



cherenkov  
telescope  
array

# cta-lstchain

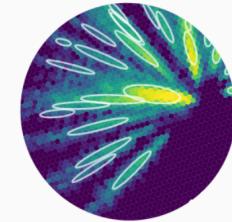
Rubén López-Coto, INFN Padova  
University of Rijeka, 17/02/21



Funded by H2020 Marie Skłodowska  
Curie FELLINI - Grant 754496



- Low level
  - Calibration
  - Image cleaning and parametrization
  - Machine Learning models for:
    - Gamma/hadron separation
    - Energy and direction reconstruction
- High level
  - Spectra
  - Lightcurves
  - Skymaps



ctapipe

$\gamma$   $\pi$

The logo for ctools, featuring the word "ctools" in a large, bold, dark blue sans-serif font. Below it, the text "cherenkov telescope array" is written in a smaller, lighter blue font. A dark blue swoosh graphic starts from the bottom left and curves around the text.

# LST Data analysis



- Low level
  - Calibration
  - Image cleaning and parametrization
  - Machine Learning models for:
    - Gamma/hadron separation
    - Energy and direction reconstruction

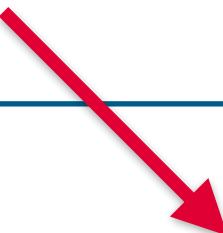
- High level
  - Spectra
  - Lightcurves
  - Skymaps

The screenshot shows the GitHub repository page for `cta-observatory / cta-lstchain`. The repository has 25 stars, 8 forks, and 57 issues. It contains 1,425 commits, 3 branches, 0 packages, 11 releases, and 19 contributors. The latest commit was made 24 minutes ago by MaxNoe. The repository includes sections for .github, licenses, lstchain, notebooks, and utils.

Category	Value
Commits	1,425
Branches	3
Packages	0
Releases	11
Contributors	19

File	Description	Date
.github	Typo in release-drafter	5 months ago
licenses	moving the license	2 years ago
lstchain	Merge pull request #334 from rlopezcoto/solve_misleading_names	4 hours ago
notebooks	update notebooks	5 hours ago
utils	solve conflict	12 months ago

Please **Watch** the code development  
and keep updated



cta-observatory / cta-lstchain

Code Issues 43 Pull requests 29 Actions Projects 2 Wiki Security Insights Settings

master 10 branches 19 tags Go to file Add file Code

**rlopezcoto** Merge pull request #551 from SeiyaNozaki/srcdep\_for\_realdatal 746fa95 2 hours ago 2,536 commits

.github	modify pip install in github ci	2 months ago
docs/examples/post_dl2_analysis	Update of notebook and logging, fix remaining bugs	2 months ago
licenses	moving the license	3 years ago
Istchain	Merge branch 'master' into srcdep_for_realdatal	2 hours ago
notebooks	Update of notebook and logging, fix remaining bugs	2 months ago
.gitignore	Remove unused imports and fix docstring location	10 months ago
README.md	Switch to github actions	3 months ago
environment.yml	add missing toml from environment/setup	3 hours ago

About LST prototype testbench chain

Readme

Releases 19

v0.6.3 Latest on 14 Oct 2020 + 18 releases

Packages No packages published Publish your first package

- cta-lstchain (<https://github.com/cta-observatory/cta-lstchain>):
  - ctapipe-based pipeline that includes all the tools for LST data processing from R1 up to DL2.
  - Currently following v0.6.3 version

Latest release

v0.6.3

release-drafter released this on 14 Oct 2020 · 169 commits to master since this release

Verified

Compare ▾

## What's Changed

- update astropy version (#541) @garciagenrique
- Fix an error while processing prod5 MC (updated) (#540) @mari-taka

# What is inside? Structure



 morcuended move the update of disp params outside the event loop

 f22ae2c 3 days ago 

..		
 analysis	Update of notebook and logging, fix remaining bugs	2 months ago
 calib	Update test_calib.py	4 months ago
 data	remove commas	19 days ago
 datachecks	Replaced triple quotes by hashes in commented code	5 months ago
 image	fix writing of all energies for every muon event	4 months ago
 io	Merge branch 'master' into fix_dl1ab	4 days ago
 mc	revert test values	3 months ago
 pointing	include only used functions in inits	10 months ago
 reco	Update of notebook and logging, fix remaining bugs	2 months ago
 resources	Moved LST_pixid_to_cluster.txt to newly created lstchain/resources, and	8 months ago
 scripts	move the update of disp params outside the event loop	3 days ago
 spectra	include only used functions in inits	10 months ago
 tests	use standard configuration file for test_lstchain.py	3 months ago
 tools	Small fixes	7 months ago
 visualization	Update of notebook and logging, fix remaining bugs	2 months ago



# General information

---

- Presentations:
  - Latest CTA collaboration meeting
    - [https://indico.cta-observatory.org/event/3020/contributions/25963/attachments/18148/24547/LST\\_analysis\\_20201014.pdf](https://indico.cta-observatory.org/event/3020/contributions/25963/attachments/18148/24547/LST_analysis_20201014.pdf)
    - Latest LST collaboration meeting
      - <https://indico.cta-observatory.org/event/3048/timetable/#20201030.detailed>
  - LST Analysis calls: Every second Monday (next one: Mon. 1st Mar. 2021)
    - <https://indico.cta-observatory.org/category/149/>
      - Sometimes also reports on ASWG calls
      - Every second Wednesday/Thursday

# Workflow

R0: Raw data directly from the camera server

DLX: Data Level X

**R0 -> DL1**

- Low level camera calibration
- High level camera calibration
- Image cleaning
- Image parameter calculation

**DL1 -> DL2**

Training of machine learning methods to perform:

- Energy estimation
- Arrival direction
- gamma/hadron separation

**DL2 -> DL3**

Apply cuts and select ON/OFF data to search for significant signals

DL3 Data can be further processed with the existing high-level gamma-ray analysis tools

# cta-lstchain recap

- **R1** ⇒ **DL1** (from camera raw waveforms to calibrated & parametrized images)

- Low level (DRS4) waveform corrections.
- Pulse integration & calibration (pixel-wise charge in p.e., time in ns)
- Image cleaning & parametrization ⇒ DL1
- Identification and muon analysis

Notes:

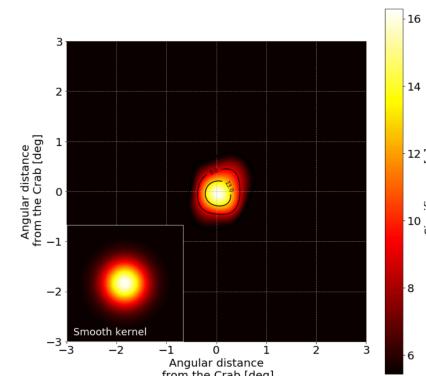
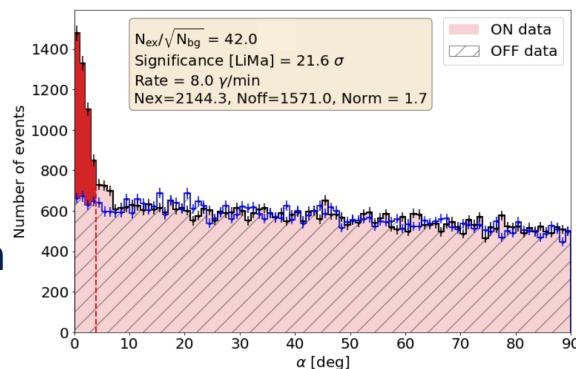
- currently **R1** is stored permanently (all pixels, all waveforms)
- no official DL0 data format & model yet
- no lossy data reduction scheme established yet

- **DL1** ⇒ **DL2**

Use scikit-learn's Random Forest, trained on MC, for gamma/hadron separation and direction and energy reconstruction

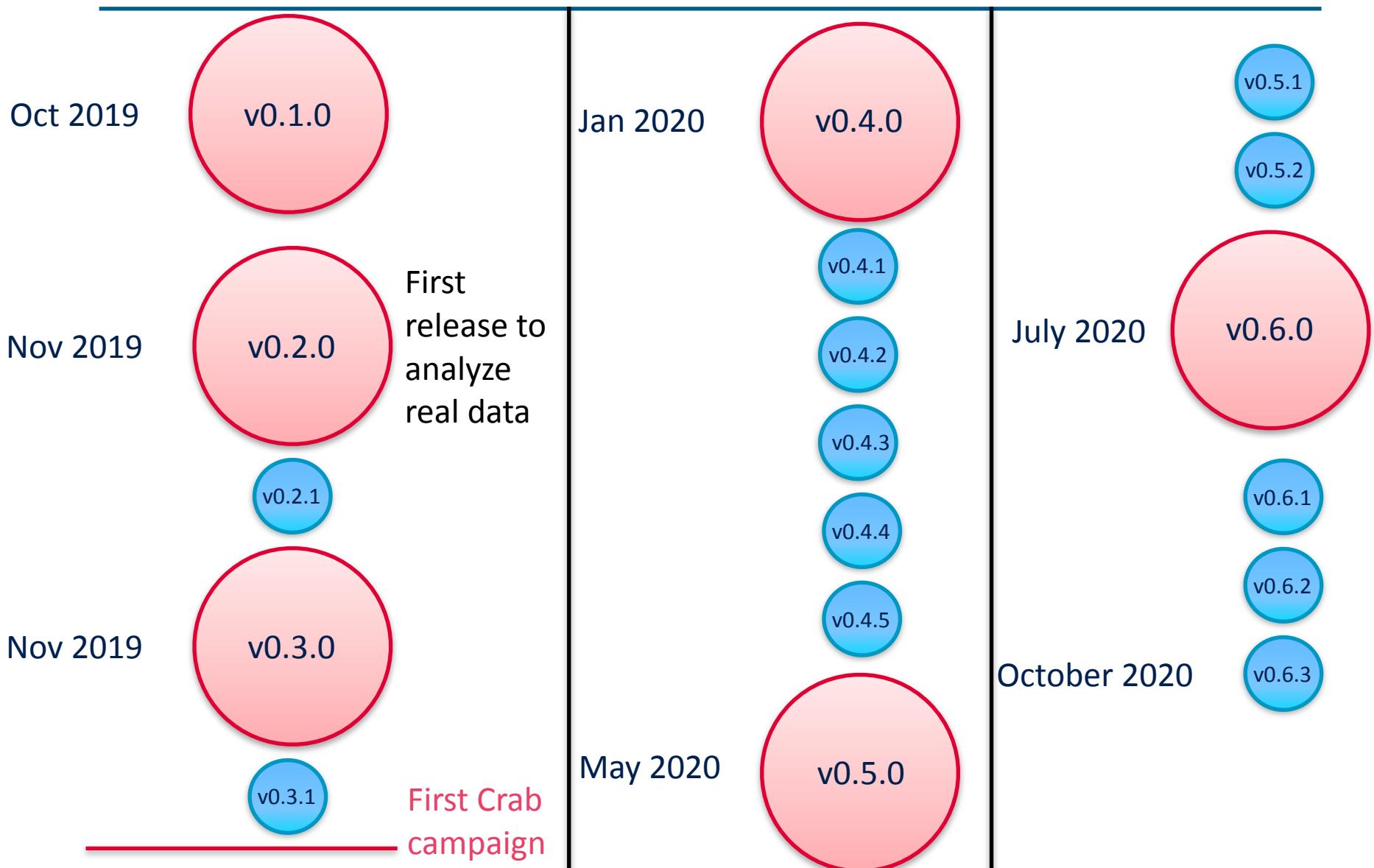
- **DL2** ⇒ **DL3**

apply gammaness and direction cut to produce list of gamma candidates



First Crab LST detection  
December 2019

# lstchain evolution



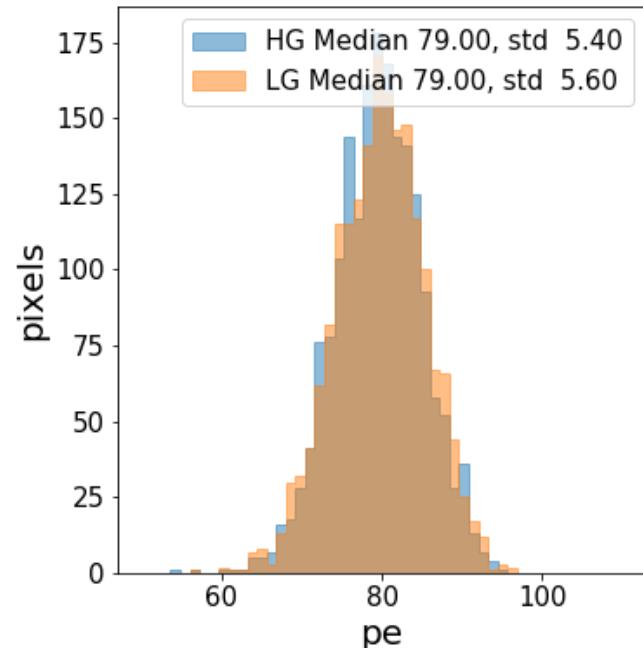
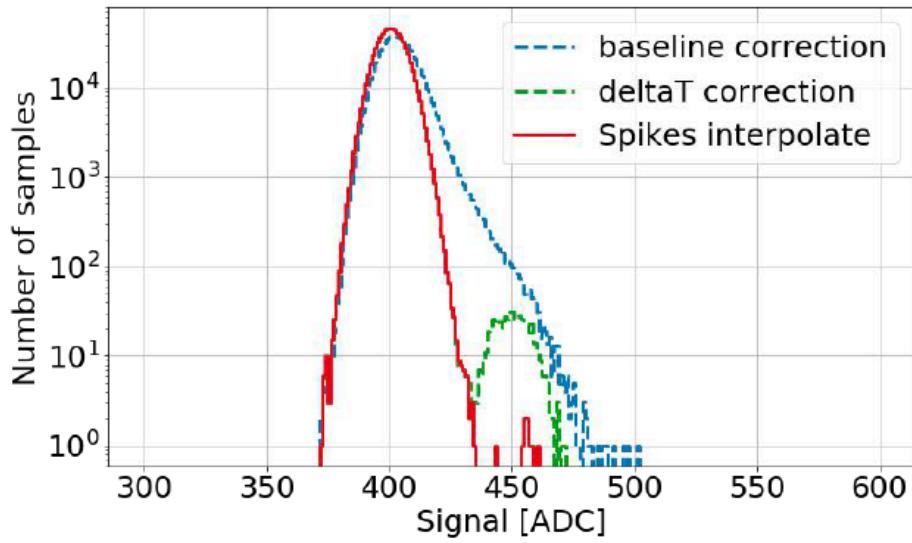
# Istchain development

Progress since May 13<sup>th</sup> [report](#) @ remote consortium meeting:

- Three new releases 0.5.2, 0.6.0, **0.6.1** (Oct 5<sup>th</sup>)  
**(+0.6.2 on Oct 13<sup>th</sup>, fix minor bug in datacheck plots)**  
<https://github.com/cta-observatory/cta-Istchain/releases>
  - using ctapipe 0.8.0 since Istchain 0.6.0
  - many small improvements and bugfixes
  - software patches to fix known issues in the real data: **correct timestamps** and (when possible) **correct event tagging** (interleaved pedestals)
  - adapt to ctapipe API changes
    - for now, only the bare minimum to make the pipeline work
  - tuning of camera calibration
  - better data check tools
- Contributors: [@FrancaCassol](#), [@maxnoe](#), [@moralejo](#), [@pawel21](#), [@rlopezcoto](#), [@vuillaut](#), [@JouvinLea](#), [@SeiyaNozaki](#), [@yrenier](#), [@lfoffano](#), [@morcueded](#), [@Bultako](#), [@chaimain](#), [@misabelber](#), [@satoshifukami0115](#), [@mexanick](#), [@yutonogami](#), [@Diestbarr](#)

# Calibration

- lstchain calibrates data from R1 level up to phe conversion.
  - Low level (DRS4) waveform corrections (P. Gliwny, J. Sitarek).
  - Pulse integration and calibration (F. Cassol, Y. Kobayashi).
  - (more details in the LST Real data analysis presentation by A. Moralejo).



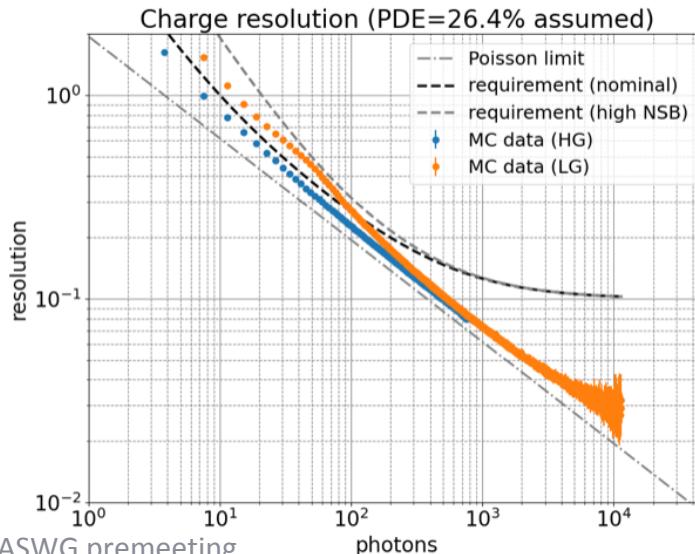
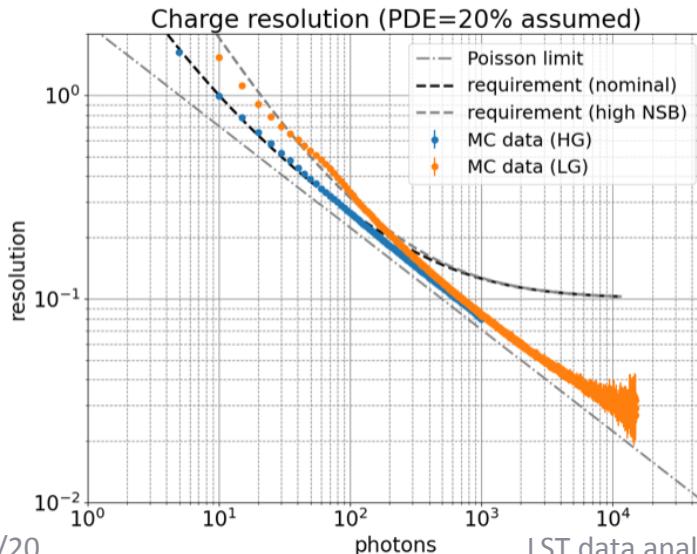
HG/LG comparison

# Charge resolution vs. # of photons

Estimate from Prod-5 MC



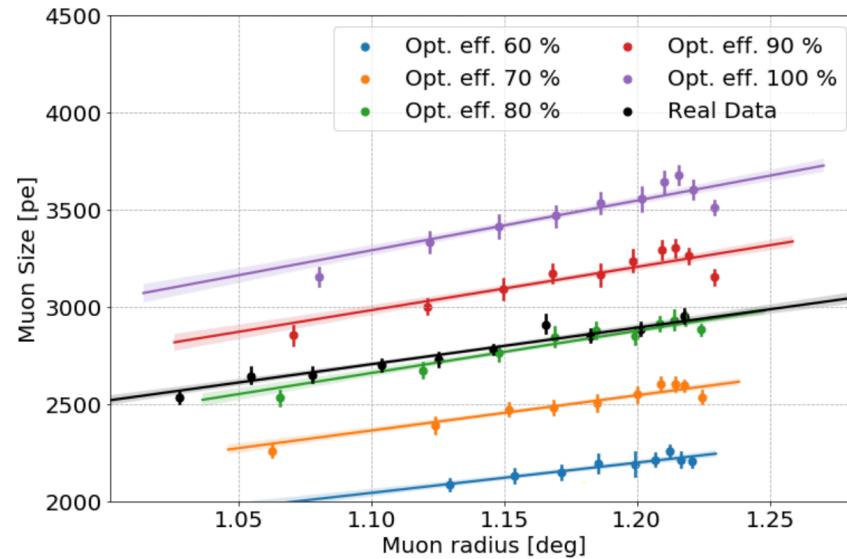
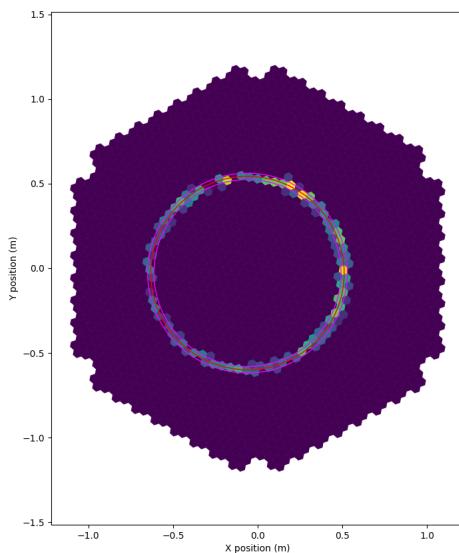
- Based on the charge resolution reported at  
<https://indico.cta-observatory.org/event/2853/contributions/24597/attachments/17750/23825/ChargeRecoYukiho20200629.pdf>,
- The x-axis was just scaled by assumed PDE: 26.4% (Prod5) or 20% (req.)  
[https://www.mpi-hd.mpg.de/hfm/CTA/MC/Prod5/Config/Efficiencies/p4eff\\_LST-prototype.pdf](https://www.mpi-hd.mpg.de/hfm/CTA/MC/Prod5/Config/Efficiencies/p4eff_LST-prototype.pdf)
- The requirements:
  - <https://jama.cta-observatory.org/perspective.req#/items/30725?projectId=11>
  - <https://jama.cta-observatory.org/perspective.req#/items/28666?projectId=11>



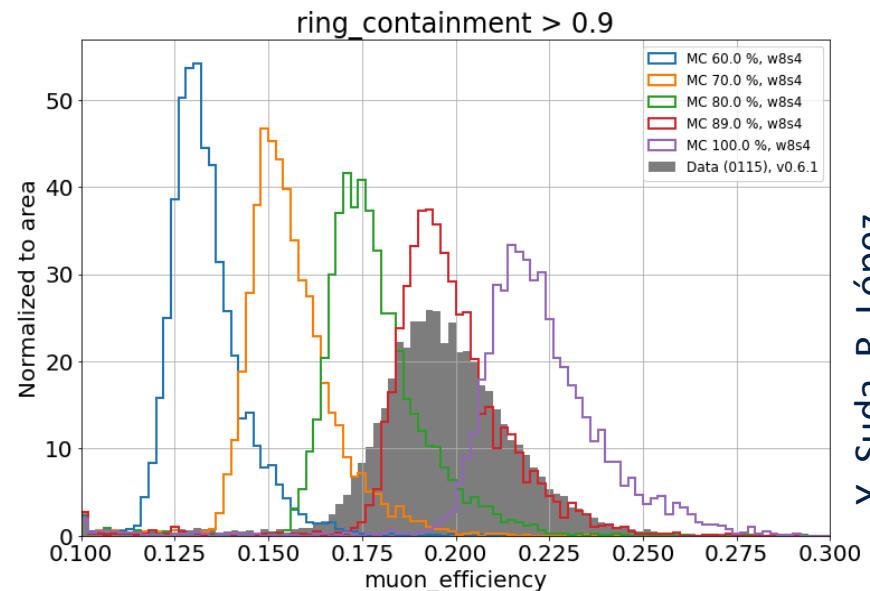
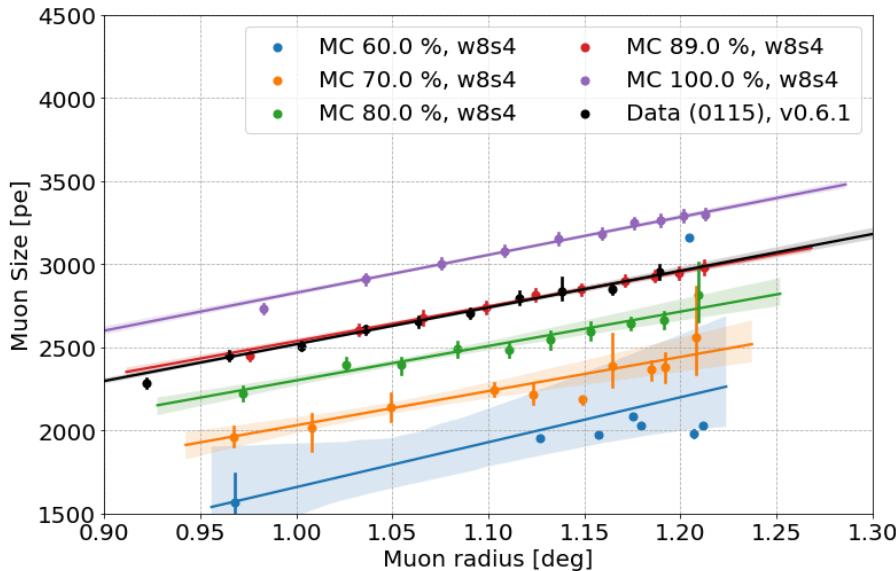
# Muon analysis



- Now performed together with the R1  $\rightarrow$  DL1 step (no significant increase in processing time)
  - To avoid signal extraction biases, the GlobalPeakWindowSum is now used.
  - At the moment, an ~80% overall Optical efficiency is reached, with respect to Prod3b simulations  $\rightarrow$  currently working on more realistic, measured parameters for Prod5.



# Tuning the telescope efficiency

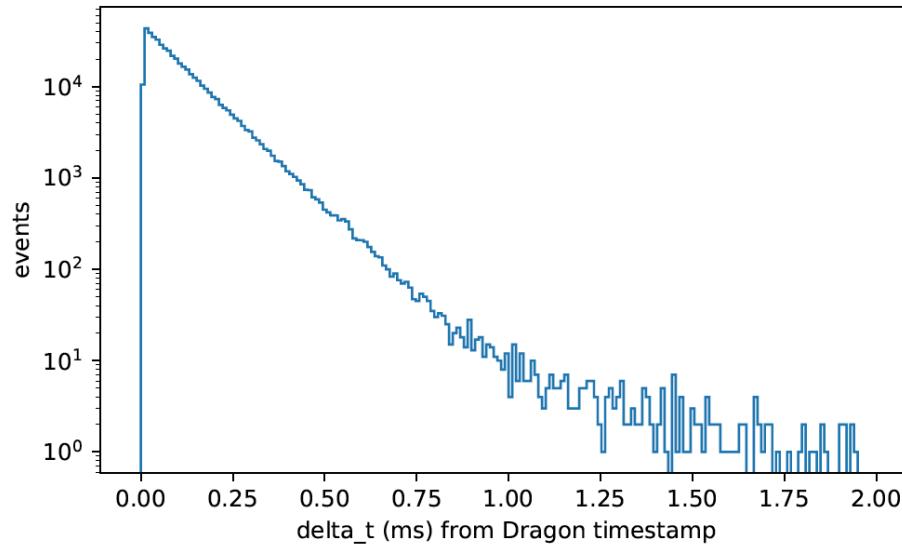


Y. Suda, R. López

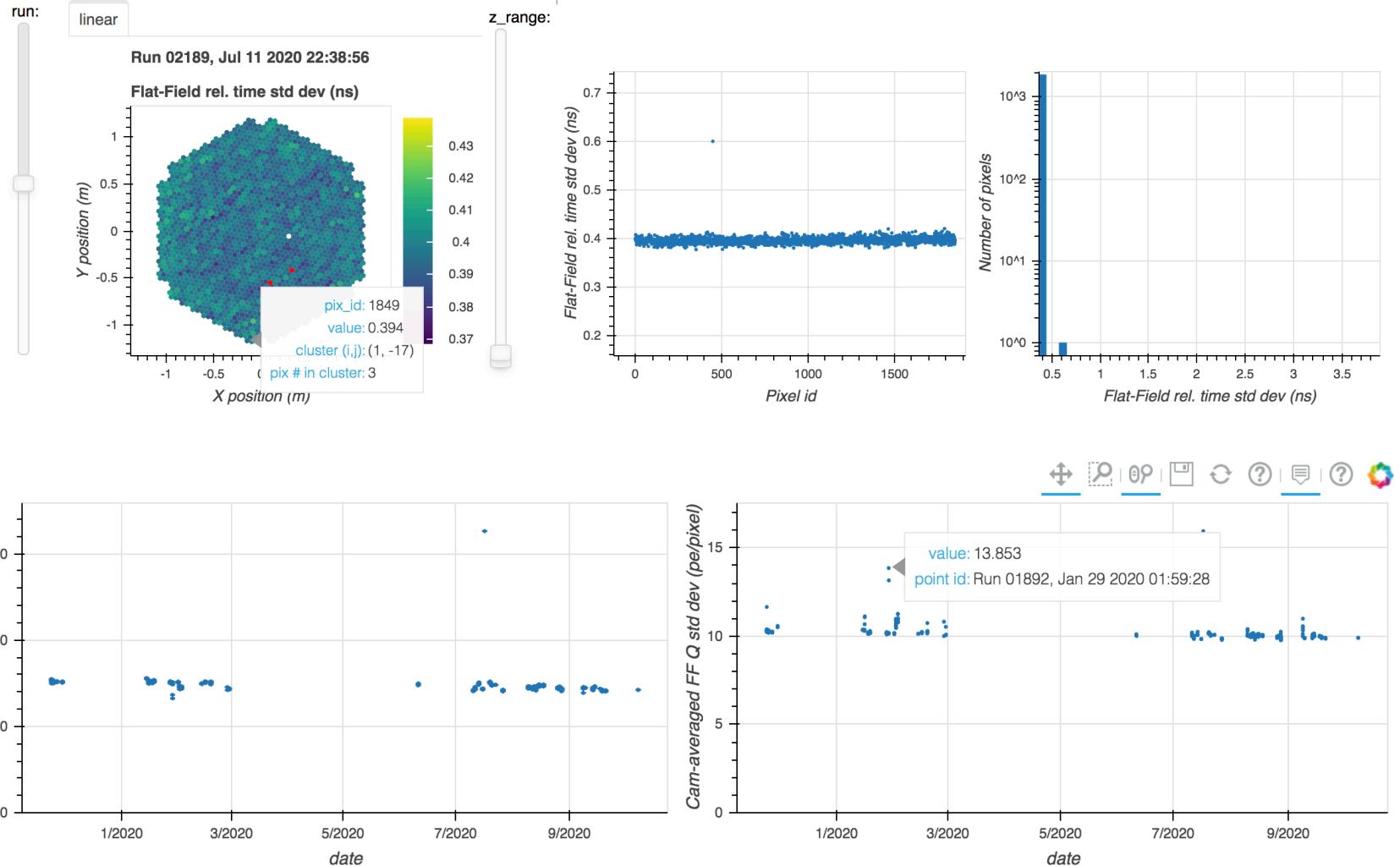
- For the best available LST-1 data, muon ring light ratio (data/MC) is  $\sim 0.89$ 
  - Variations through the dataset ( $\sim 15\%$ ) due to calima, fraction of properly aligned mirror dish panels...  $\Rightarrow$  will need more MC versions
- The difference is not entirely from "less light in data", but accounts for small differences in signal extraction & calibration
  - e.g. : "Global Peak" integrator in real muon data is affected by non-perfect pixel t-synchronization)

# DL1 Datacheck

- Quantities to be checked are written into an h5 file per subrun analyzed -> Later merged and plotted together per run (A. Moralejo)
  - Many checks currently implemented -> necessary to spot data problems the day after the data taking.
  - Includes rates, timestamps, flatfield, pedestal, cosmic and muon event checks.



# Better data check tool (DL1 level)

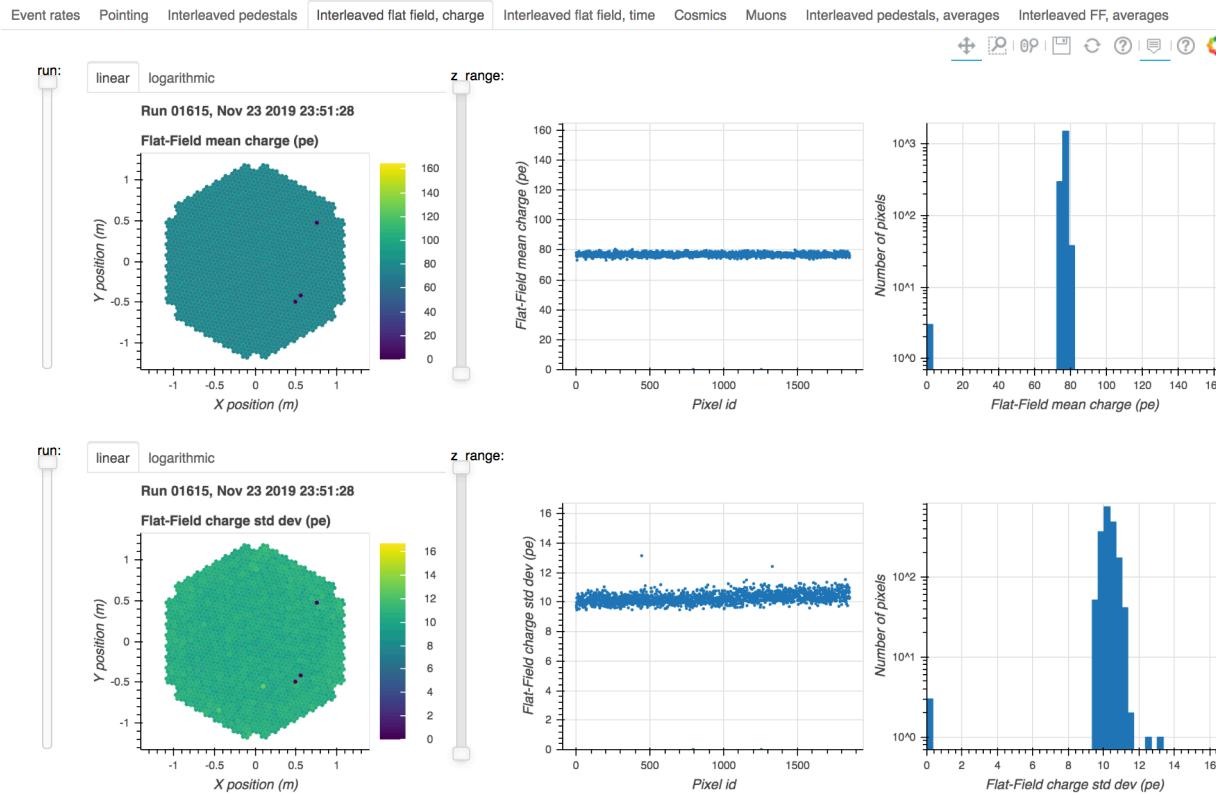


# Better data check tool (DL1 level)

← → ⌂ File | /Users/moralejo/CTA/LST/RealData/datacheck\_long\_term/v0.6.1/longterm\_dl1\_check.html

Apps Bookmarks Safety Kashiwa IFAEmail ScholarOne Manu... Overleaf Log In < Vibe — W... Elsevier EVISE ref...

## Long-term DL1 data check

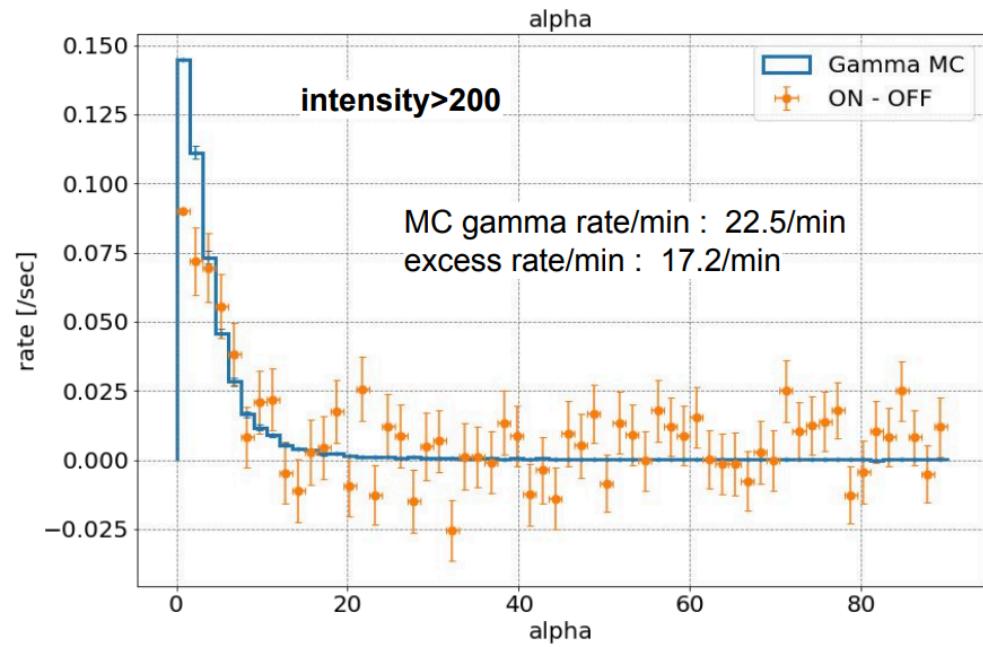
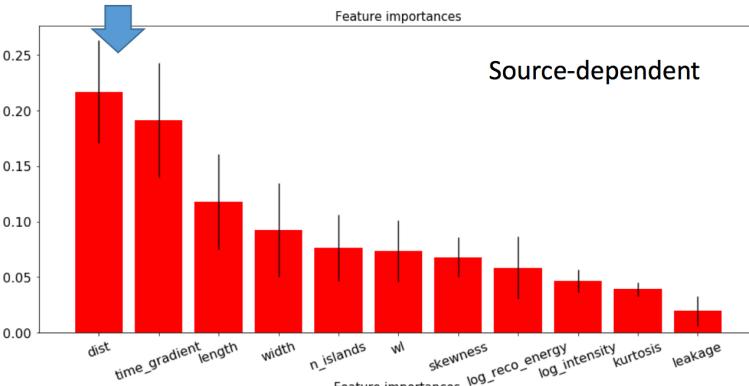


- Interactive web page (using the bokeh library)
- allows easy comparison of output of DL1 calibration for different runs, and visualization of data evolution

# Source-dependent analysis

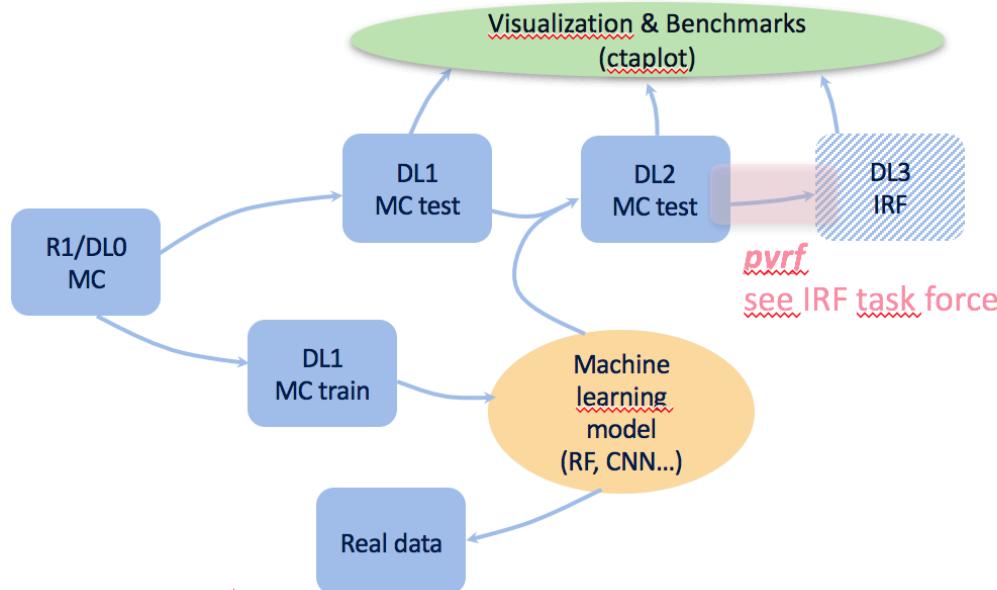


- Single telescope source dependent analysis (S. Nozaki)
  - Usage of the information of the assumed location of the source in the analysis.
  - Source-dependent parameters as “dist” are very useful for image reconstruction



# High level analysis

- Automatized training of RF models after software releases (T. Vuillaume, E. Garcia)
  - Preliminary results of training using real data as OFF to improve gamma/hadron separation (A. Baquero).
  - Standard analysis uses models trained on MC (Gammas/Protons).
  - IRF production:
    - Currently custom-made formats.
    - Development of pyIRF within the IRF working group to produce IRFs in FITS format to be analyzed with standard high level software (T. Vuillaume).



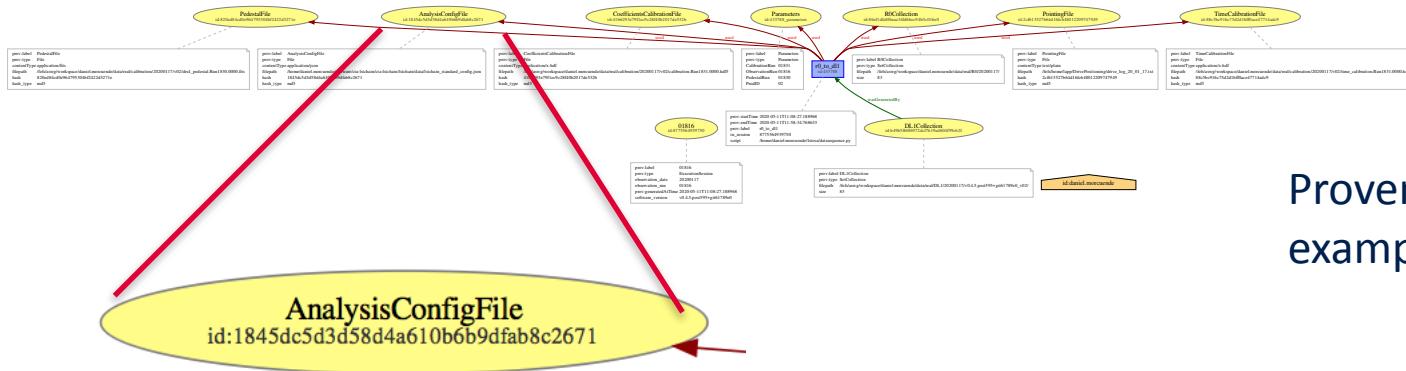
# Higher-level analysis

- $\text{DL1} \Rightarrow \text{DL2} (E_{\text{reco}}, \text{gammaness}, \text{direction}_{\text{reco}})$ 
  - using MC-trained random forests, fed with image parameters, for background suppression and direction & energy reconstruction
  - either assuming a source position or not...
- Standardization of the post-DL2 stages only starting
  - proposal from L. Foffano+ (PR#509)
- for LST-1 standalone observations, DL2+ would come in two versions:
  - Source-dependent approach for point-like sources
    - requires some 'custom' tools for spectral analysis & light curves
  - Source-independent approach (the standard one in CTA), i.e. DL3 list of gamma candidates with IRFs, to be fed to **gammaPy / ctools** for further analysis
    - first draft of a  $\text{DL2} \Rightarrow \text{DL3}$  stage script using pyIRF (developed within ASWG's IRF task group): PR#535, C. Priyadarshi+

# R1 -> DL2 automatic processing



- LSTOSA (OnSite Analysis) (D. Morcuende, J.L. Contreras, A. Baquero)
  - Automatic production of low level DRS4 correction files, calibration and time-calibration files.
  - R1-> DL1
    - Provenance implemented to keep track of the configuration files, version and auxiliary files used in the analysis (J.E. Ruiz)
  - DL1 -> DL2: model application

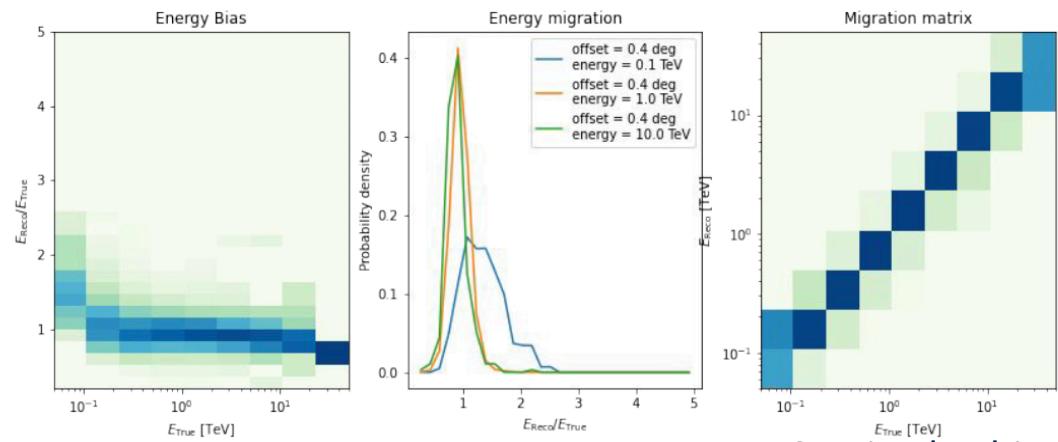
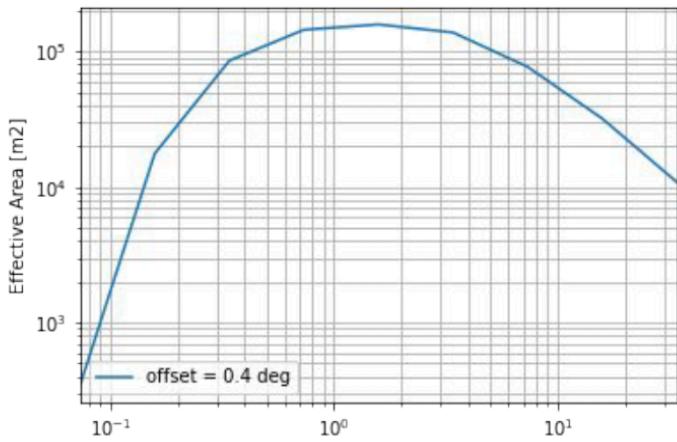
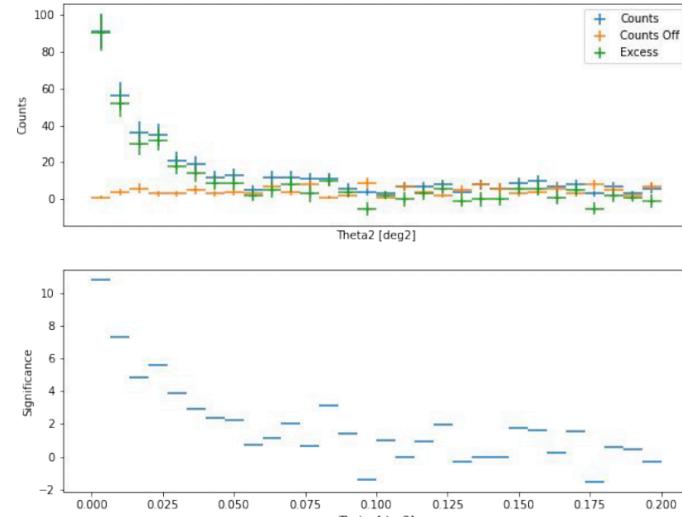


Provenance graph example

# DL2 $\Rightarrow$ DL3



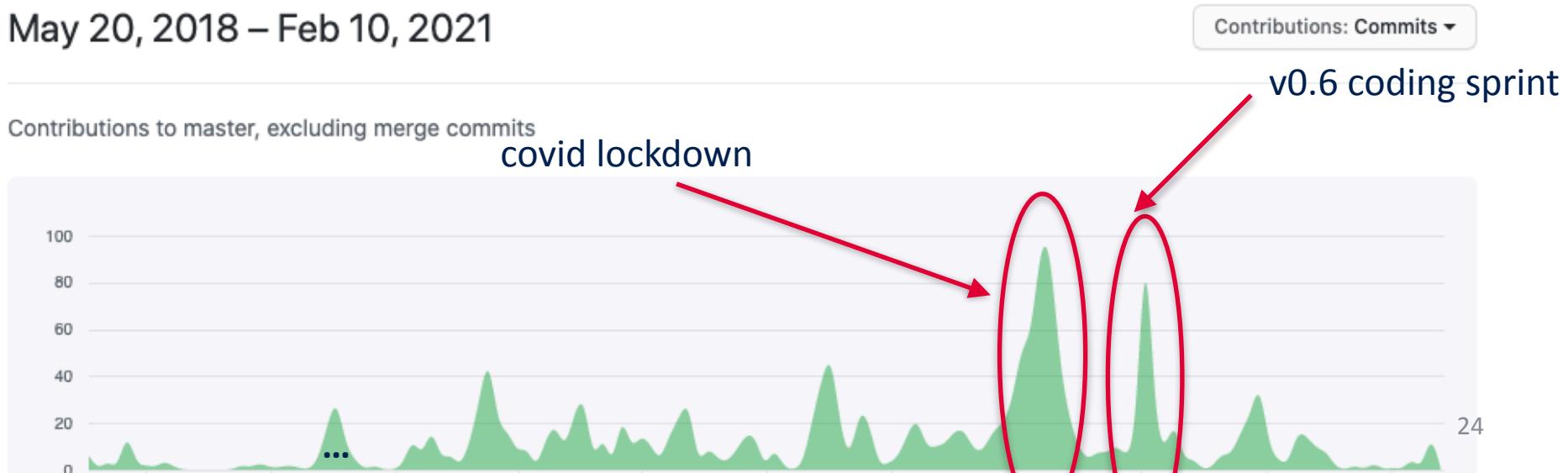
- Implementing a first version of this analysis stage in lstchain (eventually part of ctapipe/protopipe) for mono analysis
- <https://github.com/cta-observatory/cta-lstchain/pull/535>
- Still very preliminary



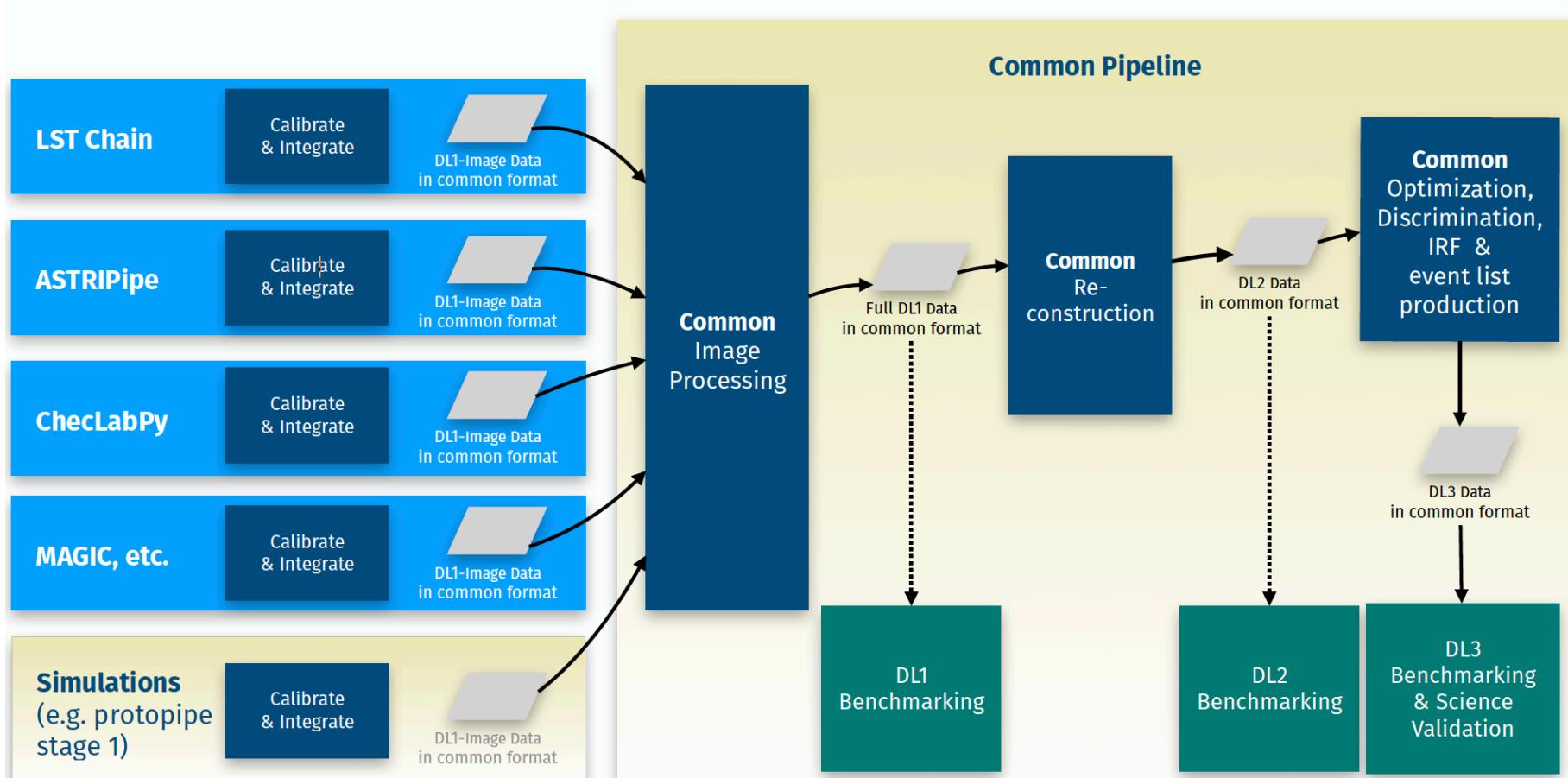
# Future

- Future?
  - Follow ctapipe v0.10.2 –
    - Move to the ctapipe-stage1 writer
  - Optimize cleaning levels using interleaved information.

May 20, 2018 – Feb 10, 2021



# Future



# Contributors

(cta)

