

Build it and they will come...

13 July 2018

Dissecting the region around IceCube-170922A: the blazar TXS 0506+056 as the first cosmic neutrino source.

E. Resconi, N. Sahakyan, P. Padovani, P. Giommi, B. Arsioli, M. Huber, T. Glauch

22 February 2019

A hadronuclear interpretation of a high-energy neutrino event coincident with a blazar flare.

Ruo-yu Liu, Kai Wang, Rui Xue, Andrew M. Taylor, Xiang-yu Wang, Zhuo Li, Huirong Yan

17 December 2018

Models for the historical flare of TXS 0506+056.

Xavier Rodrigues, Shan Gao, Anatoli Fedynitch, Andrea Palladino, Walter Winter

13 July 2018

A multiwavelength view of BL Lacs neutrino candidates.

C. Righi, L. Pacciani, F. Tavecchio

23 January 2019

TXS 0506+056, the first cosmic neutrino source, is not a BL Lac.

P. Padovani, F. Oikonomou, M. Petropoulou, P. Giommi, E. Resconi

13 July 2018

Blazar Flares as an Origin of High-Energy Cosmic Neutrinos?.

Maria Petropoulou, Foteini Oikonomou, Kohta Murase

23 October 2018

Gammas and neutrinos from TXS 0506+056.

S. Inoue, C. Boisson, G. Emery, M. Cerruti, J.-p. Lenain, A. Zech

20 August 2018

Lepto-hadronic γ -ray and neutrino emission from the jet of TXS 0506+056.

N. Sahakyan

20 November 2018

On the Neutrino Flares from the Direction of TXS 0506+056.

Francis Halzen, Ali Kheirandish, Thomas Weisgarber, Scott P. Wakely

13 July 2018

A Multimessenger Picture of the Flaring Blazar TXS 0506+056: implications for High-Energy Neutrino Emission and Cosmic Ray Acceleration.

A. Coleiro, S. Chaty, M. Petropoulou, C. F. Turley, K. Murase, M. Santander, J. J. DeLaunay, A. Mastichiadis, F. E. Marshall, & 8 more

7 March 2019

High-Energy Neutrinos from Blazar Flares and Implications of TXS 0506+056. (arXiv:1903.02006v1 [astro-ph.HE])

Foteini Oikonomou, Kohta Murase, & 1 more

Photo-hadronic contributions

We assume the standard interpretation of the leptonic model.

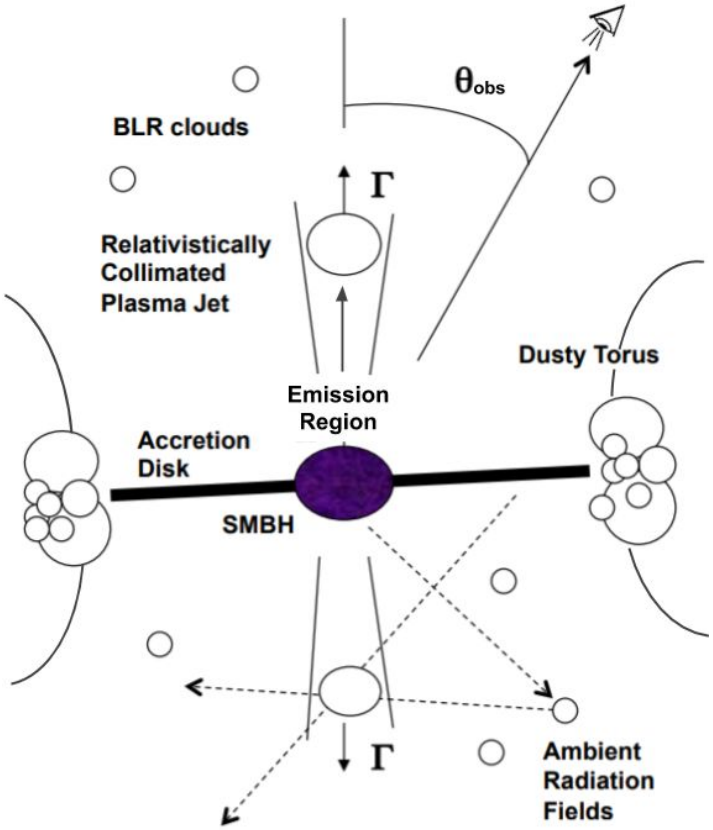
Standard Leptonic = electron-synchrotron + SSC

One zone model:
Spherical region (R)
Propagating along the jet with a velocity $v = \beta_\Gamma c$
Bulk Lorentz factor (Γ)
Doppler boosted (D)
Magnetic field (B)

$$D = (\Gamma[1 - \beta_\Gamma cos\theta_{obs}]) - 1$$

$$t_{obs}^{var} = t'_{var}(1+z)/D$$

$$R \leqslant Dct_{\rm var}/(1+z)$$



Dermer (2001)

The accelerated high energy protons will interact with the Synchrotron Self Compton (SSC) photons to produce the Δ-resonance

$$p + \gamma \rightarrow \Delta^{+} \rightarrow \begin{cases} p\,\pi^{0} \rightarrow p\gamma\gamma, \\ n\,\pi^{+} \rightarrow n e^{+} \nu_{e} \nu_{\mu} \bar{\nu}_{\mu} \end{cases}$$

In the observer's reference frame, the TeV photon energy E_γ, the target SSC photon energy ε_γ, and the proton energy E_p satisfy the approximations:

$$E_{\gamma}\epsilon_{\gamma} \simeq 0.032 \, \frac{\mathcal{D}^{2}}{(1+z)^{2}} \, \mathrm{GeV}^{2}.$$

S. Sahu, L. S. Miranda and S. Rajpoot, Eur. Phys. J. C 76, 127 (2016)

And the intrinsic flux can be given as:

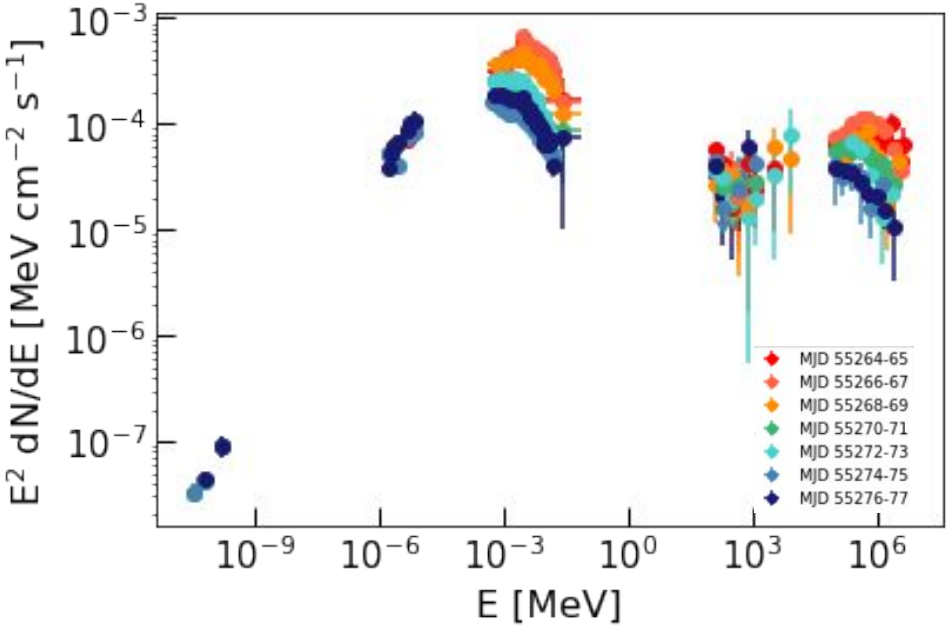
$$F_{int}(E_\gamma) = A_\gamma \Phi(\epsilon_\gamma) \left(\frac{E_\gamma}{TeV} \right)^{-\alpha+3}$$

Where A_γ is a dimensionless normalization constant, α is a power index and $\Phi(\epsilon_\gamma)$ is the corresponding flux from the seed photon.

Taking into account the Extragalactic Background Light (EBL) attenuation, the observed VHE flux F_γ can be expressed in terms of the intrinsic flux:

$$F_\gamma(E_\gamma) = F_{int}(E_\gamma) e^{-\tau_{\gamma\gamma}(E_\gamma, z)}.$$

Markarian 421 - 2010 Flaring Activity



Mrk 421 MWL data MJD 55264-55277

Aleksic et al. 2015

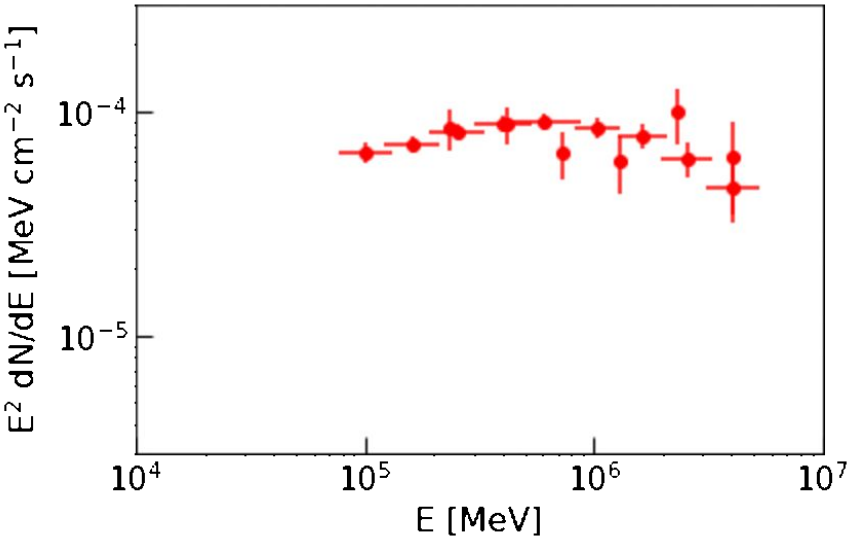
Mrk 421 (HBL, RA=66.11, Dec=38.20, z=0.031)

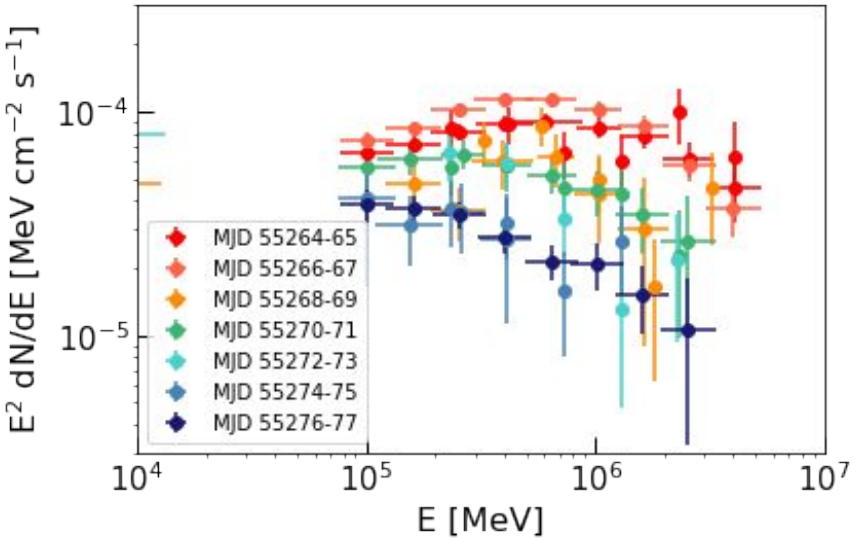
TeV gamma-ray source

showed flaring activity during a 13 day period in 2010 from March 10-22 (MJD 55264-55277).

At the time a multi-instrument campaign was performed, MWL data from: Fermi, MAGIC, VERITAS, Whipple.

gamma-ray flaring data



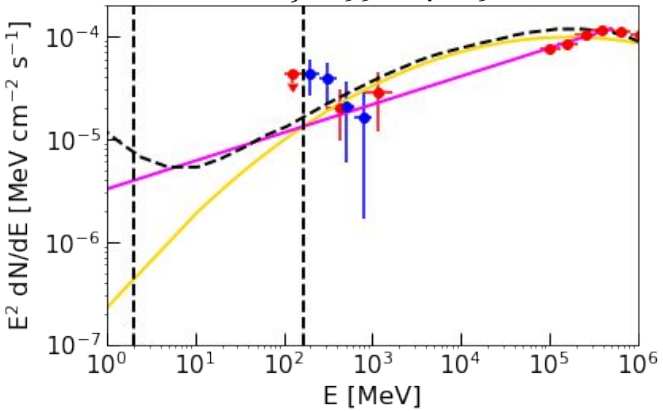


HE gamma-ray data during the 13 days flaring period of Mrk421 in March 2010 (MJD 55264-55277)

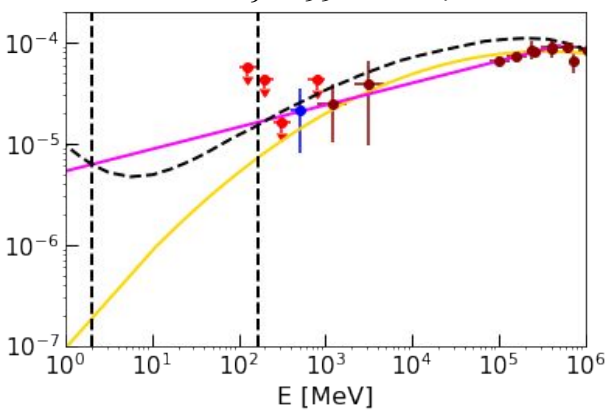
Aleksic et al. 2015

Fit to MeV range using Fermi data

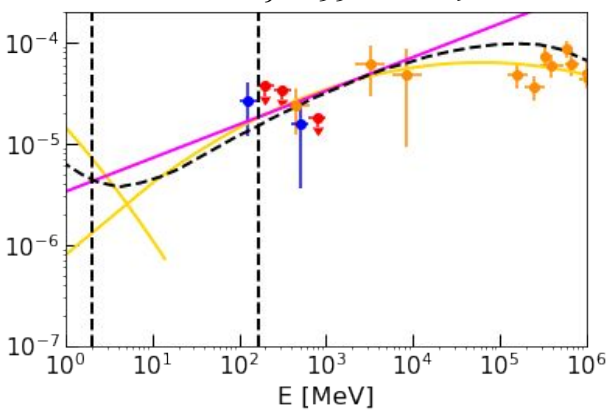
MJD 55264-65



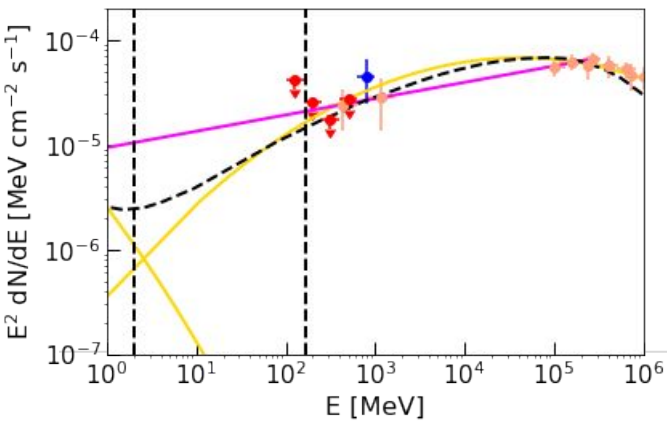
MJD 55266-67



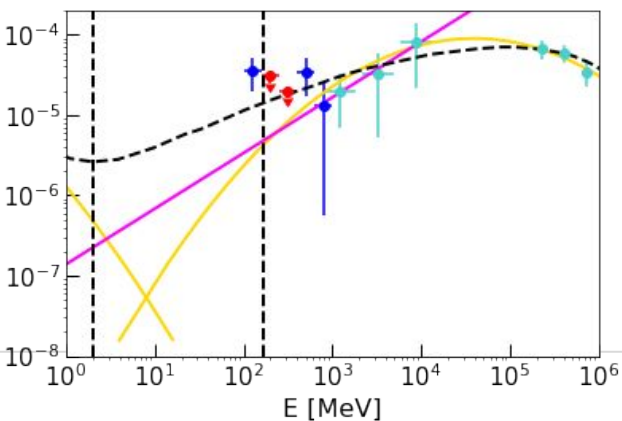
MJD 55268-69



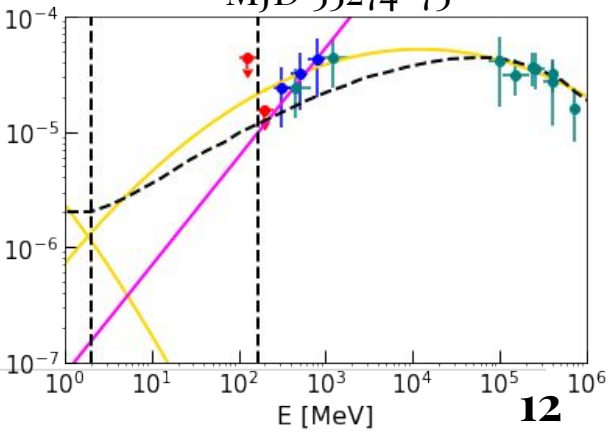
MJD 55270-71



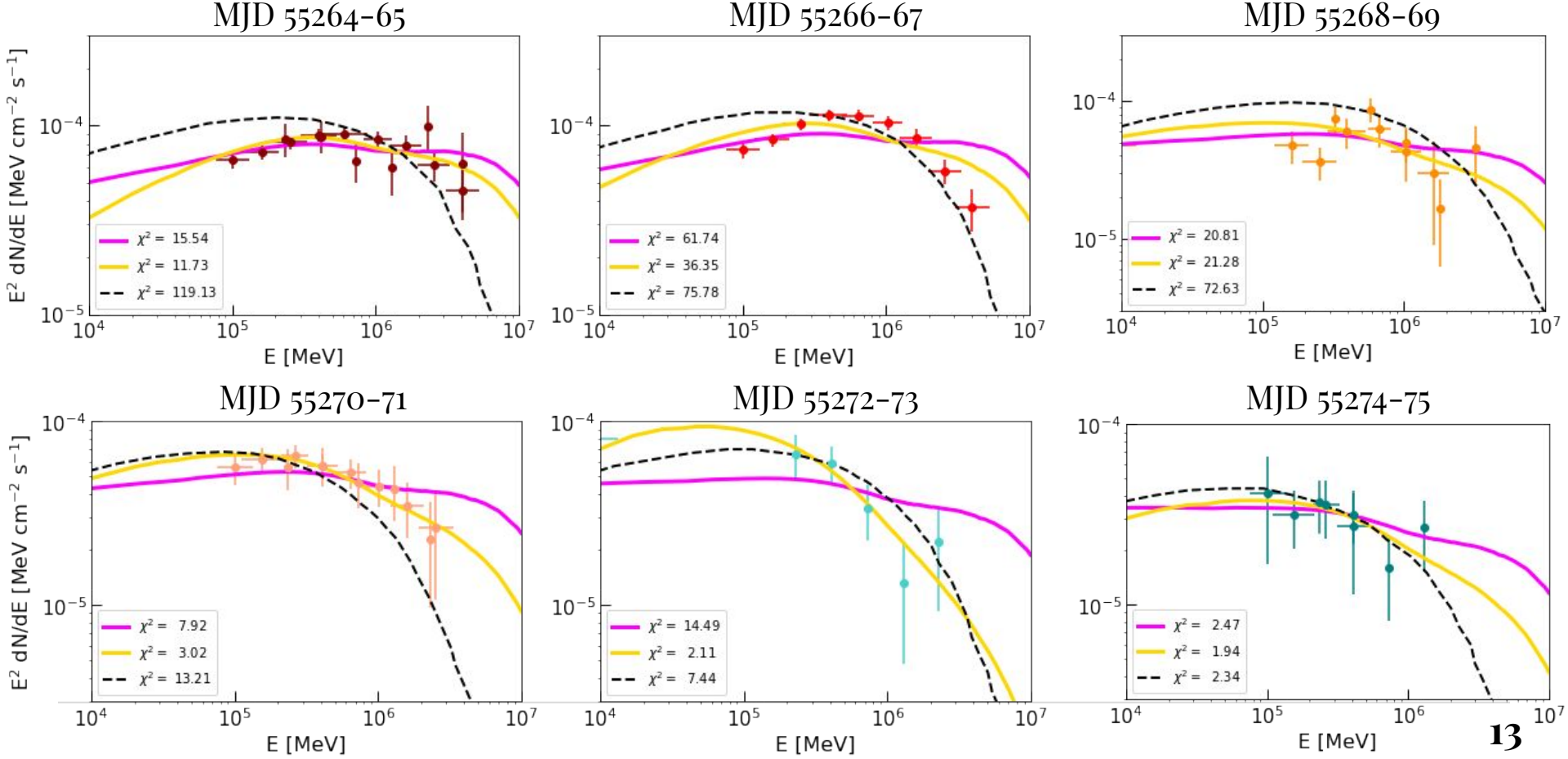
MJD 55272-73



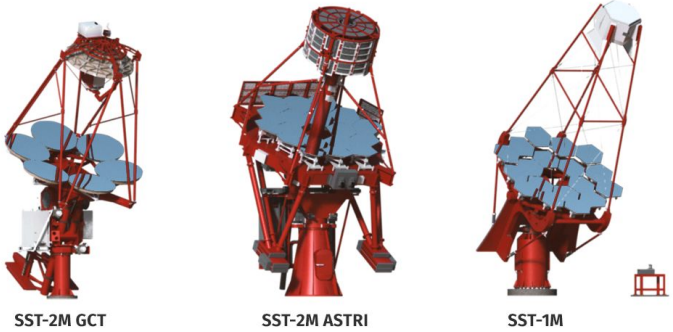
MJD 55274-75

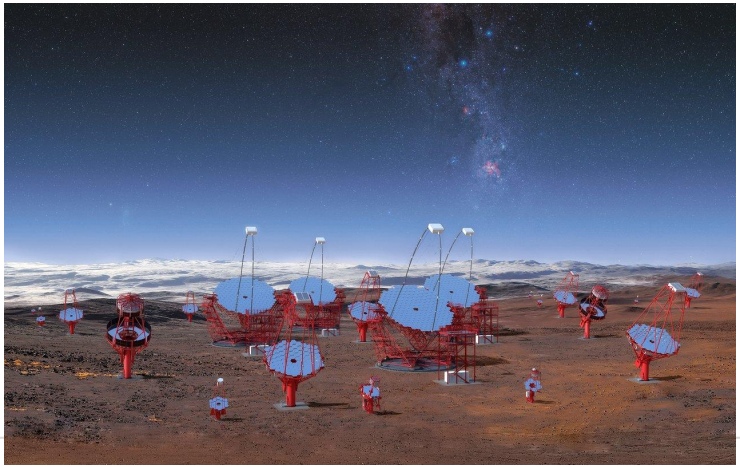


Hadronic component



CTA is coming...





20 GeV up to 300 TeV

with enhanced angular resolution and sensitivity

Large-Sized (23 m): Low sensitivity 20-150 GeV.

Medium-Sized (12 m): core energy range, 150 GeV to 5 TeV.

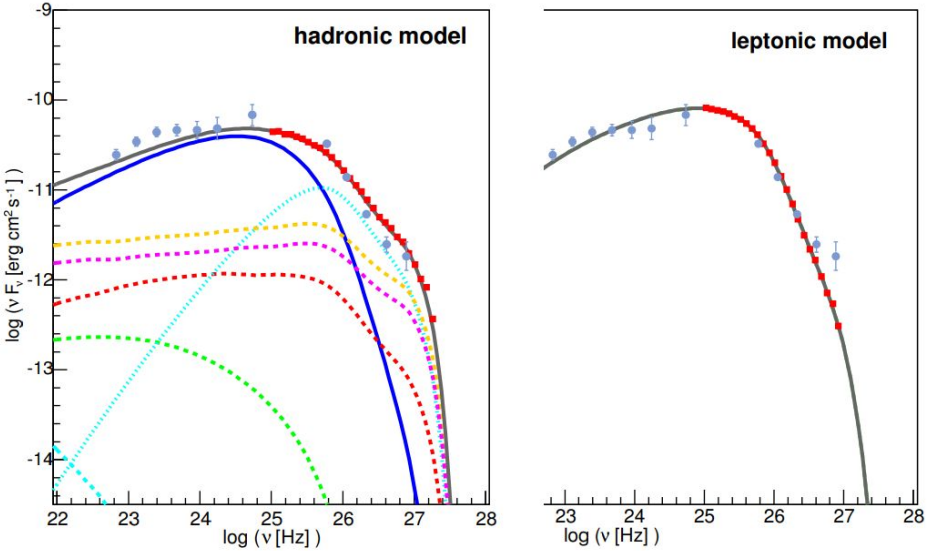
Small-Sized (~4 m): HE range, few TeV and 300 TeV.

Northern site: 0.6 km^2 array in La Palma, Spain. Focus on the low- and mid-energy ranges from 20 GeV to 20 TeV.

Southern site: 4 km^2 array at Paranal observatory in Chile. Cover the entire energy range.

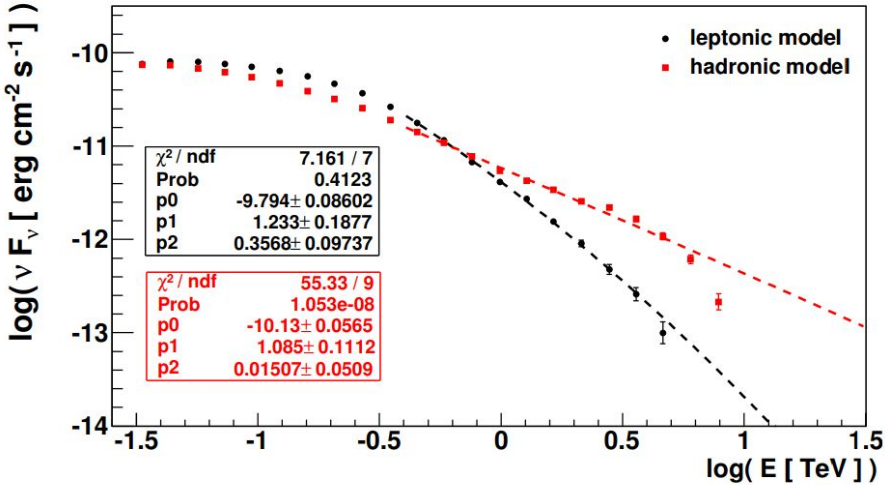
CTA is coming...

Looking for hadronic contributions:



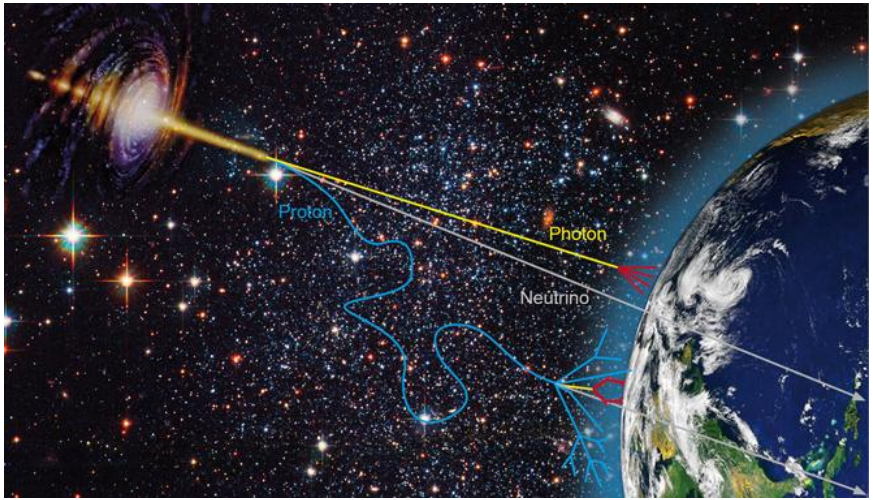
Difference between models at TeV energies.

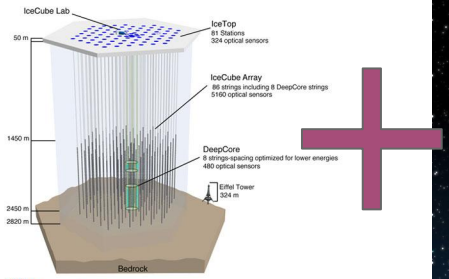
Zech et al. 2017

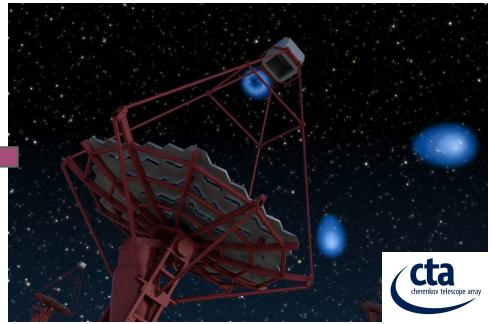


The quality of a log-parabolic fit can be used to discriminate between the two models

Multi-messenger era







Neutrino Target of Opportunity Program (NToO)

CTA will look for a gamma-ray counterpart to a neutrino source alert

We are using FIRESONG [Taboada et al. 2015] to simulate different neutrino sources populations

We aim to scan different local source densities and transient emission durations.

Different CTA instrument response functions (Prod3b-v2) configurations are tested in order to derive optimal follow-up strategies.

THANKS FOR YOUR ATTENTION

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Fermi Summer School

May-June, 2019