Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
UNIVERSITÀ DI TORINO

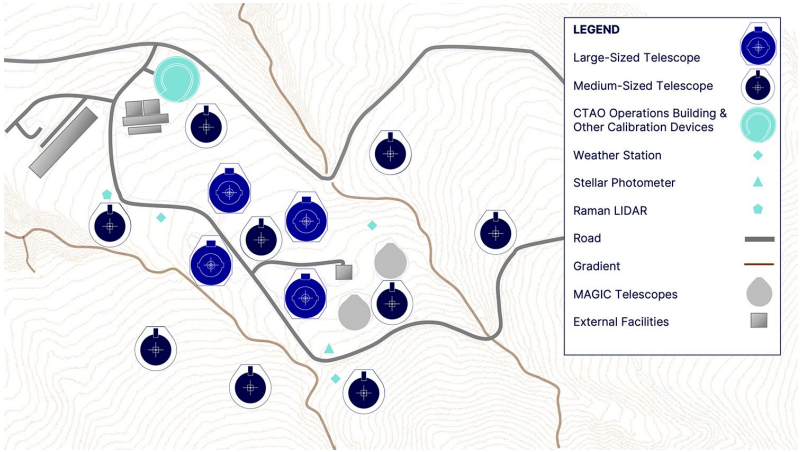
Analysis of joint MAGIC+LST-1 observations

Elisa Visentin, Alessio Berti, Raniere de Menezes, Jordi Delgado, Federico Di Pierro, Adithiya Dinesh, Samanta Morales, Julian Sitarek, Joanna Ślot, Yusuke Suda, Carlo F. Vigorito, Georgios Voutsinas
for the MAGIC and LST/CTAO Collaborations

INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI TORINO
MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes
CTAO LST COLLABORATION

Instruments

- La Palma (Canary Islands), 2200 m a.s.l.
- MAGIC telescopes + LST-1 (first Large-Sized Telescope of the Cherenkov Telescope Array Observatory)



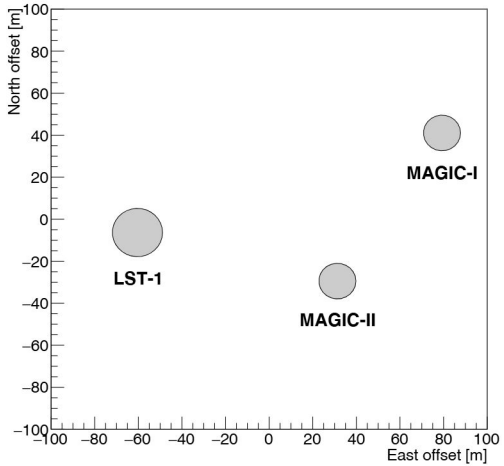
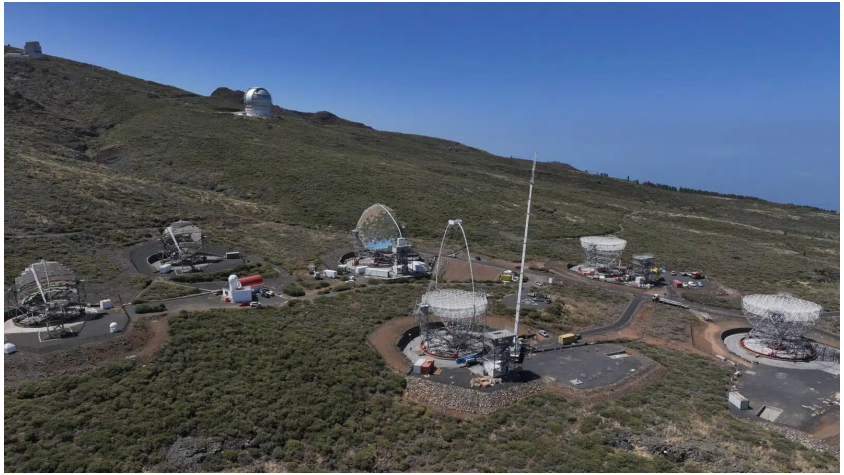


Figure from [1]



Instruments

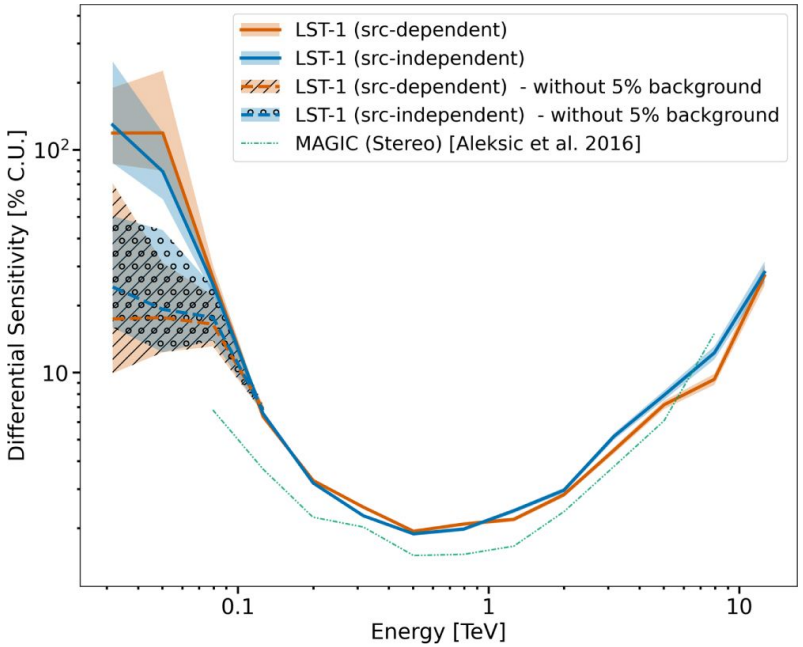


Figure from [2]

MAGIC

- 17 m diameter
- 3.5° fov
- 1039 PMTs (0.1°)
- 70 tons
- 85 m separation
- MAGIC-1 in 2004, stereo since 2009
- Energy threshold ~ 50 GeV
- repointing: 25 s

LST-1

- 23 m diameter
- 4.3° fov
- 1855 PMTs (0.1°)
- 100 tons
- data taking since 2019
- Energy threshold ~ 20 GeV
- repointing: 20 s

TRANSIENT PHENOMENA

Introduction: why joint analysis

- LST-1: stand-alone trigger
- MAGIC: stereo trigger
- Joint analysis: improved performance (sensitivity, background rejection)
- Joint analysis: if one of the MAGIC images cannot survive cleaning, we can **recover the stereoscopic event through LST-1**

JOINT ANALYSIS

- the events of the two independent systems are matched using their timestamps
- after image reconstruction, all events with ≥ 2 images are analyzed.

Table from [1]

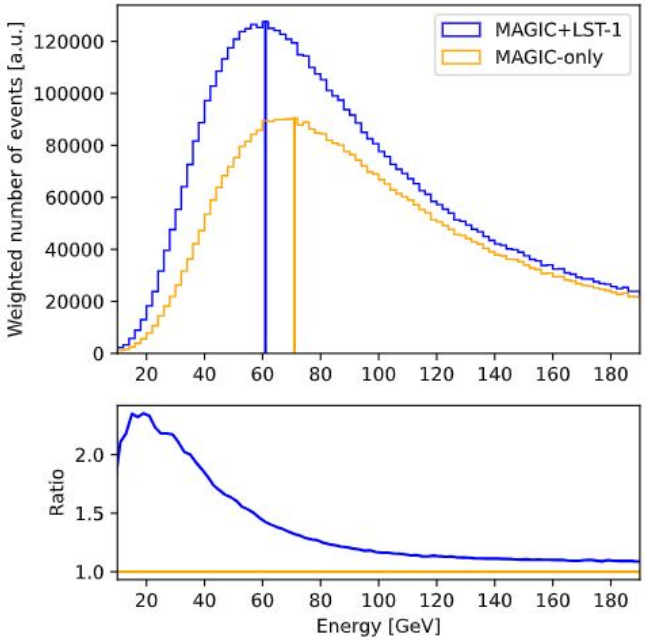
Type	MC γ (0.4°)	MC γ (0 – 2.5°)	MC p	Observations
M1+M2	6.2%	4.8%	20.4%	21.5%
LST-1+M1	7.1%	7.7%	6.2%	5.3%
LST-1+M2	12.5%	12.6%	11.9%	14.2%
LST-1+M1+M2	74.1%	74.8%	61.5%	59.0%

Table 2. Percentage of different event types in different types of MC simulations and in the observations.

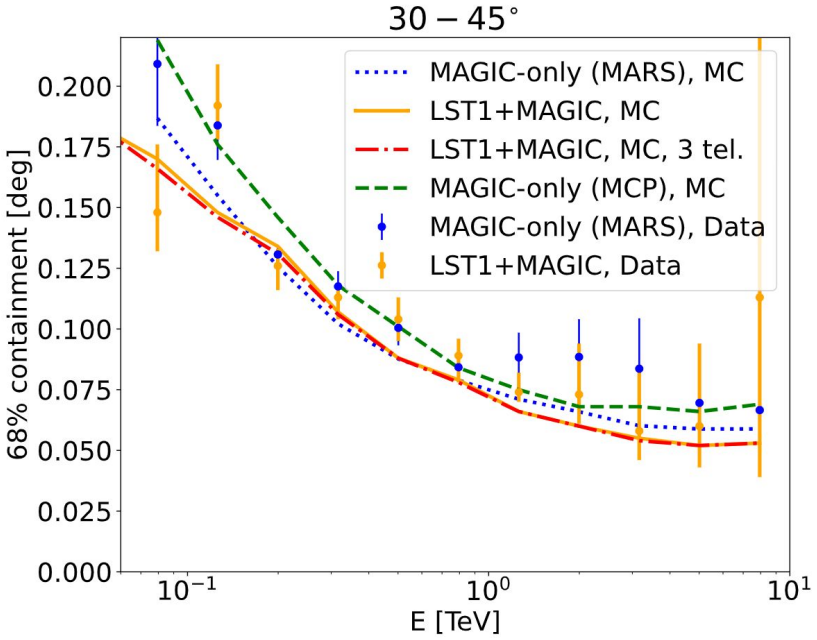
Performance of the MAGIC+LST-1 system

Energy threshold

Figures from [1]

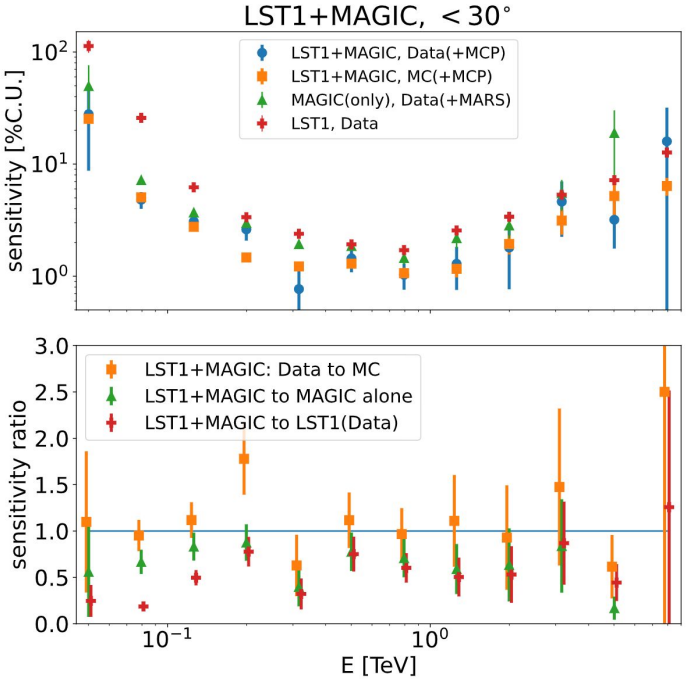


Angular resolution



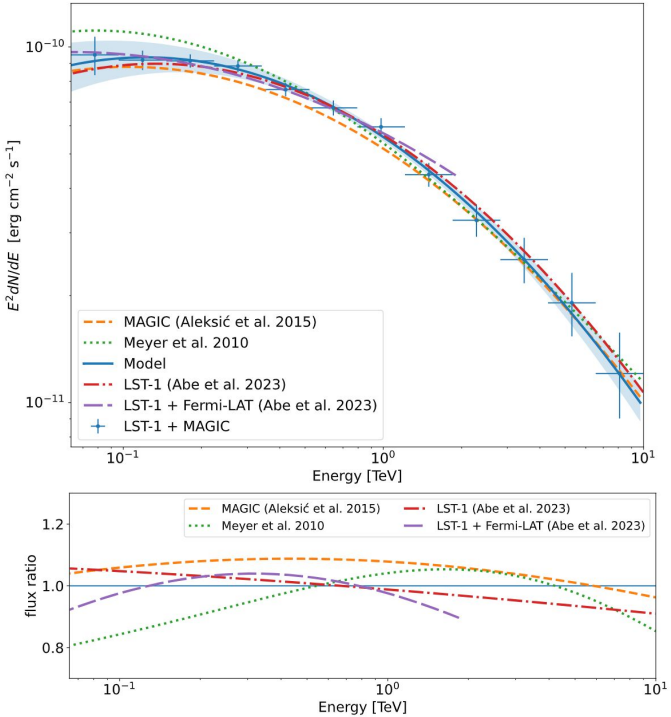
Performance of the MAGIC+LST-1 system

Sensitivity



Figures from [1]

Crab spectrum



Software

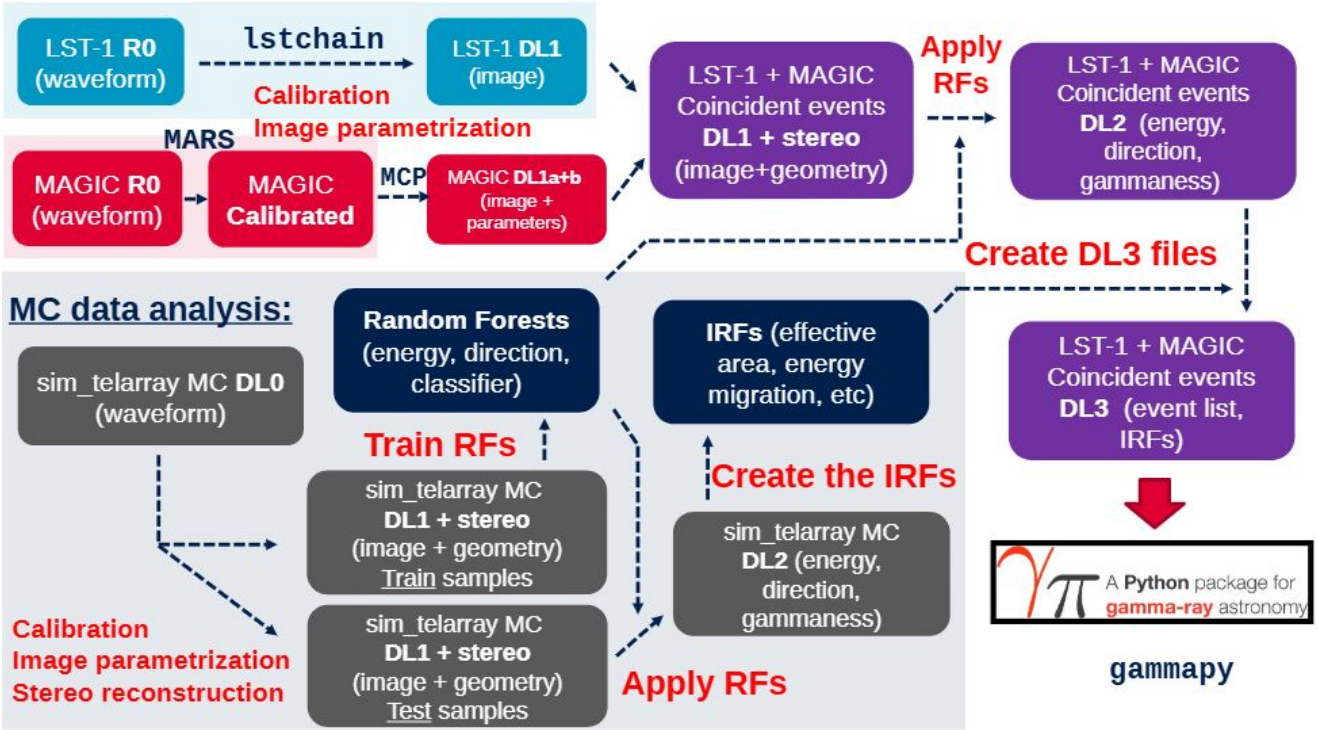


Figure from [1]

Semi-automatic data processing

- New scripts and databases to allow for a **massive semi-automatic processing** of (all) the standard past and future joint observations
    - Users won't have to **know how to** produce them by themselves
    - Data processing is **computationally intensive and requires a lot of storage space**
    - More LST-1+MAGIC **science results**
    - **QUICKER and SIMPLER data analysis: ideal for 'urgent' analyses (e.g., AGN flares)**

What we need for this semi-automatic data processing

- MAGIC input data, to be produced and copied in between computing centers
- LST-1 input data
- database of joint observations
- MCs (generated and processed)
- released version(s) of the pipeline
- data processing (launching semi-automatic scripts and checking jobs' status)

Many people involved in this huge collective effort to provide processed data as soon as possible (in particular for 'hot' sources, ToOs…)

MC productions

Libraries for MCs have been produced and processed:

- different declination lines (RF training)
  - **["22.76", "34.76", "48.22", "61.66", "66.76", "9.31", "-18.02", "-29.24", "-4.13"]**
- different (6) levels of night sky background
- different (6) MAGIC observation periods (based on changes in the hardware, new simulations are needed and a new period starts)
- different versions of the software

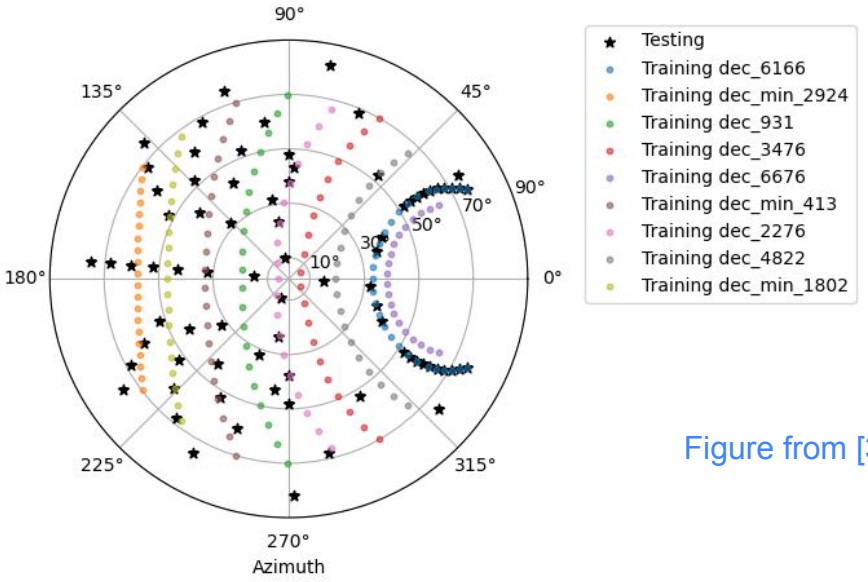


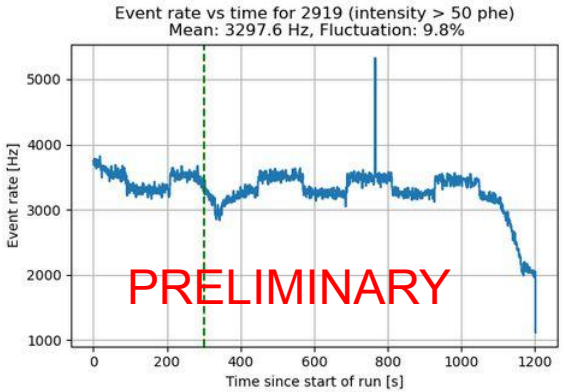
Figure from [3]

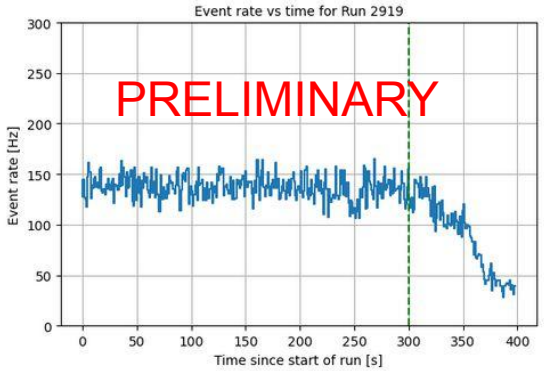
Data processing

- Which data we process:
  - Standard MAGIC trigger and high voltage settings
  - Stereo or mono MAGIC (+ LST-1) data
  - Actually joint data (matching of MAGIC and LST-1 pointing directions)
  - Dark/low moon data (standard cleaning cuts)
  - For high level (DL3) data: availability of IRFs (target offset with respect to pointing direction)
- What we processed up to now:
  - all joint data from October 2020 (start of joint observations) until March 2025
  - ~ 1.7 TB of produced data (sum over all the outputs for all the steps of the pipeline); ~ 500 MB high level (DL3) data

Data quality

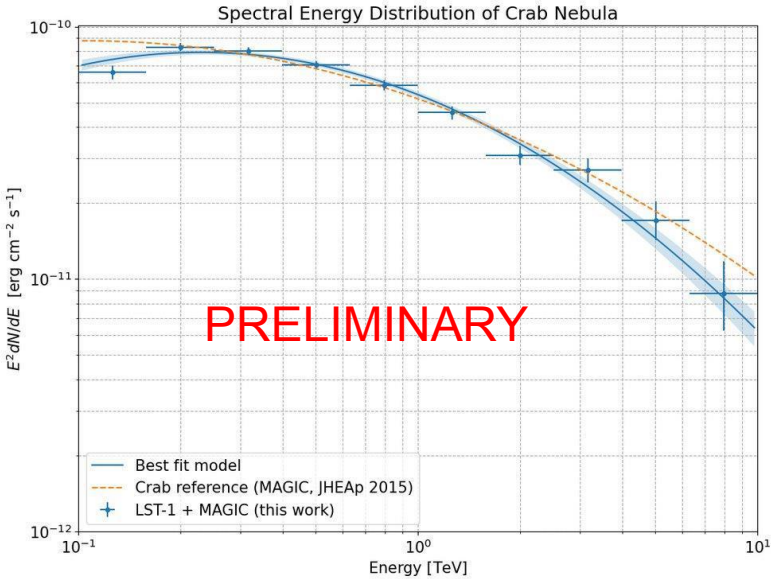
- LST-mono:
  - features:
    - low energy threshold (~20–30 GeV in optimal conditions)
  - data quality selection:
    - Zenith angle
    - Night Sky Background
    - event rates
    - pointing stability
    - MAGIC lidar events
- MAGIC+LST-1
  - features:
    - higher energy threshold (~60–70 GeV)
    - lower probability of LIDAR events
    - pointing stability: still important, but less critical than in mono
    - background much reduced
  - data quality selection:
    - Zenith angle
    - Night Sky Background
    - Event rates





Crab validation for data quality

After selection: ~4.5 h

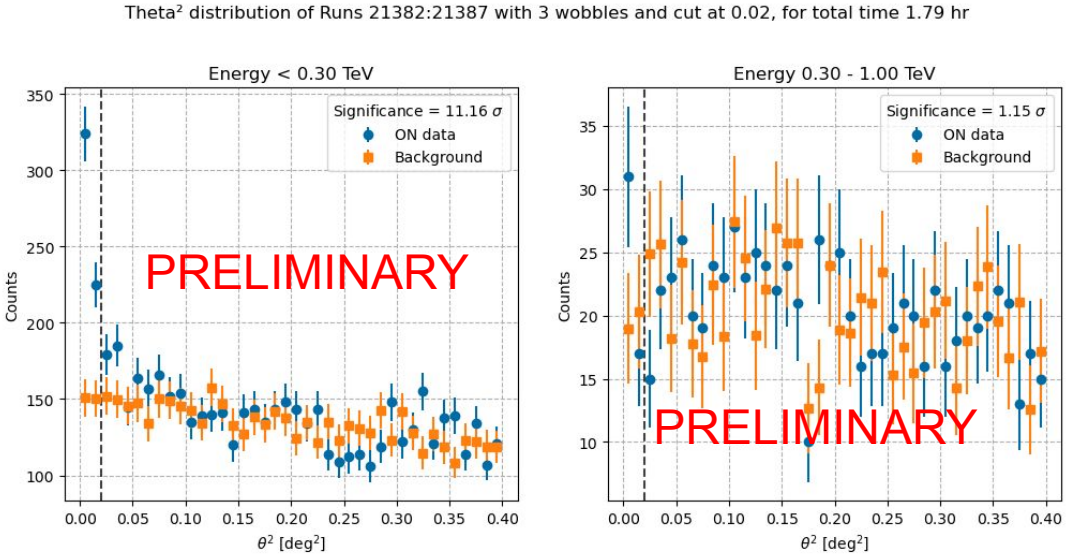


Whole high-level (DL3) dataset in between 2020/10/24 and 2021/09/29, from semi-automatic data processing, after applying data selection:

- Zenith < 60 deg
- Event rate patterns
- Mean event rate vs Zenith

Science applications: PKS 1725+123, first night

ATel 17344 https://www.astronomerstelegram.org/?read=17344



significance/sqrt(obs. time)

LST-1: ~ 3.05 σ
MAGIC: ~ 4.56 σ
joint: ~ 8.34 σ

PRELIMINARY

Conclusions

- Joint analysis allows for improved performance with respect to MAGIC and LST-1 analyses
- Data volume for joint observations is large and information from both MAGIC and LST-1 must be used, resulting in a computationally intensive data processing, so we are aiming to provide high level data (ready to produce spectra and light curves) to users
    - MC sets are produced every time we have a change in MAGIC observation period or a major change in software
    - new data are regularly processed, to allow both monitoring of known sources and study of transients/ToOs
    - data quality algorithm has been implemented so that the users can select their dataset in between all the processed data for a given source
- Joint analysis is used in many projects, belonging to different fields of Astrophysics
    - Most of them are using the high level data produced thanks to the automatization of the software

References

[1] Performance of the joint LST-1 and MAGIC observations evaluated with Crab Nebula data

MAGIC and LST Collaborations

A&A, 680 (2023) A66

DOI: https://doi.org/10.1051/0004-6361/202346927

[2] Observations of the Crab Nebula and Pulsar with the Large-sized Telescope Prototype of the Cherenkov Telescope Array

LST Collaboration

ApJ, 956 (2023) 80

DOI: https://doi.org/10.3847/1538-4357/ace89d

[3] https://cta-observatory.github.io/lstmcpipe/examples/configs_pointings.html