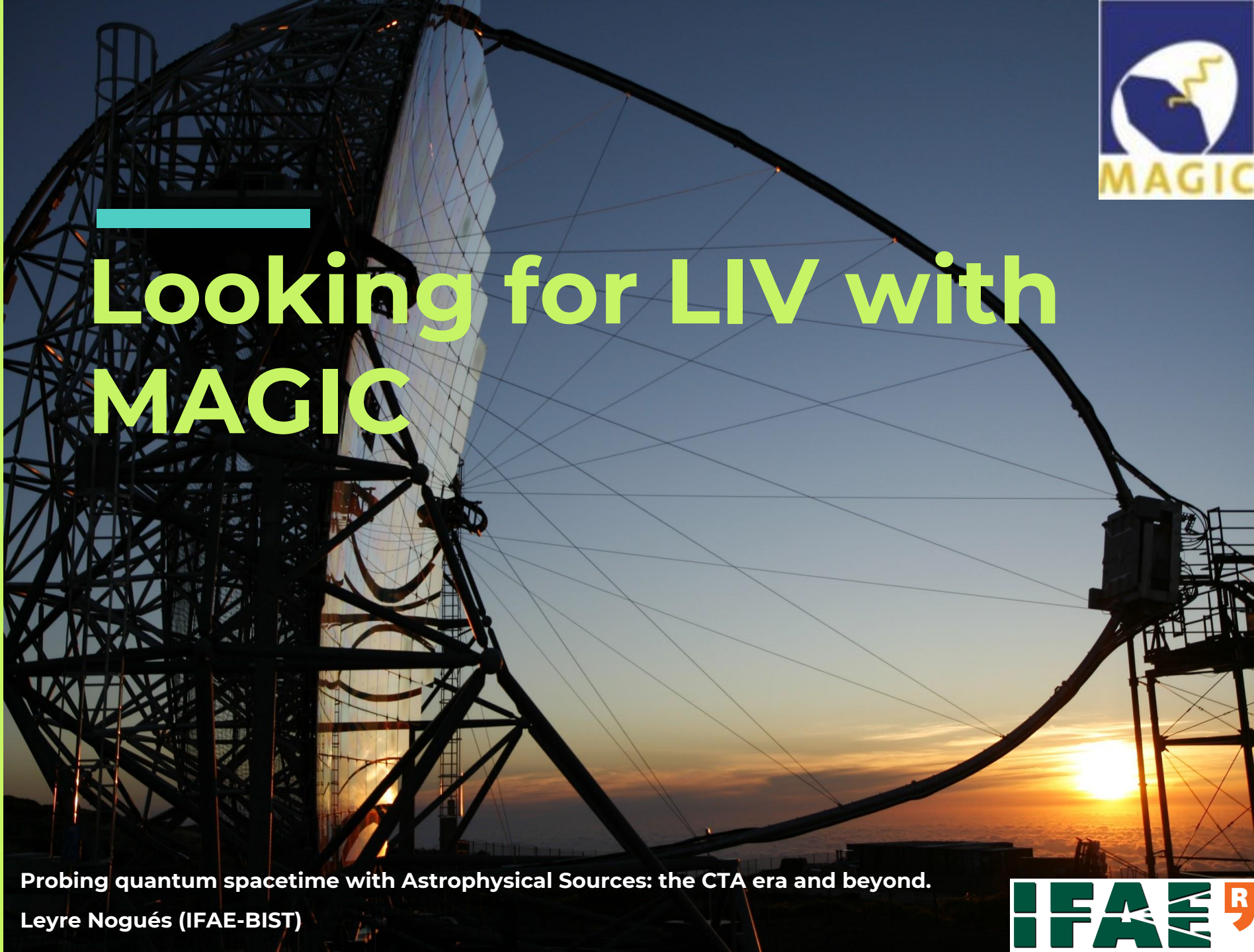


Looking for LIV with MAGIC

Probing quantum spacetime with Astrophysical Sources: the CTA era and beyond.

Leyre Nogués (IFAE-BIST)

Outline

- What is MAGIC?
- What is MAGIC doing now?
- LIV: Method and results.
- Towards LIV Collaboration.
- Summary/Prospective.

The MAGIC telescopes

MAGIC (Major Atmospheric Gamma Imaging Cherenkov) is a system of two IACTs located at El Roque de los Muchacho observatory, in the Canary Island of La Palma (Spain). The collaboration is comprised by 170 scientists from 10 countries in Europe and Asia.

Main characteristics

- Distance inter-telescope: 85 m.
- Mirror size: 17 m diameter.
- Field of View: 3.5º
- Indirect VHE gamma-ray detection.
- Energy range: 50 GeV - 50 TeV.
- High repositioning speed: movement from two opposite positions in 30 seconds. (~7deg/s). Transient sources search.

MAGIC I was inaugurated in 2004 and MAGIC II was inaugurated in 2009. Camera of MAGIC I was upgraded to be like the MAGIC II and both telescopes went under a major upgrade in 2011-2012. Detail about the upgrade can be found in (Hardware article) and in (Software article)

The MAGIC telescopes

MAGIC uses stereo trigger and two different trigger modes: Majority and Sum. The last one allow to go to energies as low as 50 GeV.

Performance

- Time resolution of ns.
- Energy resolution: 15% (1 TeV), 23% (100 GeV).
- Angular resolution: $\lesssim 0.06°$ (1 TeV), 0.1° (100 GeV)
- Integral sensitivity 0.66% of Crab Nebula in 50h (E>220 GeV).
- Stereo Energy threshold of 50 GeV (low Zenith, dark conditions)

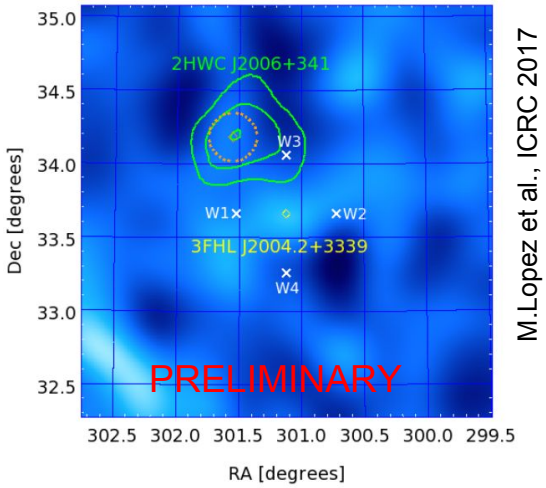
More information about the physics performance can be found in the software paper and information about the MAGIC analysis chain (MARS) can be found in the following paper: MARS paper.

Current MAGIC activity

Magic science scopes are divided in 4 working groups: **Galactic sources** (Pulsars, SNRs, binaries...), **AGN** (BL Lacs, FSRQs, radio galaxies...), **Fundamental physics** (DM, LIV, tau neutrinos...) and **Transients & MM**(GRBs, GWs, FRBs...).

HAWC follow-up

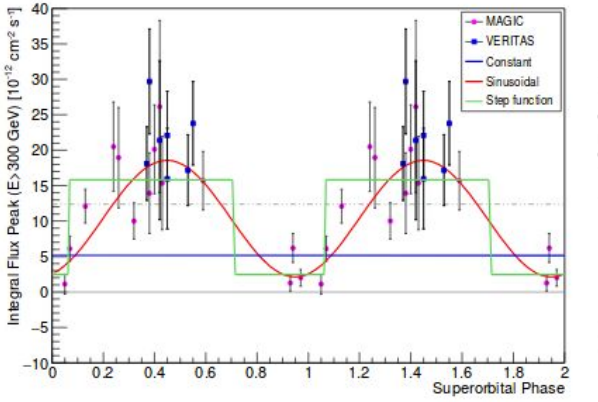
Re-analysis of archival MAGIC data is whose FoV there are sources detected by HAWC with no association with any VHE source. The analysis looks for point-like or extended sources and discuss about the nature of these unknown sources. Paper ongoing.



M.Lopez et al., ICRC 2017

Super-orbital TeV emission

The gamma-ray binary LS I +61 303 has been observed by MAGIC since its discovery in 2006. After observing significant flux decreases in the source, MAGIC folded all the data from the source giving place to a lightcurve whose probability of a constant flux is negligible. This is compatible with the 4.5y radio modulation seen in other frequencies.

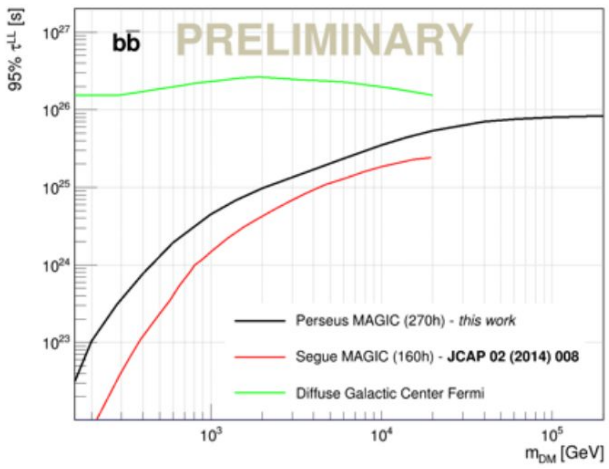


M.Lopez et al., ICRC 2017

Current MAGIC activity

DM in Perseus cluster

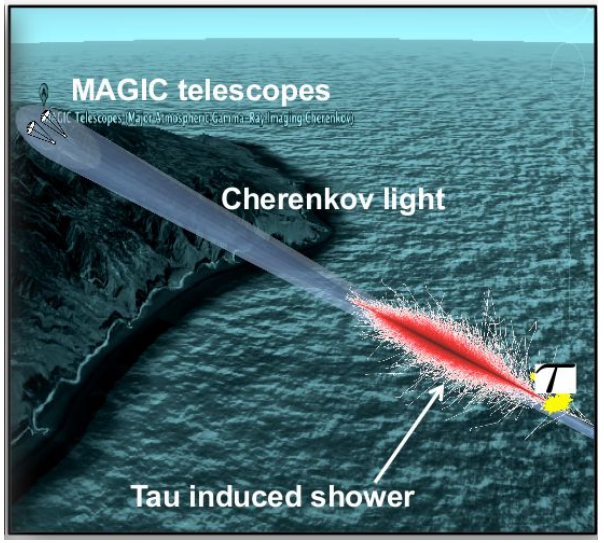
Perseus galaxy cluster was chosen to search for decay DM for its DM contents (80%) and distance (z=0.0183). After 270h hours (2009-2017) of good quality data, no evidence of DM day was found. However the results are 10 times better than last MAGIC results for both decaying channel and we go the best limits on decay lifetimes in tau-tau channel for DM masses above 2 TeV.



Q.Palacio et al., ICRC 2017

MAGIC as neutrino detector

MAGIC has started to be used as a neutrino detector to look for Earth skimming tau neutrinos. The observations point towards the sea and the Earth itself shields the CR background. For optimistic fluxes, ULs at the order of the ones of Auger could be set. In addition the observation time is very cheap since is the weather-independent. Article with the results from the first observations ongoing.



D.Gòra et al., EPS-HEP 2017

LIV: Methodology at MAGIC

Multiparametric Likelihood analysis

PDF of the event: makes use of all the available information about the event, the effect and the experiment.

$$\frac{dP}{dEdt} = \frac{\int_0^{\infty} \Gamma(E_s) C(E_s,t) G(E-E_s, \sigma_E(E_s)) F_s(t - D(E_s,\alpha,z))}{\int_{E_{min}}^{E_{max}} \int_{t_{min}}^{t_{max}} \int_0^{\infty} \Gamma(E_s) C(E_s,t) G(E-E_s, \sigma_E(E_s)) F_s(t - D(E_s,\alpha,z))}$$

Likelihood: makes use of all the available information about the event, the effect and the experiment.

$$L = \prod_1^{N_{events}} \frac{dP}{dE_i dt_i} \quad \Rightarrow \quad -2log(L) = (-2) \sum_1^{N_{events}} log \frac{dP}{dE_i dt_i}$$

LIV: Methodology at MAGIC

Multiparameter treatment

The PDF has the LIV parameters (estimator) and several nuisance parameter, that can be correlated with the estimator.

$$D(E_s, M_{QGn}, z) = \frac{E_s^n - E_{s,0}^n}{M_{QGn}^n} \frac{z}{H_0}$$

$$\alpha = \frac{M_P}{M_{QG}}$$

$$D(E_S, \alpha, z) = \frac{(E_S^n - E_{S,0}^n)\alpha}{M_P} \frac{z}{H_0}$$

Advantages

- Systematics are including in the fit.
- Correlation between parameters is directly taken into account (also in Simulation).
- Use of the complete data sample.

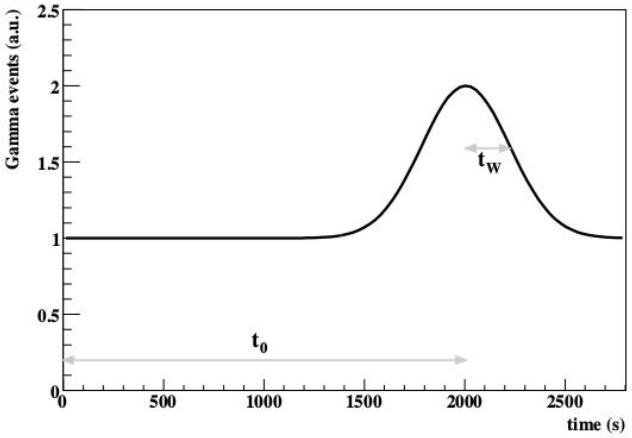
Disadvantages

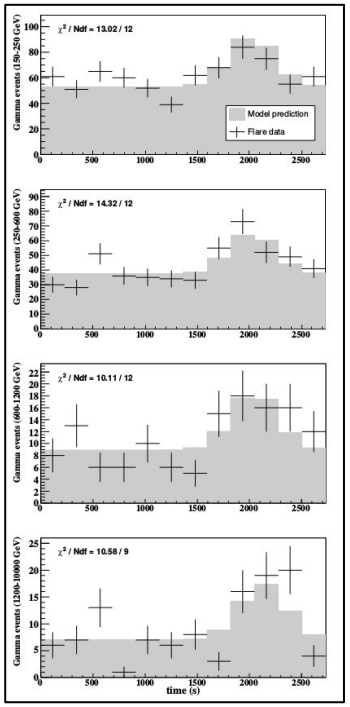
- PDF function is more complex.
- More computing time.
- More things to take into account for the fit.

LIV: Results with AGN

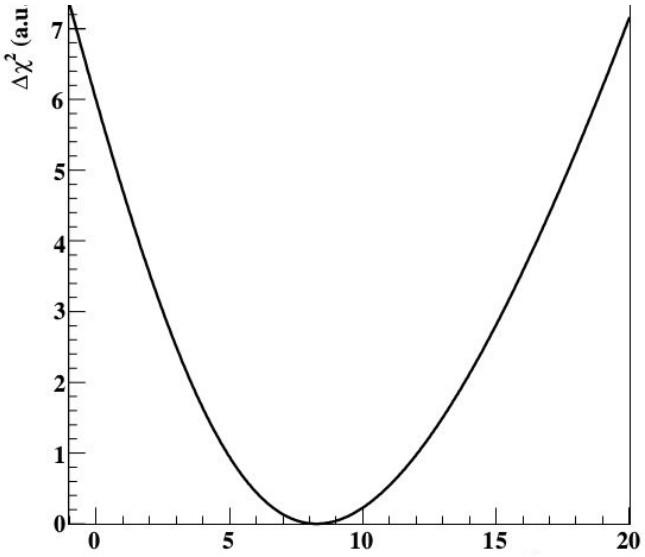
Mrk501 2005 flare by Manel Martinez and Manel Errando (LIV with Mrk510 paper)

- Time distribution
  - Gaussian flare
  - Gamma and hadron baseline.
- Energy distribution
  - PL of index 2.4 for flare.
  - PL of index 2.7 for baseline.
- Instrument response function
  - Constant acceptance
  - 22% energy resolution.
- Parameters.
  - QG parameter (α)
  - Gaus maximum (t_0)
  - Gaus width (t_w)
  - Baseline/Flare ratio (x_B)



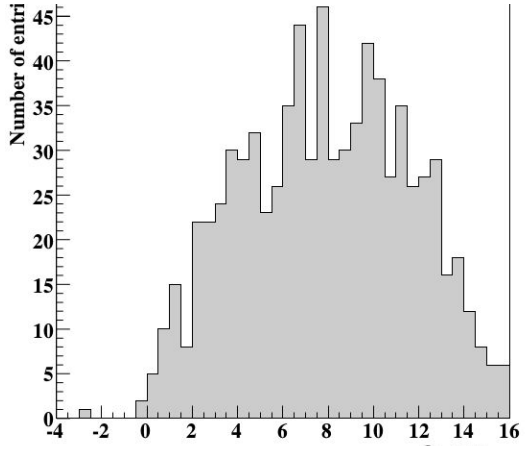


LIV: Results with AGN



Mrk501 2005 flare Results

	$n=1$	$n=2$
$\hat{M}_P/M_{QGn}$	$8.9^{+5.8}_{-4.5}$	$4.3^{+2.7}_{-1.7} \times 10^7$
t_W	219^{+28}_{-29} s	(228 ± 27) s
t_0	(2005 ± 42) s	(2041 ± 36) s
x_B	0.38 ± 0.04	0.38 ± 0.04

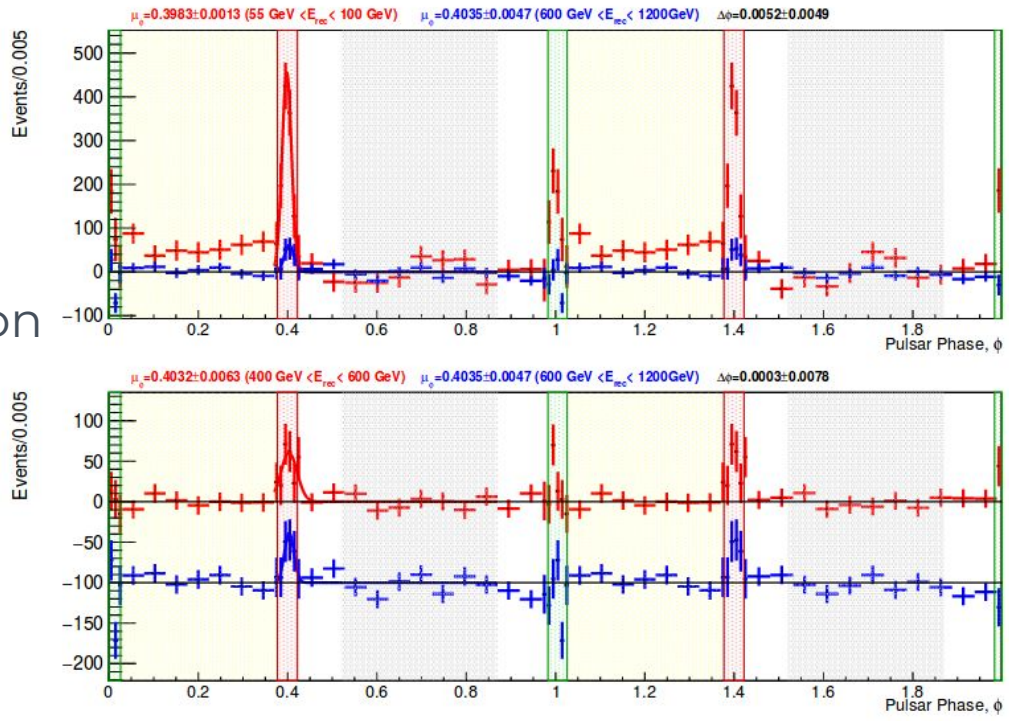


	n=1	n=2
α’	$8.9_{-4.3}^{+5.8}$	$4.3_{-1.7}^{+2.7}$
M_{QG} (GeV)	$(0.3^{+0.24}_{-0.1}) \cdot 10^{18}$	$(0.57^{+0.75}_{-0.19}) \cdot 10^{11}$
M_{QG} (Ellis)	$0.21 \cdot 10^{18}$	$0.26 \cdot 10^{11}$

LIV: Results with Pulsar

Crab Pulsar data by Daniel Garrido and Markus Gaug
(LIV with Pulsar paper)

- Time distribution
  - Gaussian peaks
- Energy distribution
  - PL for signal.
  - Data histogram for bkg.
- Instrument response function
  - 19 telescopes periods.
  - 19 different IRFs.
- Parameters.
  - QG parameter(α)
  - Gaus maximum(ϕ)
  - Gaus width(σ)
  - Flux normalization(f)

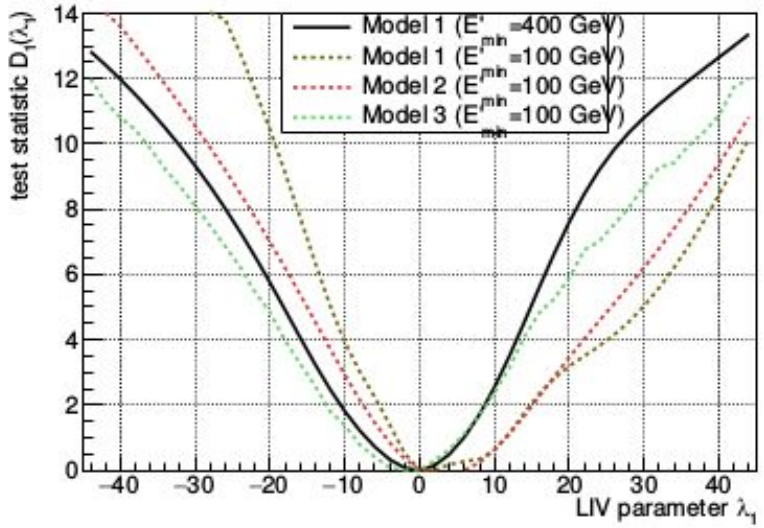


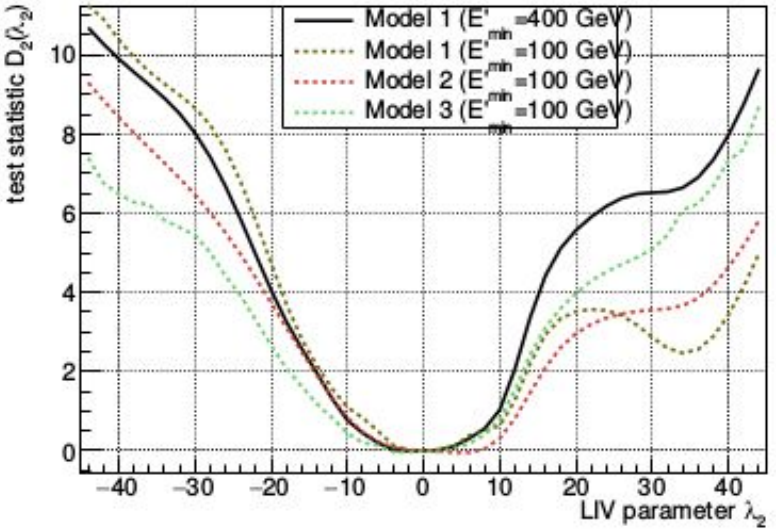
LIV: Results with Pulsar

PDF formula and results

$$\mathcal{P}_k(E_i', \phi_i' | \lambda_n; \boldsymbol{\nu}) = \frac{b_k/\tau \cdot h_k(E_i') \;+\; g_k(\lambda_n; \boldsymbol{\nu}) \cdot S_k(E_i', \phi_i' | \lambda_n; \boldsymbol{\nu})}{g_k(\lambda_n; \boldsymbol{\nu}) \;+\; b_k/\tau}$$

nuisance parameter	result ($E'_{min} = 400$ GeV)	result ($E'_{min} = 100$ GeV)
model 1		
$\widehat{f}$ ($\cdot 10^{-10}$ TeV^{-1} cm^{-2} s^{-1})	6.3 ± 0.7	6.2 ± 0.6
$\widehat{\alpha}$	2.81 ± 0.07	2.95 ± 0.07
$\widehat{\phi}_{P2}$	0.403 ± 0.003	0.401 ± 0.001
$\widehat{\sigma}_{P2}$	0.015 ± 0.003	0.011 ± 0.002



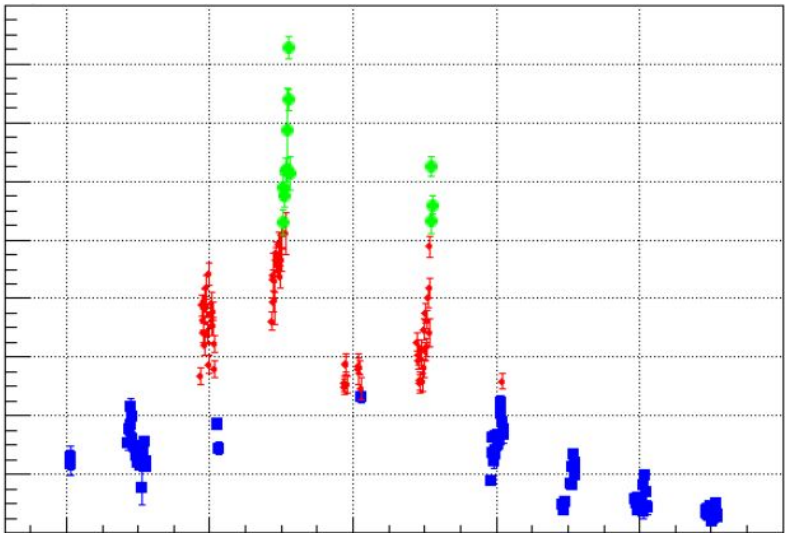


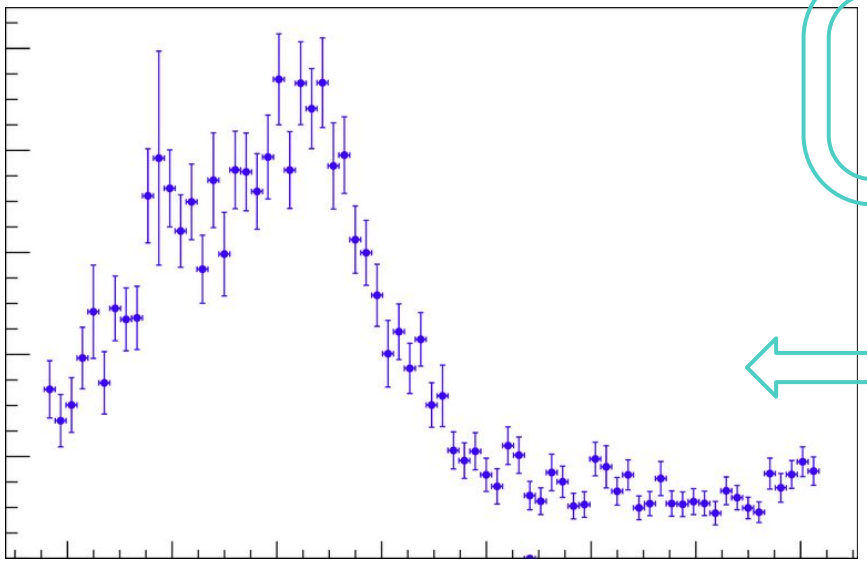
Detailed information in tomorrow's talk

LIV: Current analysis

Mrk421 2013-2014 flares by Leyre Nogués

- AGN located at z = 0.031.
- Emits energies until tens of TeV.
- Big variability.
- High flux.
- Several flares. (Combination?)





Flares currently under study

- **2013** flare
  - Biggest detected flux.
  - Many nights.
- **2014** flare
  - Big variability.
  - Lots of statistics

Towards LIV Collaboration

- MAGIC can offer offer two types of sources for the combination.
- Experience with Likelihood analysis, the only method for combination.
- The combination brings many advantages.
  - More statistics.
  - Better understanding of LIV and source effects..
  - LIV redshift study.

Summary and prospects

In MAGIC

- MAGIC is not young but it is still very active.
- A lot of topics and new projects appearing within time.
- LIV one of the active topics.
- Working on new LIV candidates.
- Using the old ones for combination.

In LIV Collaboration

- MAGIC, with H.E.S.S. and VERITAS are now collaborating for LIV studies.
- First preliminary results look promising.
- Improving the methodology.
- Next steps: dealing with real data.

Thank you!

Any questions?