General introduction to LST analysis and Performance

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University of Rijeka, 17/02/21

Funded by H2020 Marie Sklodowska Curie FELLINI - Grant 754496

General

- LST Date are proprietary to the LST sub-consortium
  - You need an LDAP-approved account to access the data
- Small datasets have been released for software testing
- A dataset is expected to be released for the ASWG group of CTA for software validation.

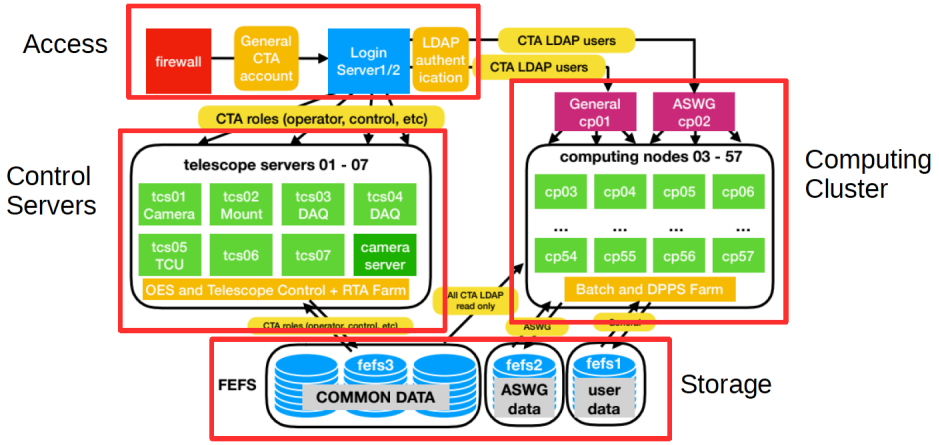
LST Data analysis, latest news

- For a description of the LST-1 pipeline, see at the previous CM: https://indico.cta-observatory.org/event/2765/contributions/23955/attachments/17447/23205/LST_real_data_analysis.pdf and https://indico.cta-observatory.org/event/2765/contributions/23952/attachments/17457/23188/2020_05_13_lstchain.pdf
- LST-1 taking data in wobble mode since Summer
- New season of joint observations of Crab with MAGIC ongoing
  - coordinated wobble pointings between the two instruments
- Just finished re-processing @La Palma IT cluster all the available sky data using LSTOSA (on-site analysis) with new version of lstchain, v0.6.1 (and ctapipe 0.8.0)
  - 305 runs on 56 nights between 2019/11/23 and 2020/10/08
  - processed up to DL1 level
  - No higher-level results (DL2+) available yet with this newest production (Prod-5 dedicated LST MC on the way); results on next two slides are from lstchain 0.5.2 and Prod-3 MC

Computing facilities

- NFS Disk: 3.4 PB
- 2000 CPU cores
- Slurm Batch system

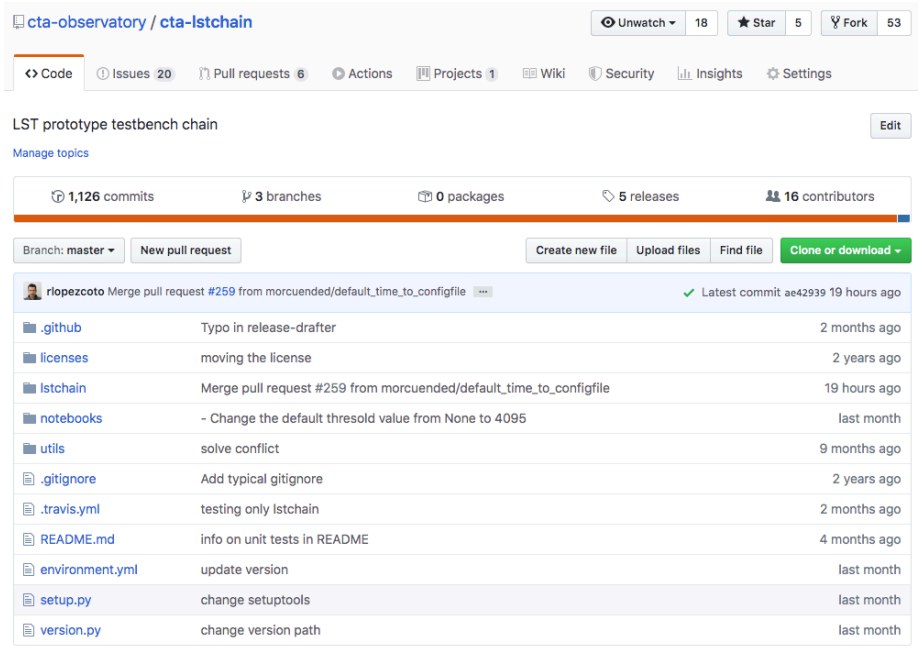
IT cluster in la Palma



LST analysis software:
What is cta-lstchain?

- Python-based analysis framework: cta-lstchain, heavily dependent on ctapipe:
  - https://github.com/cta-observatory/cta-lstchain

- More in the lstchain dedicated presentation



LST Data access in a nutshell

- Mail from D. Hadasch (29/01/2019):

Obtain an LDAP account
Please send a request to me (hadasch@icrr.u-tokyo.ac.jp) to be included in the "ctan-onsite-it" group.
Afterwards you will receive an e-mail from Microsoft Online Services Team.
Please follow the instructions in the e-mail. Once you logged in with the temporary password, you have to set your own password.
Then your LDAP account looks like this:
user name: firstname.lastname
password: <the password you just set>
with an associated e-mail address firstname.lastname@cta-observatory.org. E-mails to this new e-mail address are automatically forwarded to your currently registered e-mail in CTA.

Login to the IT center
Please follow the 2-step authentication system:

0.) You need to have a registered secure IP in your institute. Some of you already registered (MPI, Tokyo, CIEMAT, LAPP etc).
In case of doubts, please contact me.

1.)
You login with the general user CtAlAPaLmA to a general login server. The system automatically redirects you to server login01 or login02:

$ ssh -l CtAlAPaLmA 161.72.87.1

The password for this account can be found here:
https://ctaoobservatory.sharepoint.com/sites/ctan-onsite-it/Shared%20Documents/Forms/AllItems.aspx?id=%2Fsites%2Fctan%2Donsite%2Dit%2FShared%20Documents%2FGeneral%2Finformation%2Ejpg&parent=%2Fsites%2Fctan%2Donsite%2Dit%2FShared%20Documents%2FGeneral

2.)
From one of the login servers you can now login with your LDAP account either to cp01 or cp02. Special telescope accounts can login to the telescope servers tcs01-07.

$ ssh -l firstname.lastname cp01/cp02

After you have logged in for the first time your home directory with a quota of 10GB will be automatically created:
/fefs/home/firstname.lastname
From one of the two machines (cp01/02) you are allowed to submit jobs within the job managing system SLURM. There are 55 servers (cp03-cp57) with 32 cores each available.
Please find the details of the computing system and a manual for SLURM under this link:
https://portal.cta-observatory.org/WG/lst/Engineering%20Documents/TD%20-%20Technical%20Documents/TD.INFRA%20-%20Infrastructure/TD.INFRA.04%20-%20IT%20Container/CTA-N%20IT%20Center%20Fujitsu%20Schneider/Training%20Slides%20and%20Videos/CTA_End_User_Training_V2.pptx

Working directories
You can write the output of your jobs in a directory you can create yourself here:
/fefs/aswg/workspace

LST Data analysis in the IT Cluster

- anaconda and cta-lstchain v0.6.3* in the IT cluster under:
  - /fefs/aswg/software/virtual_env/anaconda3
  - /fefs/aswg/software/virtual_env/ctasoft/cta-lstchain

- To use it, you just need to add to your path:
  - export PATH="$PATH:/fefs/aswg/software/virtual_env/anaconda3/bin/"

- then type
  - conda init
- and the configuration should be added to your bashrc. The conda environment is called “cta”, therefore to activate it, every time you should type:
  - conda activate cta

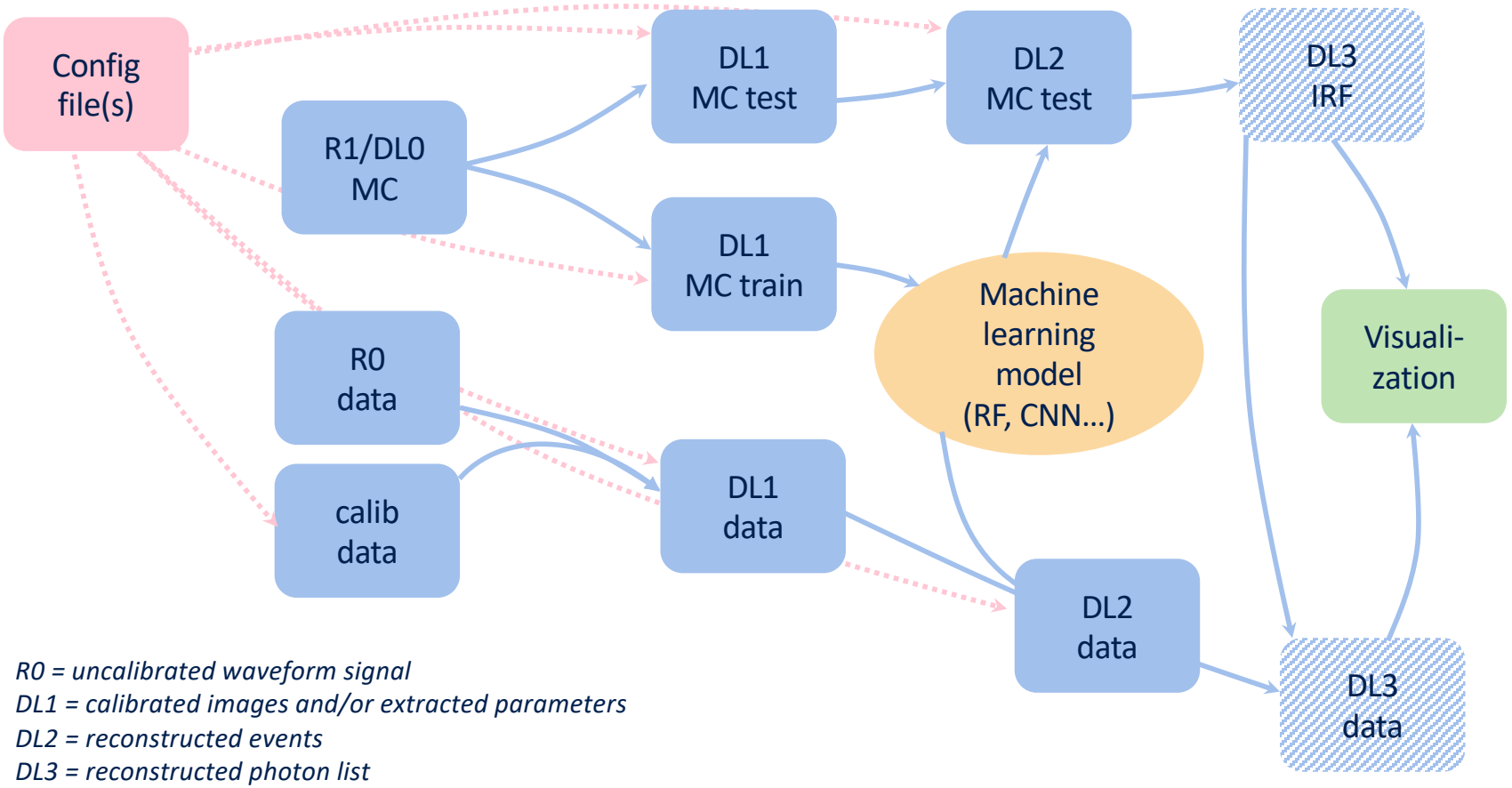
*For this workshop you need the development version of lstchain

General Data paths

- Summary
  - https://indico.cta-observatory.org/event/2538/contributions/22483/attachments/16741/21943/LST_ASWG_20191218.pdf

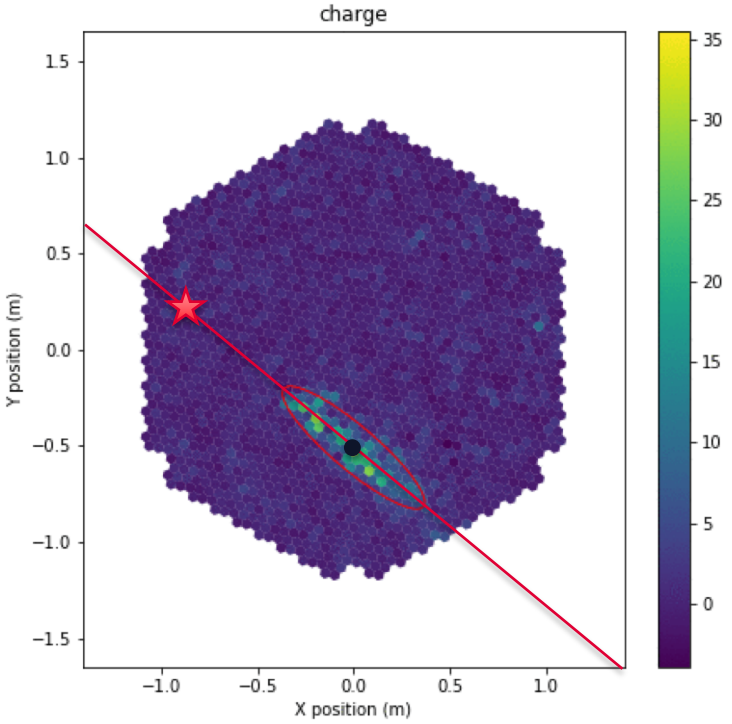
- More details
  - Calibration files:
    - /fefs/aswg/data/real/calibration/
  - DL1 files
    - /fefs/aswg/data/real/DL1/
  - DL2 files:
    - /fefs/aswg/data/real/DL2/

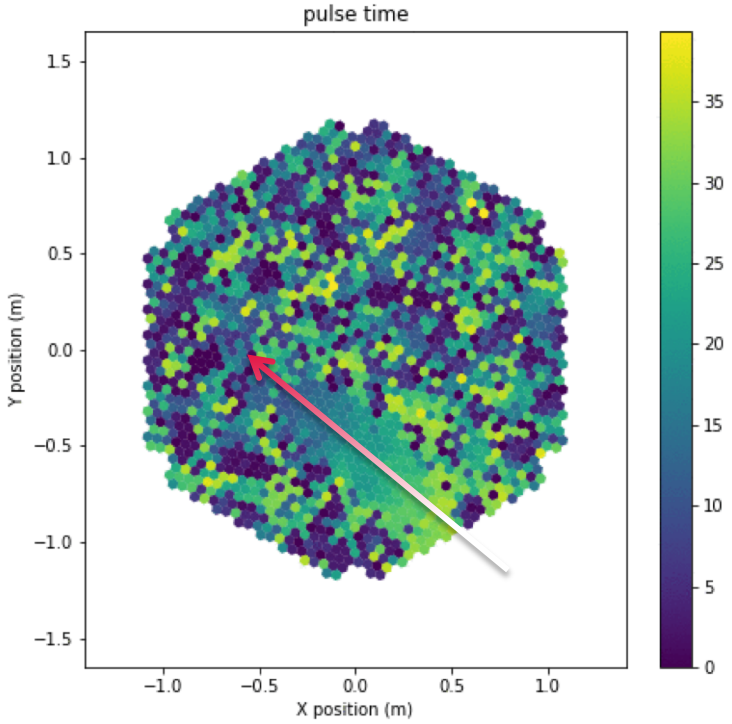
Single-telescope pipeline overview



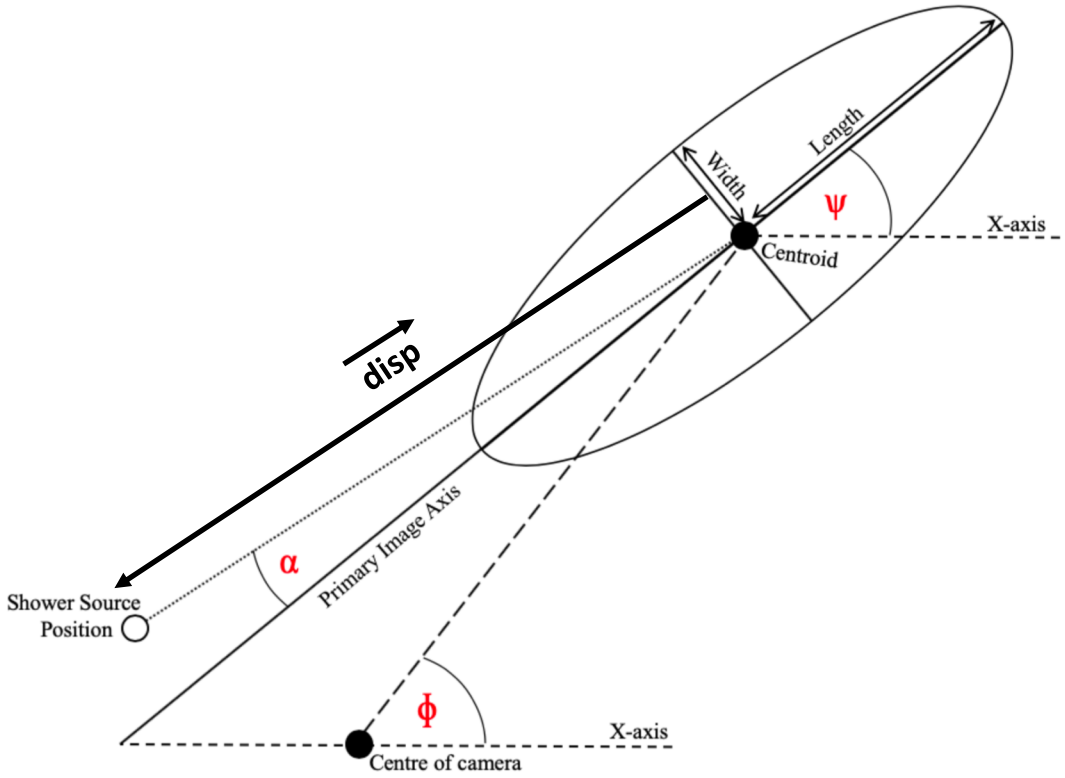
R0 = uncalibrated waveform signal
DL1 = calibrated images and/or extracted parameters
DL2 = reconstructed events
DL3 = reconstructed photon list

Feature extraction





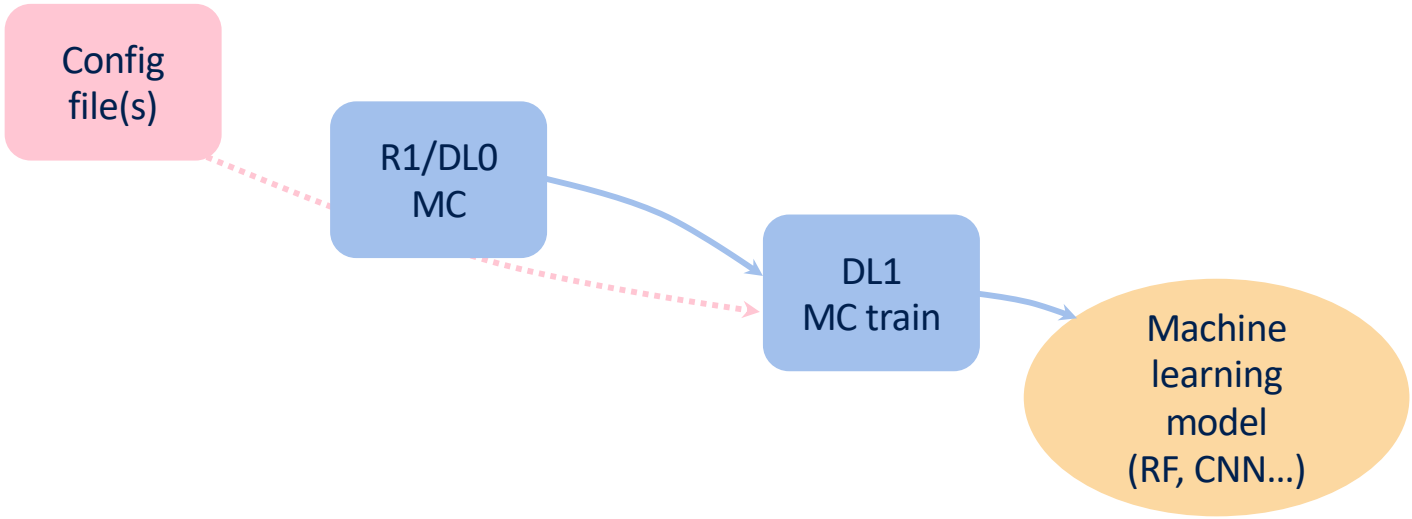
Feature extraction



List of features:

"log_intensity",
"width",
"length",
"x",
"y",
"psi",
"phi",
"wl",
"skewness",
"kurtosis",
"r=|x^2+y^2|",
"time_gradient",
"intercept",
"leakage",
"n_islands"

Random forest training



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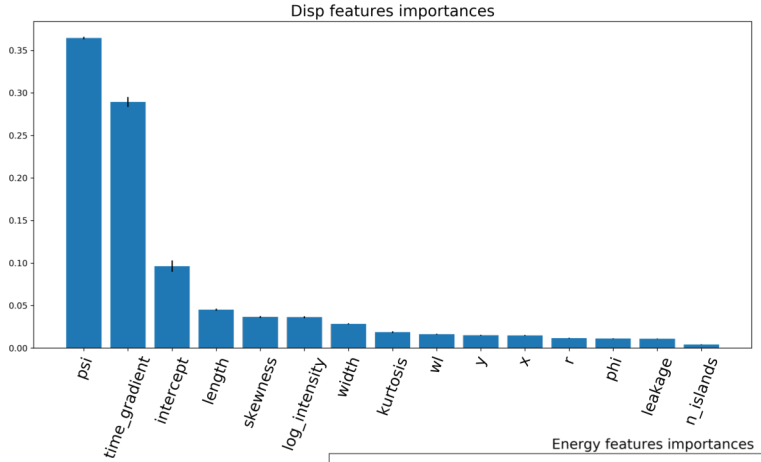
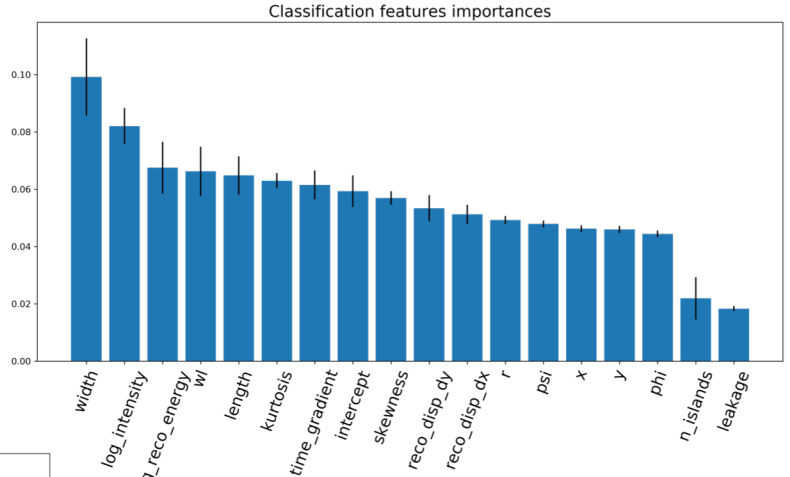
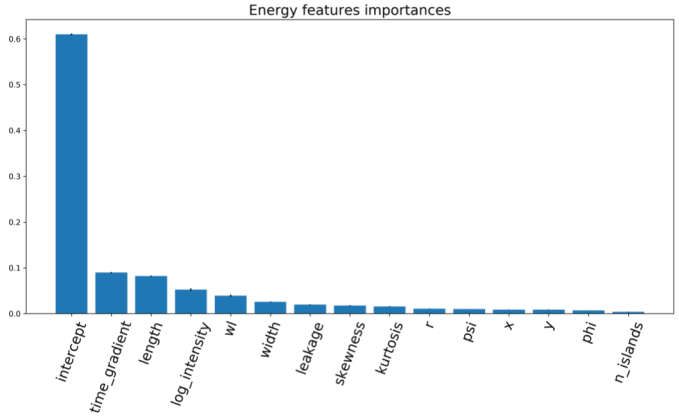
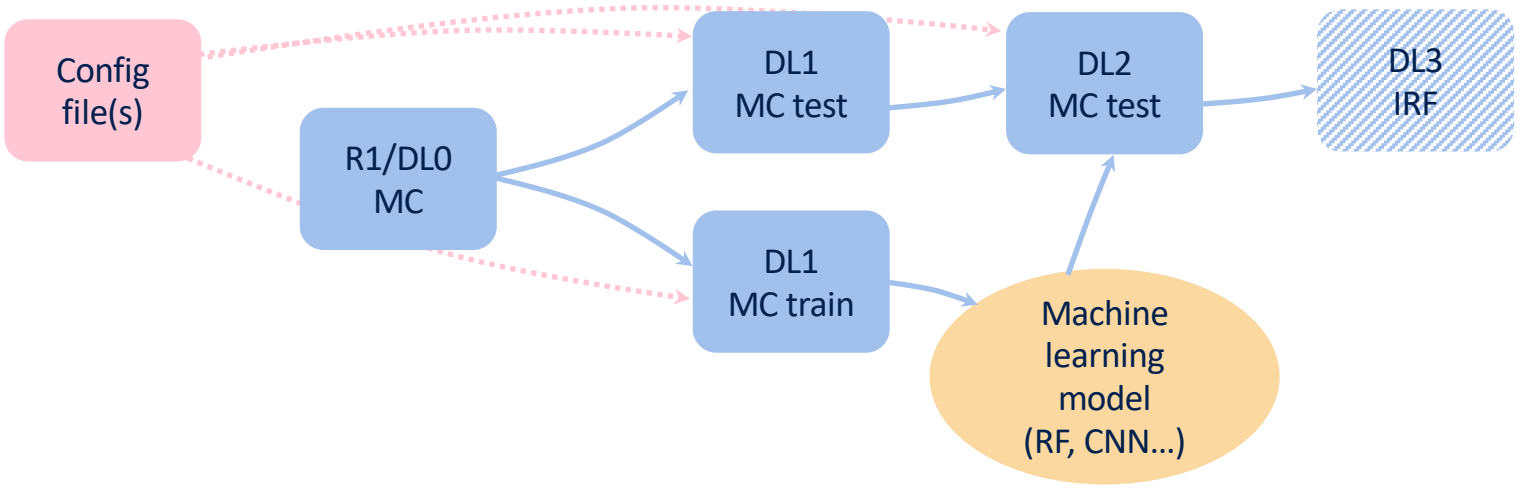
Importance features







IRF Production



- At the moment we are still working on high level analysis and only some tools are available. Explanation will come later

R0 = uncalibrated waveform signal
DL1 = calibrated images and/or extracted parameters
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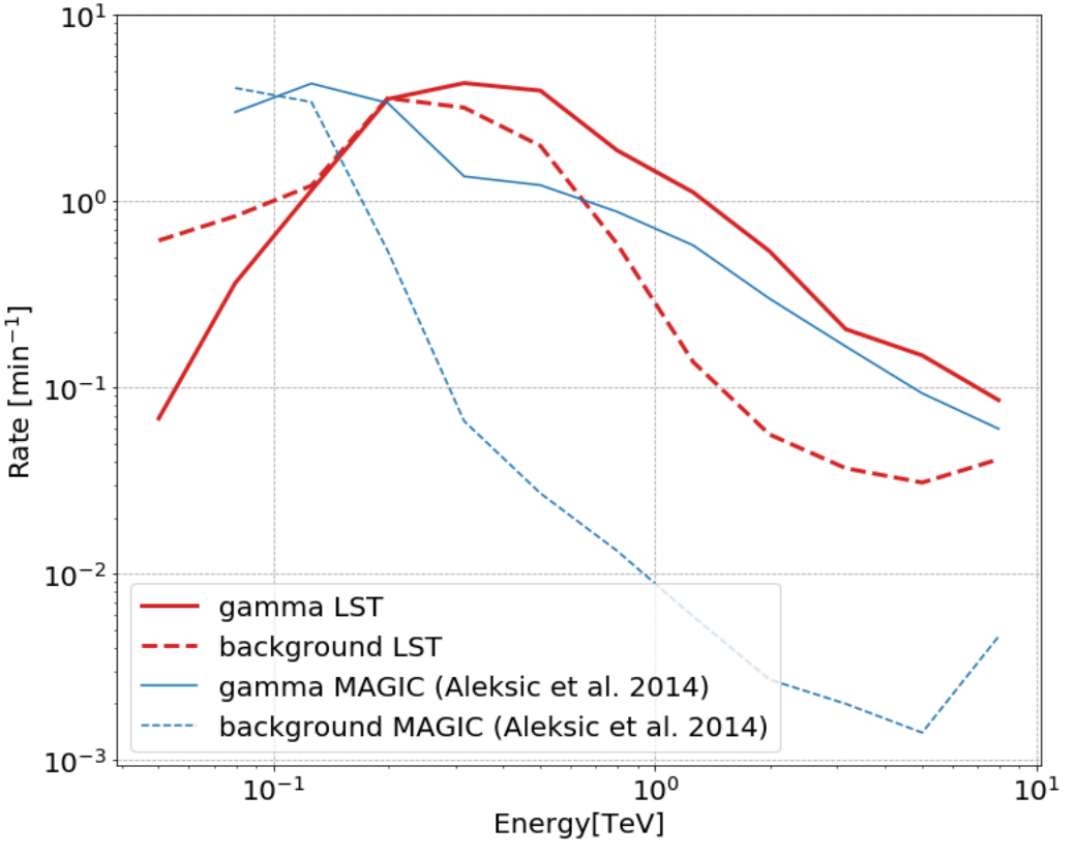
DL3 = reconstructed photon list

cherenkov telescope array

LST overall performance

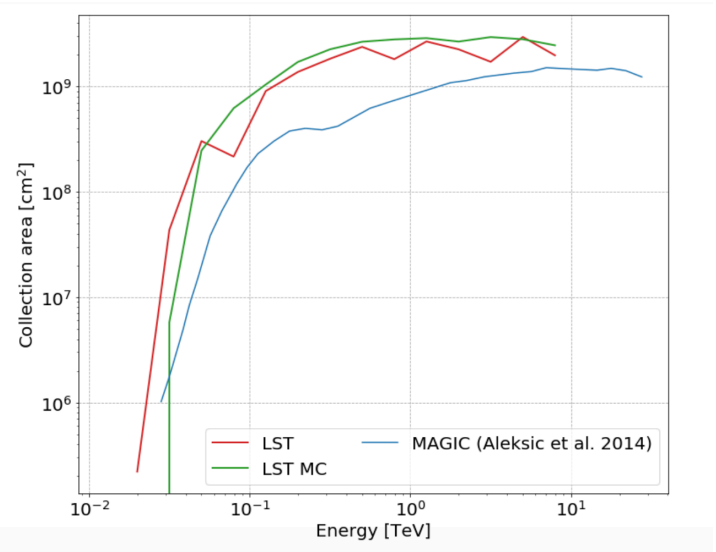
Rates

- Analysis performed using real data
  - Gamma rate corresponds to Crab excess.
- Rates at expected ballpark
  - The rates shown in the figure have been calculated using cuts to assure MC and Data matching.
  - Fixed cut in intensity > 200 phe due to MC/Data mismatches on trigger, image cleaning...

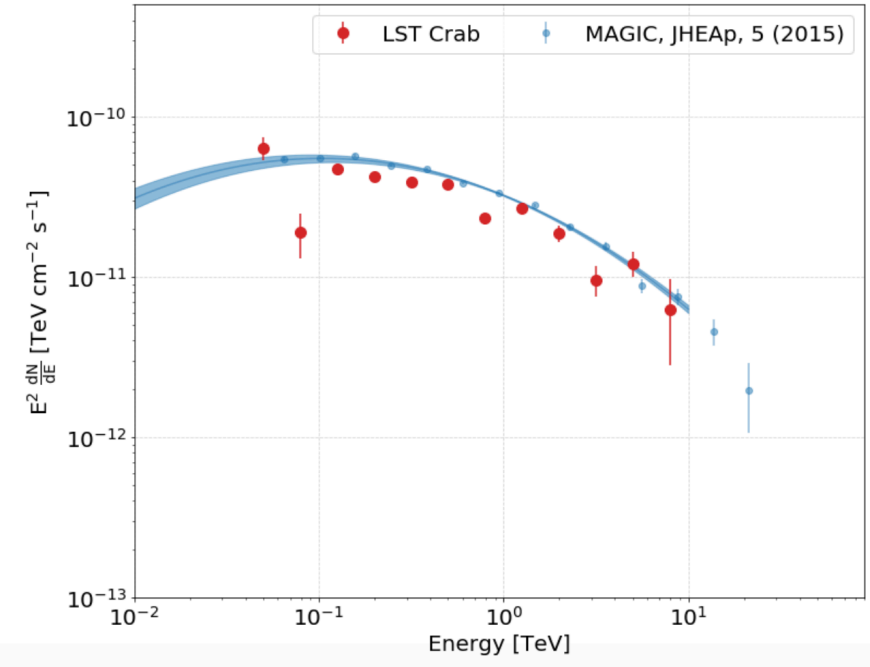


Spectrum

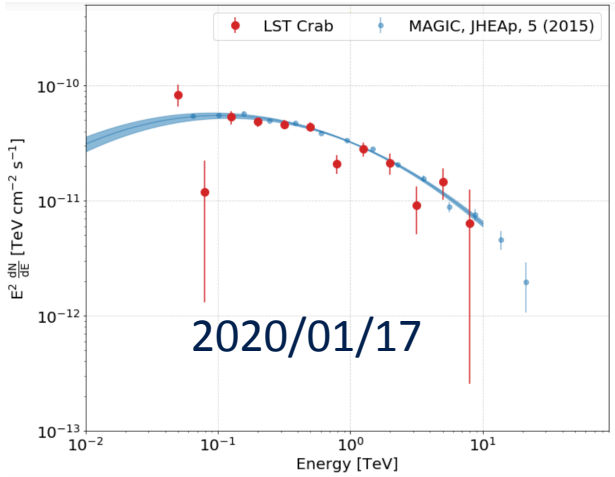
- **Very loose cuts** also applied to the collection area calculation to assure MC and Data matching.
- Collection area from MC and that derived from Crab Nebula observations.

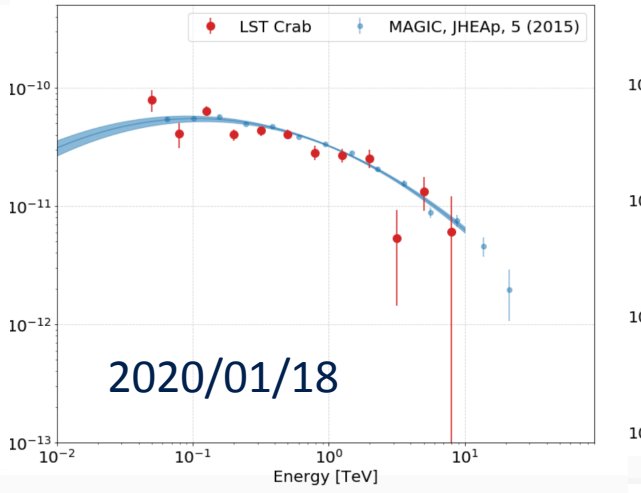


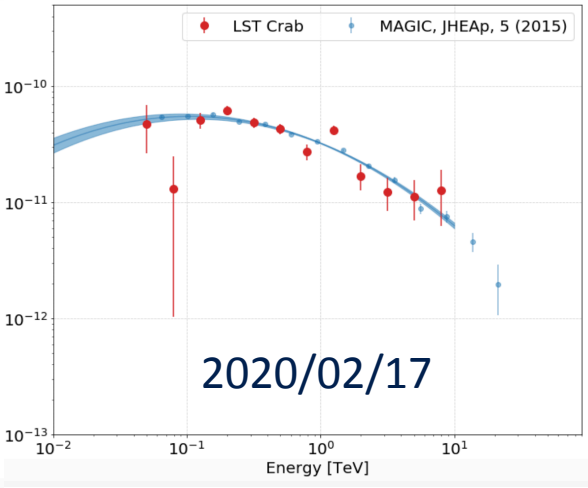
Coll. Area using very loose cuts to assure MC/Data matching

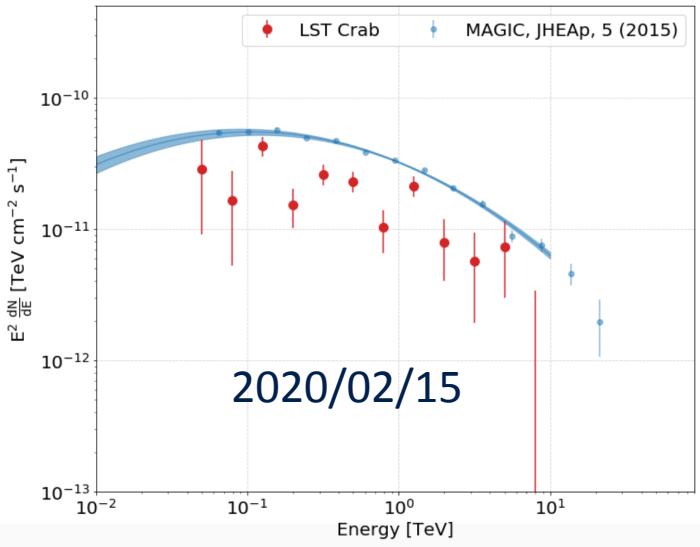


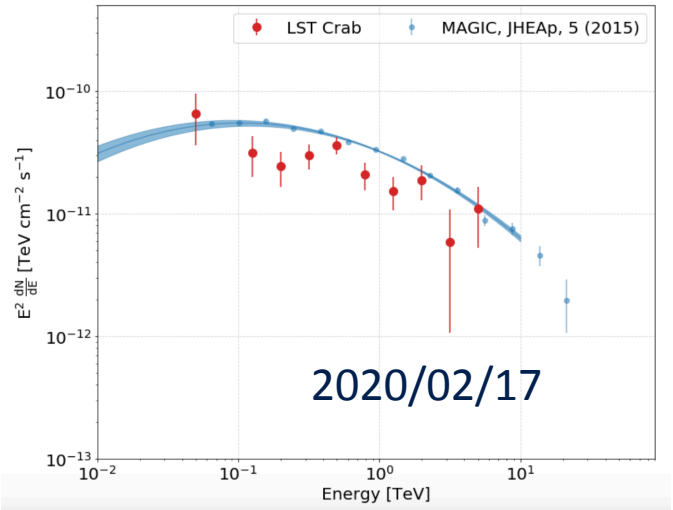
Spectra for days with ~few runs







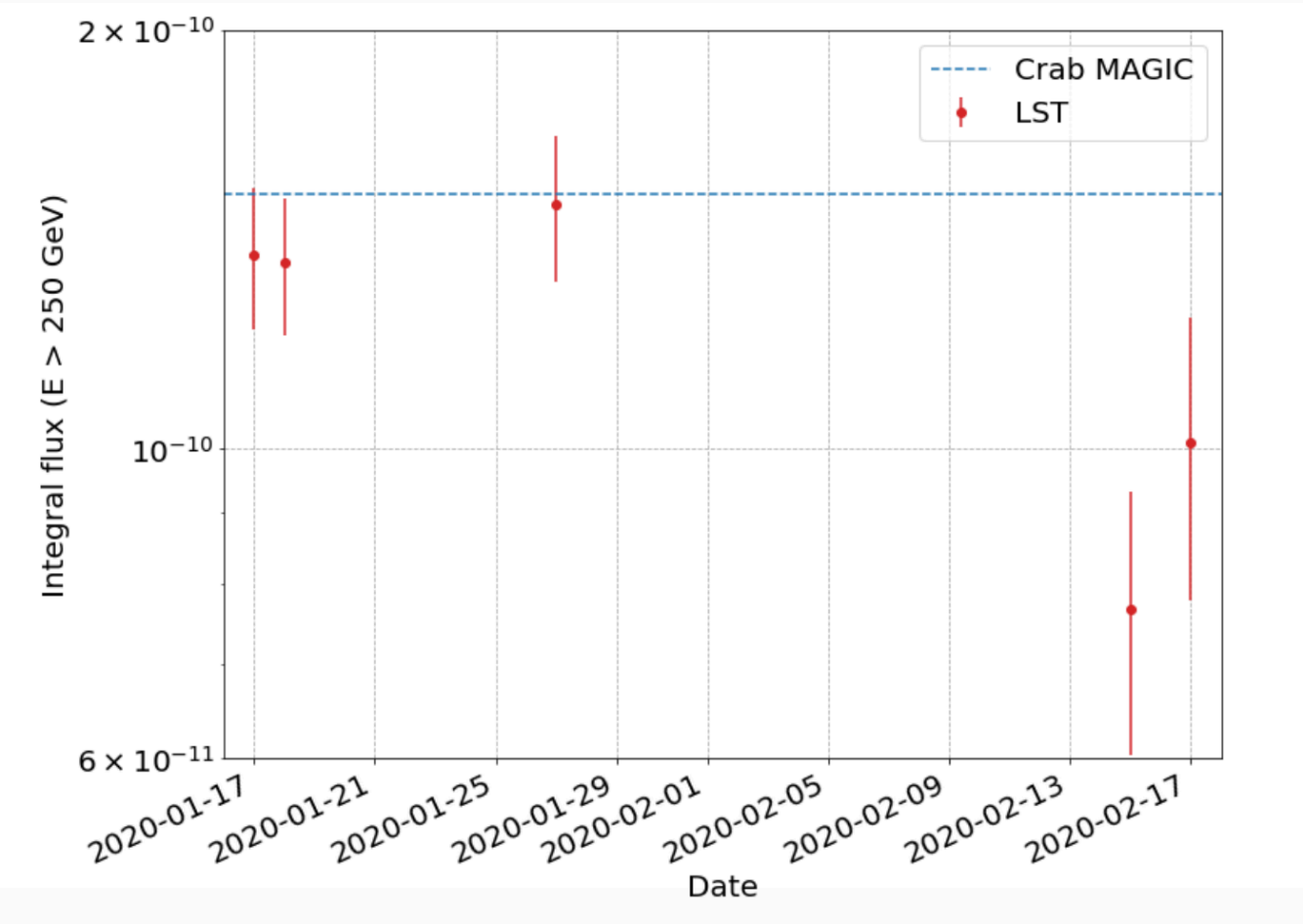




Stable spectra over time

Slight decrease in some days in February may be due to bad weather

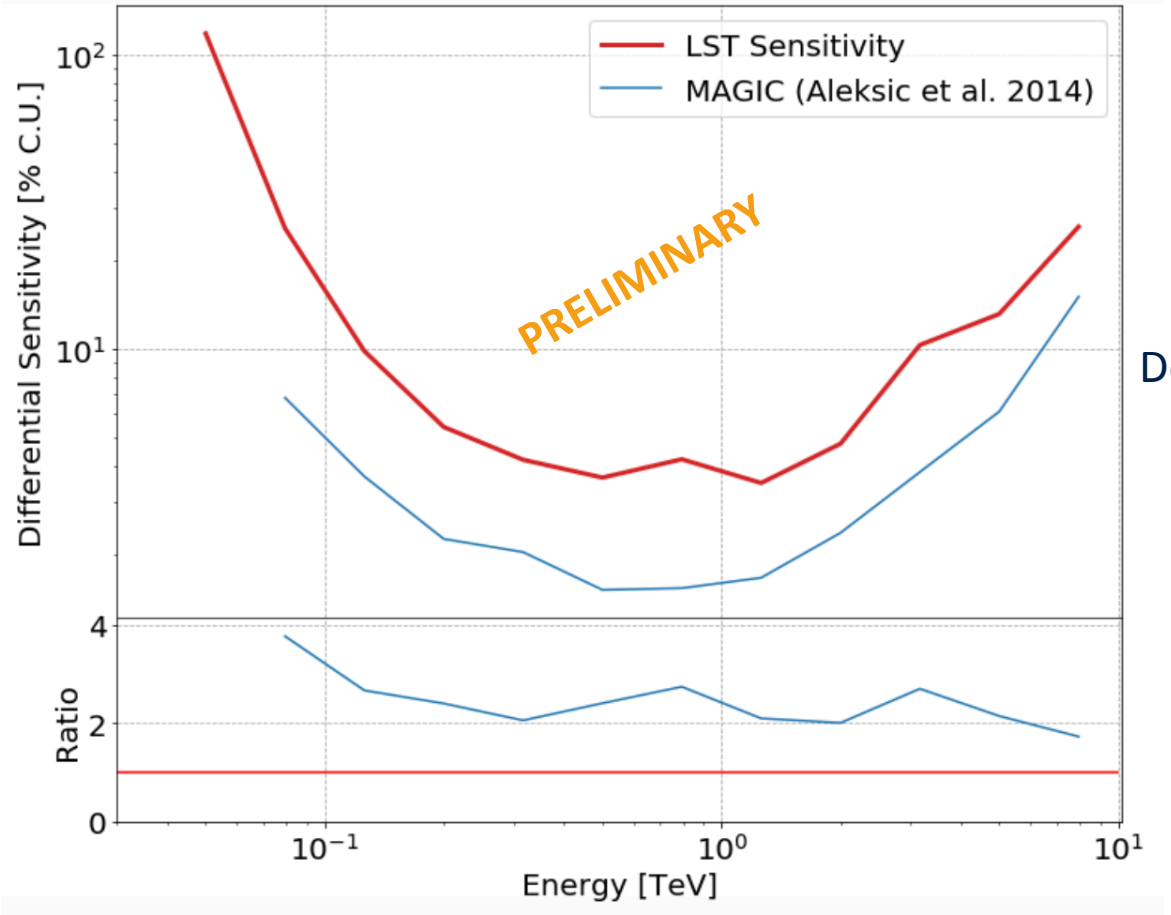
Integral flux



- Integral flux vs time at roughly the expected level if we take into account non-perfect-weather data

Differential Sensitivity

- Cuts optimized per energy bin in loose grid of alpha/gammaness



- Sensitivity goes:
  - Parallel to that of MAGIC Stereo at high energies and a factor ~2.5 worse
  - Diverges at low energies because of the worst background rejection due to observations performed in single-telescope mode

Definition

- 50 hours of observation
- Excess matching 5 sigma significance
- 5 energy bins per decade
- At least 10 gammas per bin after 50 hours.
- Exposure ratio ON/OFF = 0.2
- Excess > 5% Background (per energy bin)

Src-independent comparison

Definition:

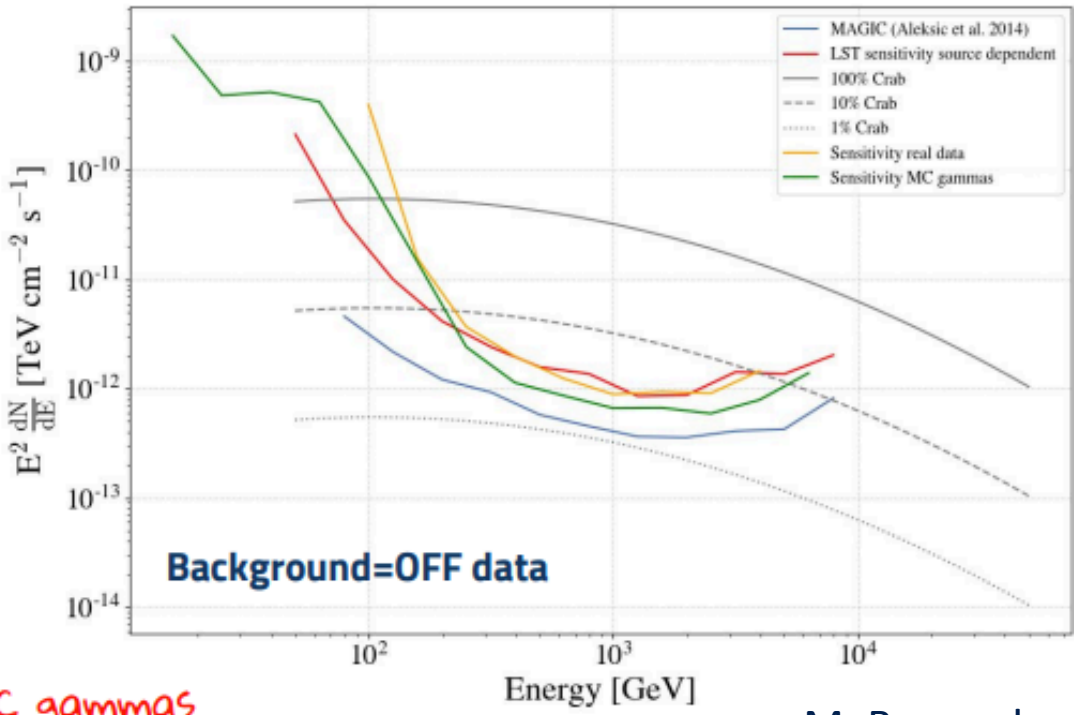
- 50h observation time
- Excess matching 5σ significance(Li&Ma)
- 20 energy bins from 5 GeV to 50 TeV
- At least 10 gammas per bin after 50 h.
- Exposure ratio ON/OFF = 0.2
- Excess > 5% Background per energy bin

Cut selection:

- **Intensity** > 100 phe.
- **Leakage2** < 0.2
- **Gammaness cut** : 80% gamma efficiency in each energy bin.
- **θ^2 cut:** 68% containment of gammas in each energy bin

Cuts optimized using MC gammas

Classifier trained with MC protons



M. Bernardos

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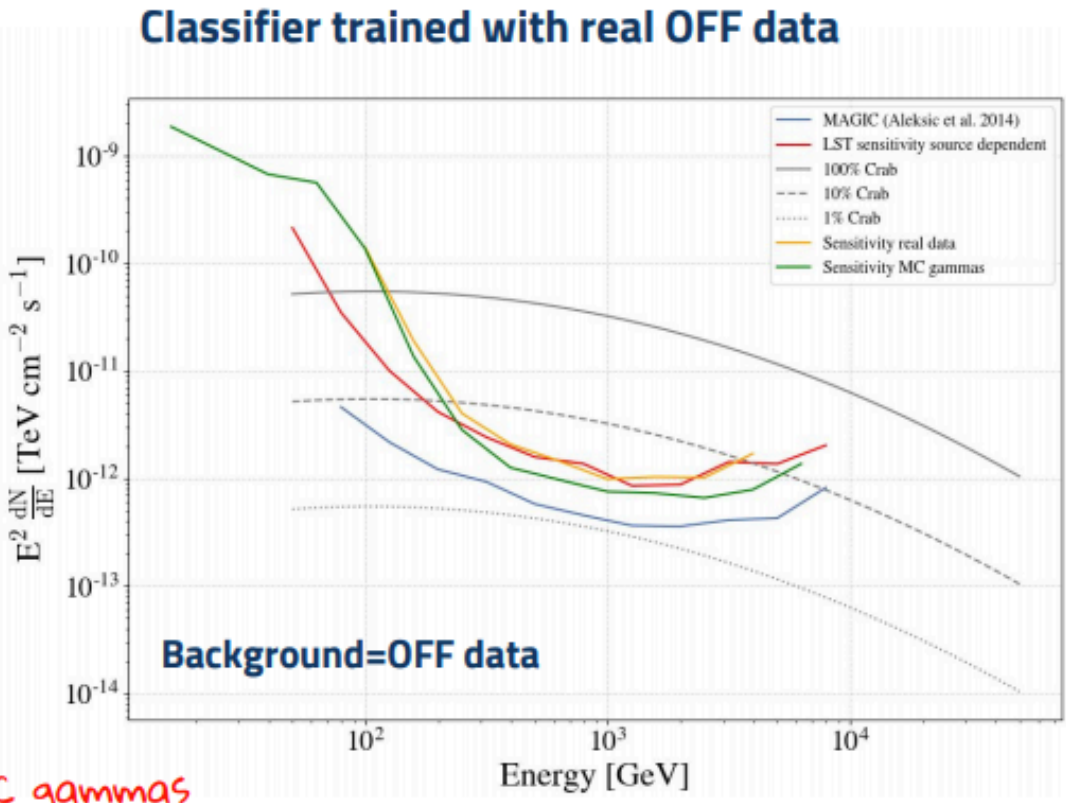
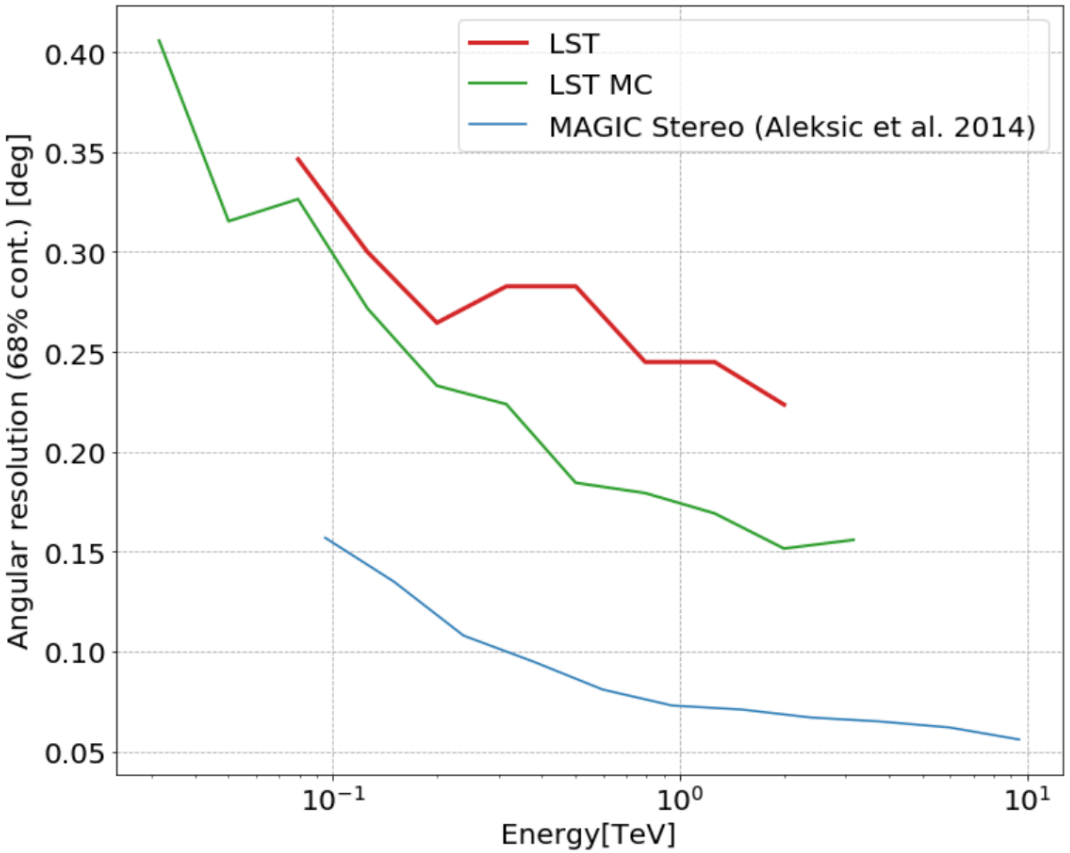


M. Bernardos

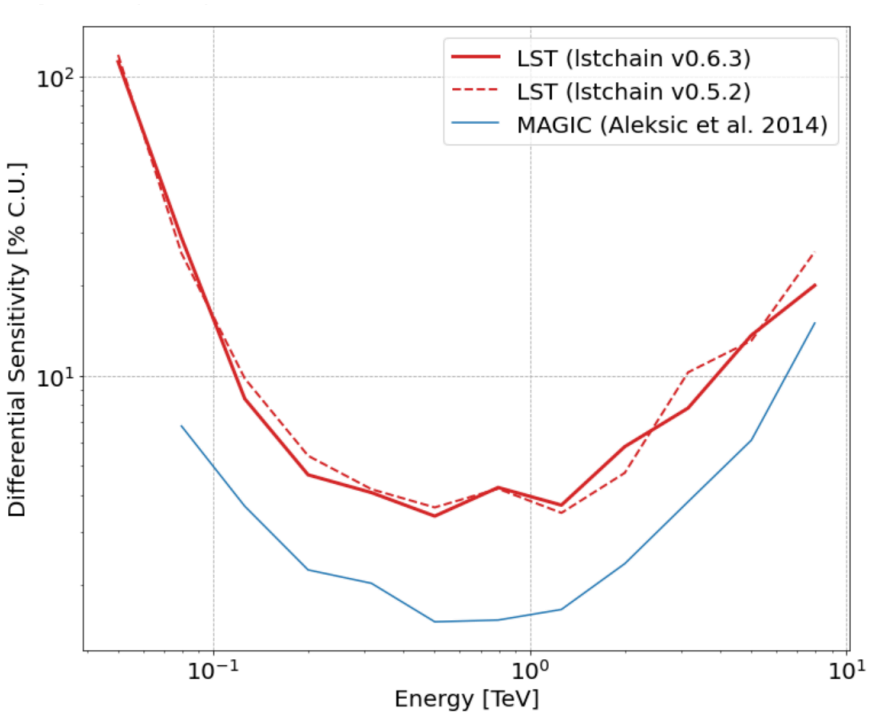
Angular resolution

- Angular resolution derived from data follows the trend expected from MC, still some Data/MC mismatch.
  - Results are also expected to be improved with optimized cleaning and usage of interleaved information



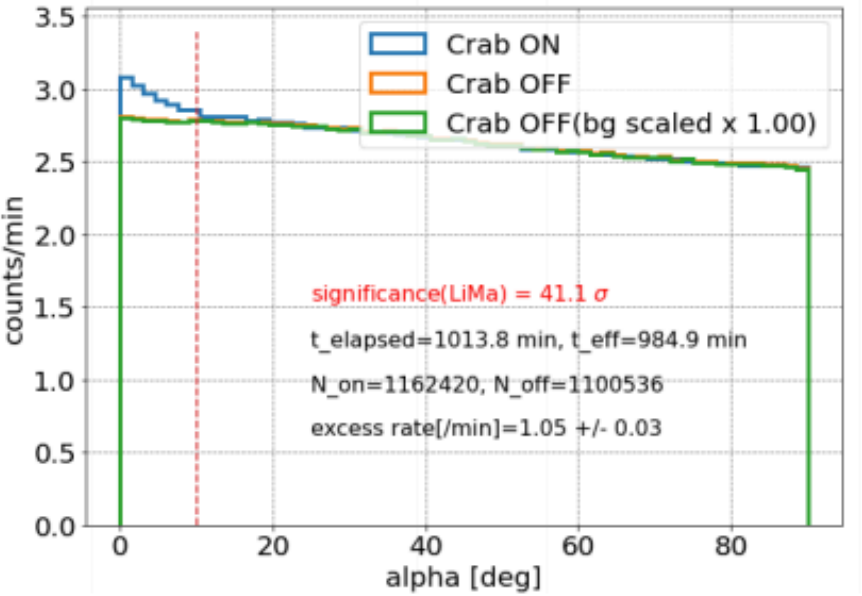
Source-dependent performance update

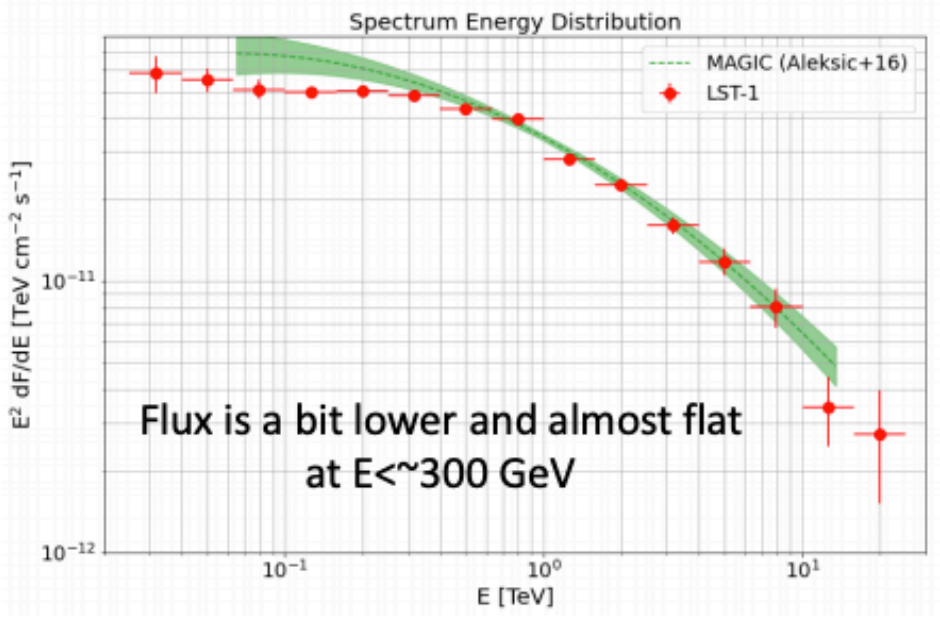
- Almost invariant w.r.t. what was shown in June using lstchain v0.5.2
  - Data had been tweaked back in June to match the old MC
  - The only expected improvement is from having a MC that matches better the telescope performance



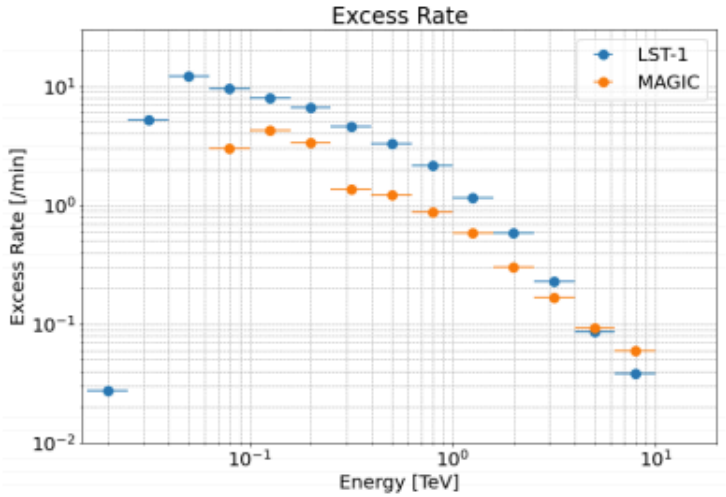
Wobble analysis

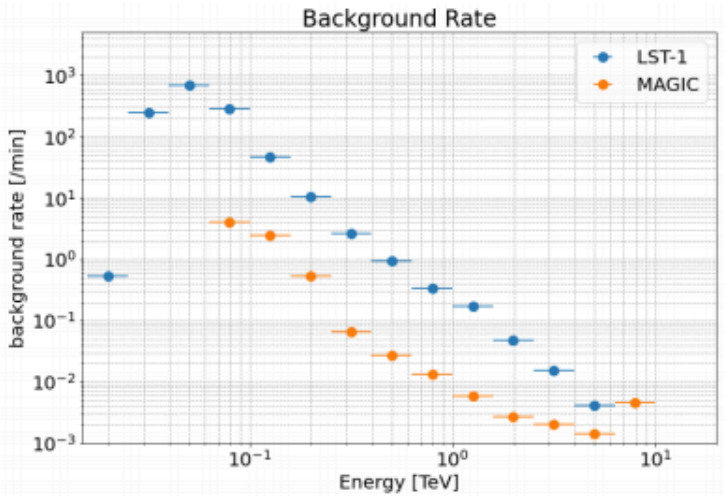
- Still <u>preliminary</u> results, specially at the lowest energies.
  - Room for improvement in cleaning (work ongoing), signal extraction...
- All the results shown here use source-dependent analysis
  - Data from November/December 2020 campaign.
  - Total of **~ 17 hours** included in the analysis

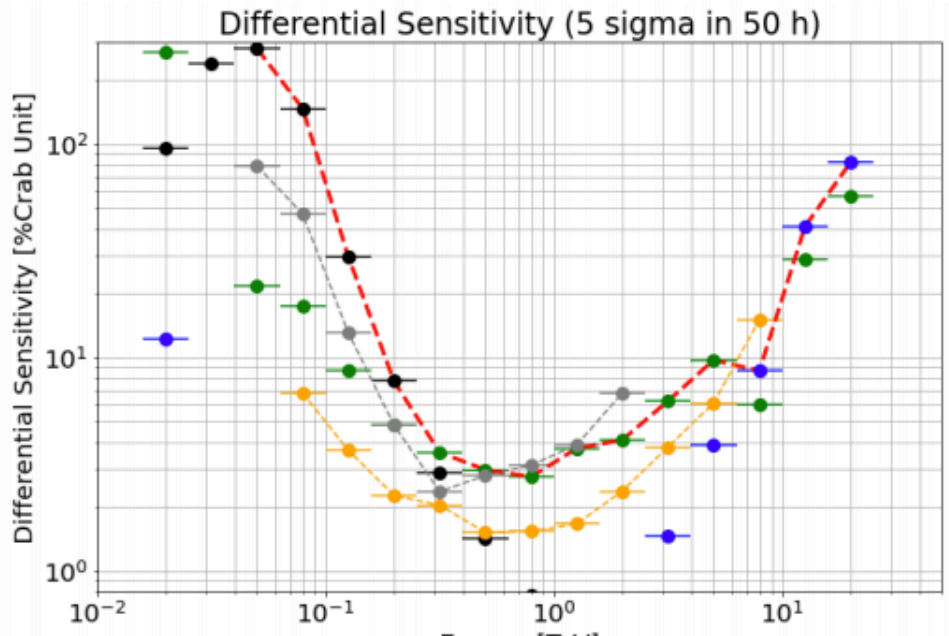




Rates and sensitivity

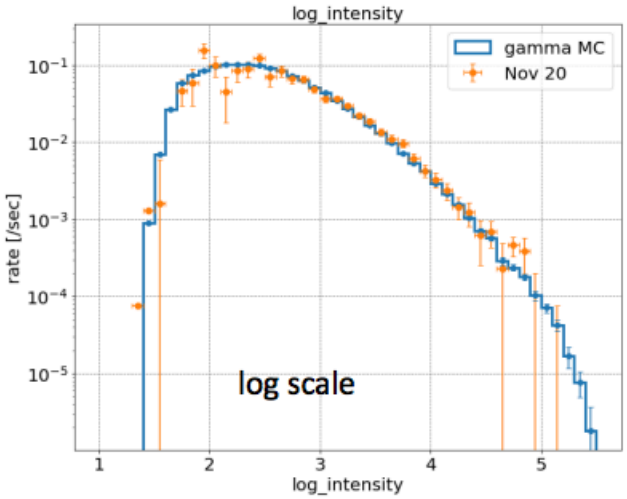




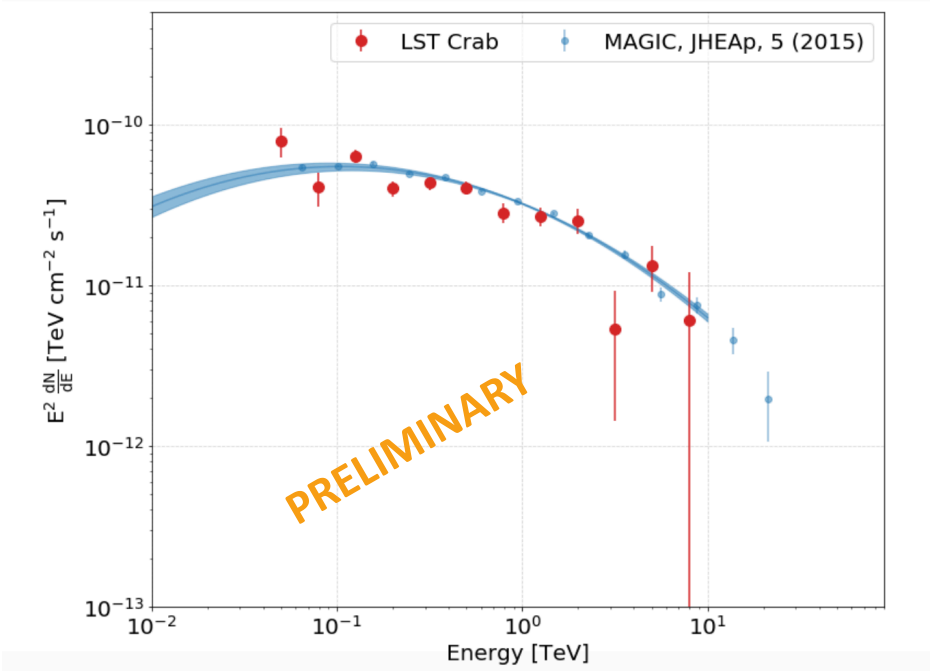


LST-1 sensitivity is worse than MAGIC by a factor of ~2 around 300 GeV
Below 300 GeV, the sensitivity is limited by the condition of $N_{excess}>0.05N_{bkg}$

Telescope Performance - Summary

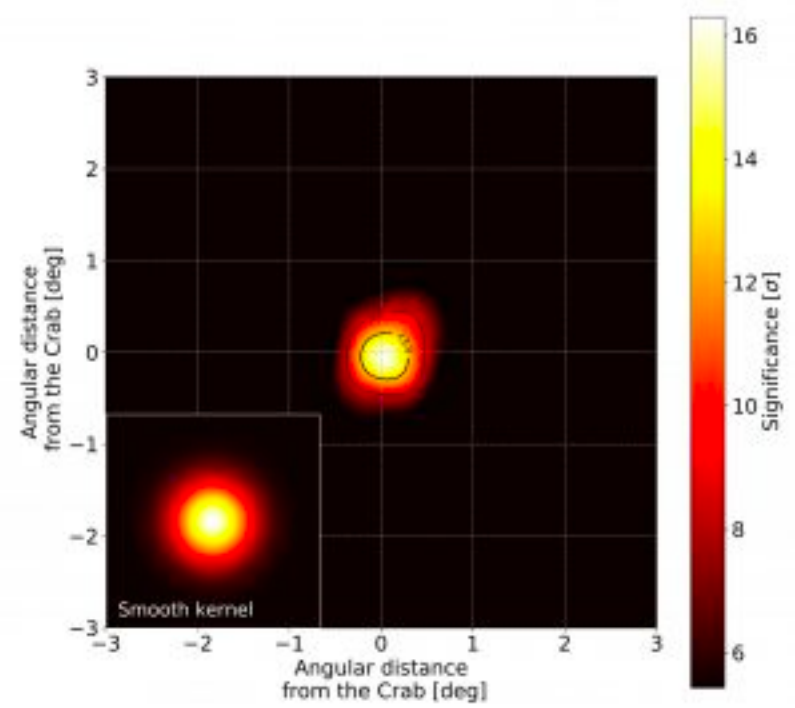


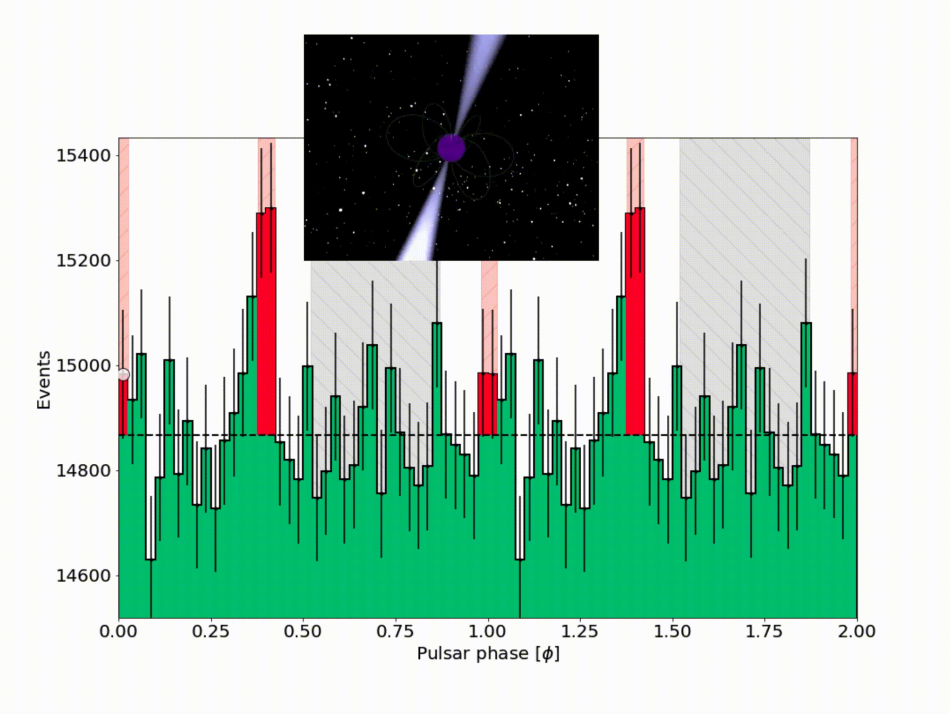
- Crab Spectrum at the expected level
  - After tuning the MC to the telescope performance
  - In general, LST-1 is gradually approaching expectations in terms of performance



LST-1 observations - Crab

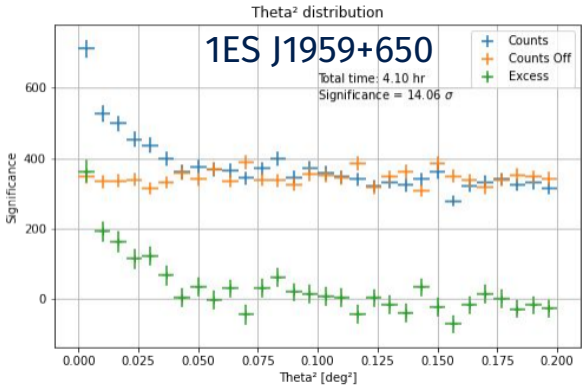
- Crab Nebula
  - Already detected the first night of observations
  - Continuously monitored for performance purposes
- Crab pulsar
  - Challenging to detect a pulsar only with commissioning data (11.4 h from early 2020)
  - P2 clearly detected with significance 5.2 σ
  - P1 significance is still marginal.

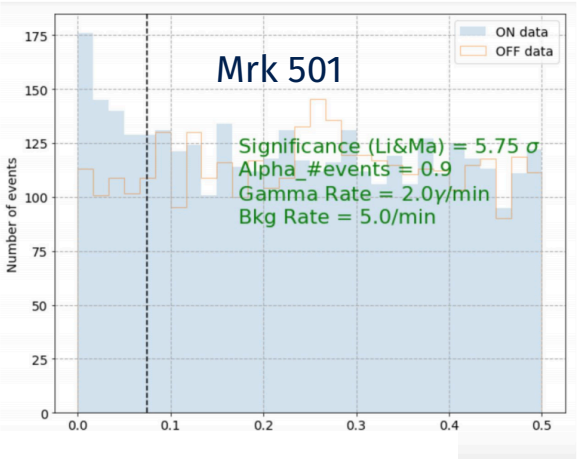


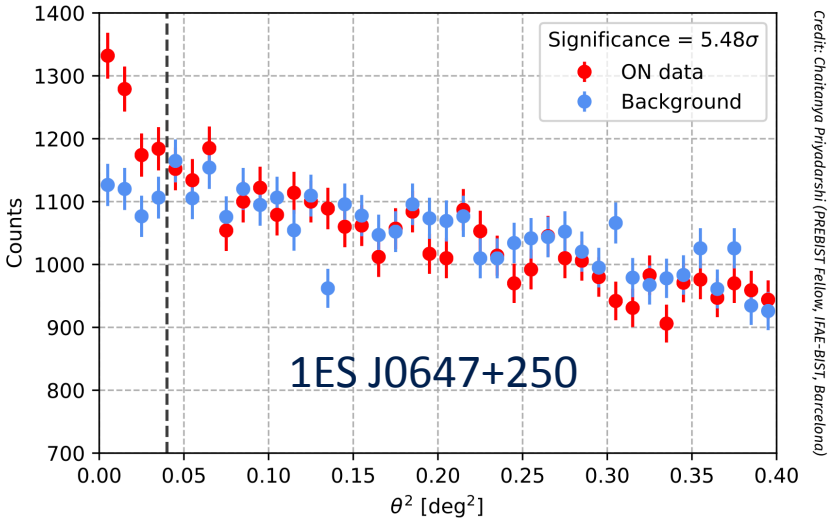


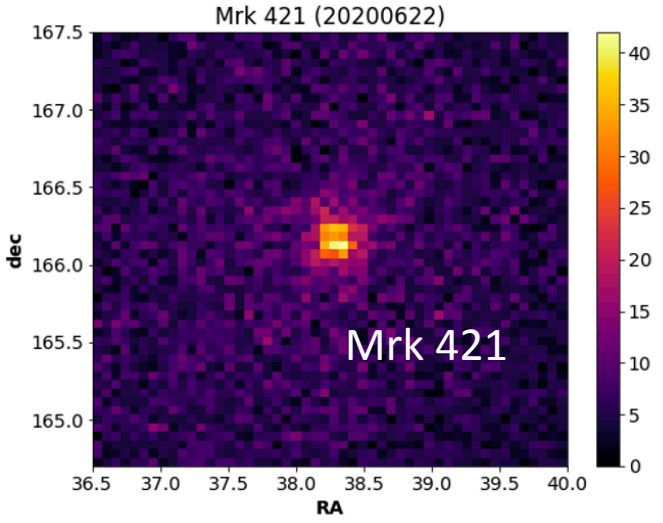
LST-1 observations - AGNs

- AGNs
  - Follow-up observations of flaring sources
  - Already detected Mrk 421, Mrk 501, 1ES J1959+650, 1ES J0647+250 (LST's most distant source)









Hands on

- Explore LST Data
  - Run notebook **notebooks/lst/real_data/explore_LST_data.ipynb**