Divergent Pointing Simulations and Analysis

Alice Donini, F. Longo, T. Gasparetto

INFN CTA Meeting – Padova

Where were we? (Lugano meeting)

- Divergent Pointing Action 1:
  - Generate MC data in divergent mode
    - First data sample available on GRID
    - Massive production to be discussed
    - First Test Layout (La Palma, Divergent MST, parallel LSTs, z20, South Pointing)
      - 1000 files of gamma and protons
- Divergent Pointing Action 2:
  - Provide documentation on redmine on existing analysis methods on divergent pointing reconstruction
    - Redmine page
    - ICRC proceedings
- Divergent Pointing Action 3:
  - Provide first analysis of divergent pointing events
    - No more development on EvDisplay
    - ctapipe development
- Divergent Pointing Action 4:
  - Keep updated the requirements for the Divergent Pointing.
    - IRF production with full ctapipe chain to be started
    - Discussion with several WGs (EGAL, Transients, DM)
- Divergent Pointing Action 5
  - Develop the ToyMC for Divergent Analysis.
    - To be restarted to test more complex configurations
    - Important for CTAO operations

New Documentation – ICRC poster

Cherenkov Telescope Array Performance in Divergent Mode

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ABSTRACT

Two of the Key Science Projects of CTA consist in performing a deep survey of the Galactic and extragalactic sky, providing an unbiased view of the Universe at energies above tens of GeV. To optimize the time spent to perform the extragalactic survey, a so-called "divergent mode" of the CTA was proposed as an alternative observation strategy to the traditional parallel pointing in order to increase its instantaneous field of view. The search for transient VHE sources would also benefit from an extended field of view. In this contribution, we present the first performance estimation from full Monte Carlo simulation of possible CTA divergent mode setups.

Supported by:

Divergent mode

Enlarge the overall field of view by pointing the telescopes in the outward direction by an angle increasing with the telescope distance from the array center [1][2].

Ctapipe event reconstruction

Correction of the **angle of the ellipse** measured in the camera:

Camera plane of each telescope **not oriented** as the common reconstruction plane. **Project** camera points **in the sky.**

Re-calculate tilt angle of the ellipse in the camera of the parallel telescope.

Re-project camera points in the sky to a camera frame of a **parallel-pointing** telescope.

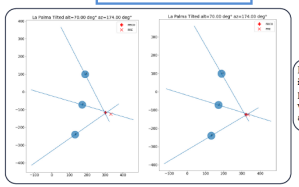


Fig. 2: **Reconstruction** of the **impact point** in a common plane (*TiltedGroundFrame*), which is perpendicular to the array pointing direction.

Monte Carlo simulations

We simulated 10^8 point source gamma-rays coming form South and originated from an azimuth of 180° and at an altitude of 70° above the horizon, in the energy range 3.0 GeV - 330 TeV.

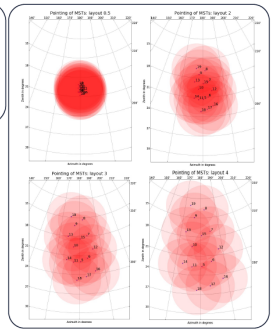


Fig. 1: **Fields of view of the tested configurations.** We tested a subarray of 15 MSTs taking the parameters from the CTA prod3 production for the CTA North site.

Results

A more divergent configuration gives a worse angular resolution with respect to a less divergent one, especially at high energies and with low multiplicity. **Higher multiplicity** gives a **better angular resolution** over the whole energy range, at the expense of a lower number of events.

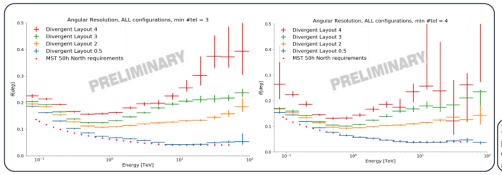
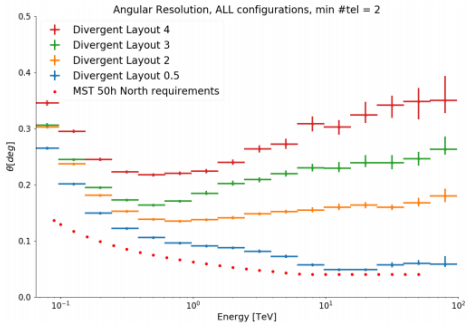
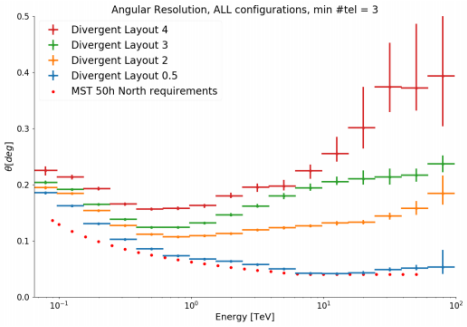


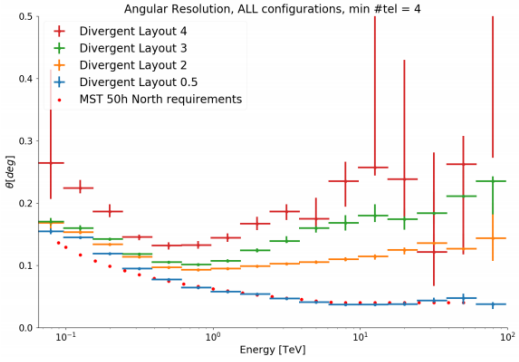
Fig. 3: **Angular resolution** for the point gamma analysed plotted against the true energy. No gamma-hadron separation cuts are applied.



(a) Minimum multiplicity equal to 2.



(b) Minimum multiplicity equal to 3.



(c) Minimum multiplicity equal to 4.

The Cherenkov Telescope Array Performance in Divergent Mode, arxiv:1907.07978

Were were we?(Bologna meeting)

- Divergent Pointing Action 1:
  - Generate MC data in divergent mode
    - First data sample available on GRID
    - Massive production to be discussed
    - First Test Layout (La Palma, Divergent MST, parallel LSTs, z20, South Pointing)
      - 1000 files of gamma and protons
    - New Production ready
- Divergent Pointing Action 2:
  - Provide documentation on redmine on existing analysis methods on divergent pointing reconstruction
    - Redmine page
    - ICRC proceedings
- Divergent Pointing Action 3:
  - Provide first analysis of divergent pointing events
    - ctapipe development
    - Divergent mode reconstruction implemented in ctapipe
    - Initial activites with protopipe
- Divergent Pointing Action 4:
  - Keep updated the requirements for the Divergent Pointing.
    - IRF production with protopipe chain started
    - Discussion with several WGs (EGAL, Transients, DM)
- Divergent Pointing Action 5
  - Develop the ToyMC for Divergent Analysis.
    - Test more complex configurations
    - Important for CTAO operations
    - Check a new paper …

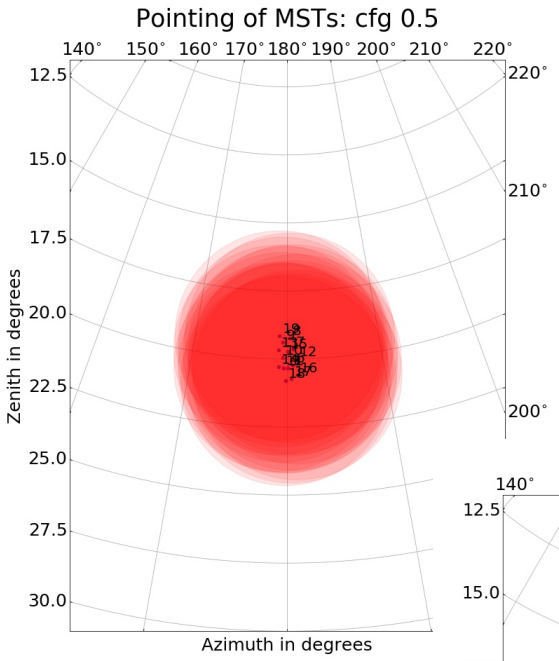
Where are we now? - Simulations

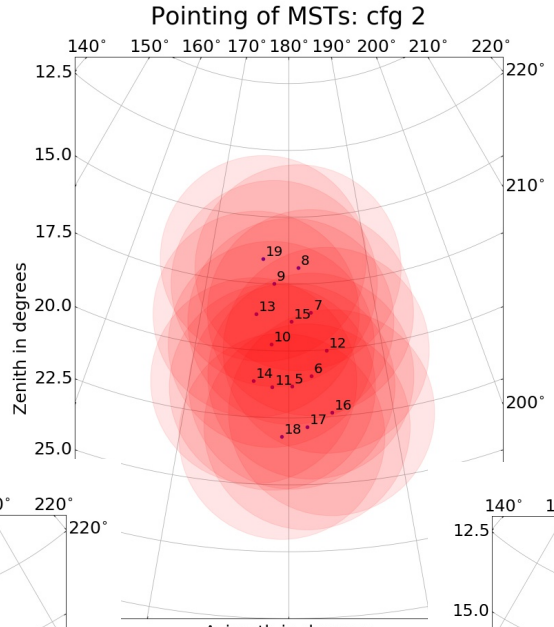
- New productions available for gamma,protons and electron, 4 different configuration:
  - http://vo.cta.in2p3.fr/MC/PROD3/LaPalma/gamma/simtel/1975/Data/000xxx/
  - http://vo.cta.in2p3.fr/MC/PROD3/LaPalma/gamma/simtel/1976/Data/000xxx/
  - http://vo.cta.in2p3.fr/MC/PROD3/LaPalma/gamma/simtel/1976/Data/000xxx/
  - http://vo.cta.in2p3.fr/MC/PROD3/LaPalma/gamma/simtel/1978/Data/000xxx/

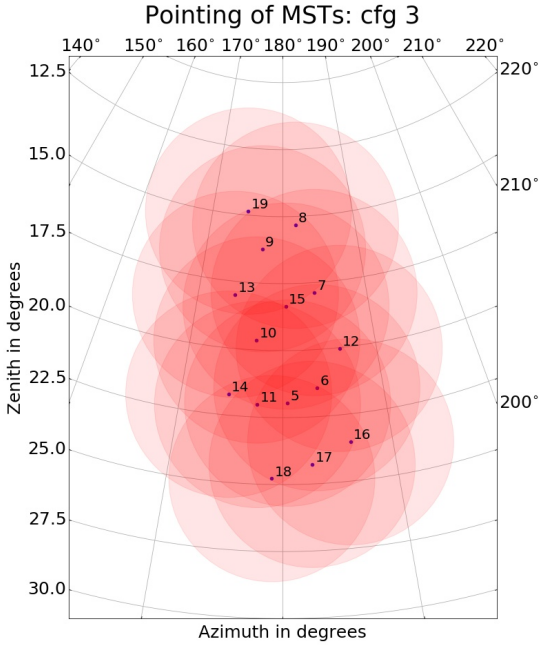
- Divergent mode reconstruction officially implemented in ctapipe

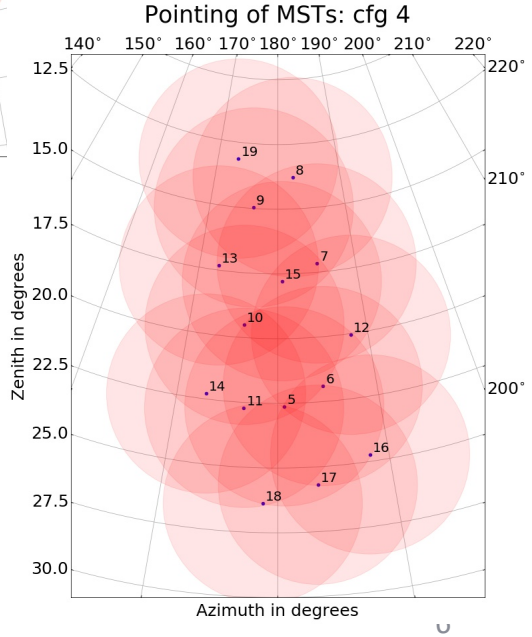
```
def __init__(self, config=None, parent=None, **kwargs):
    super().__init__(config=config, parent=parent, **kwargs)
    self.hillas_planes = {}
    self.divergent_mode = False
    self.corrected_angle_dict = {}

def predict(self, hillas_dict, inst,  array_pointing, telescopes_pointings=None):
    """
```

Pointing configurations



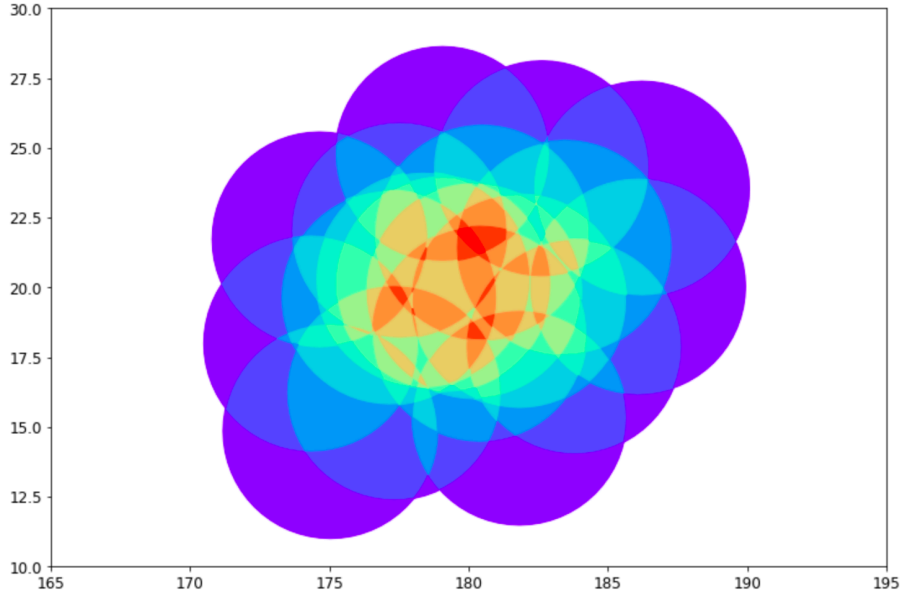


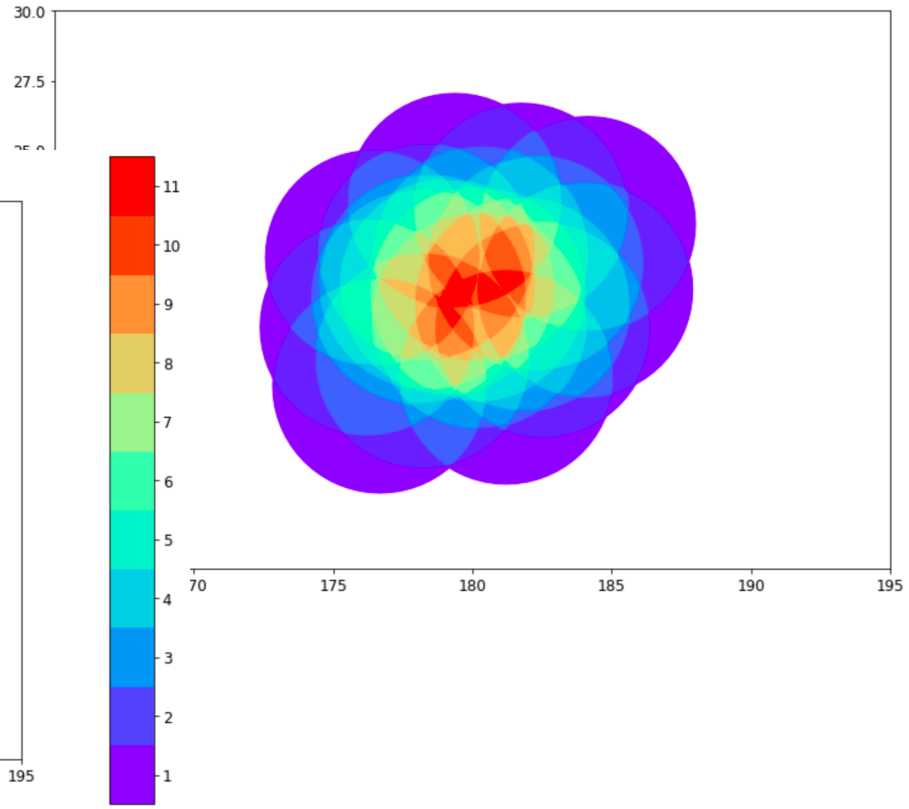




Pointing map tool

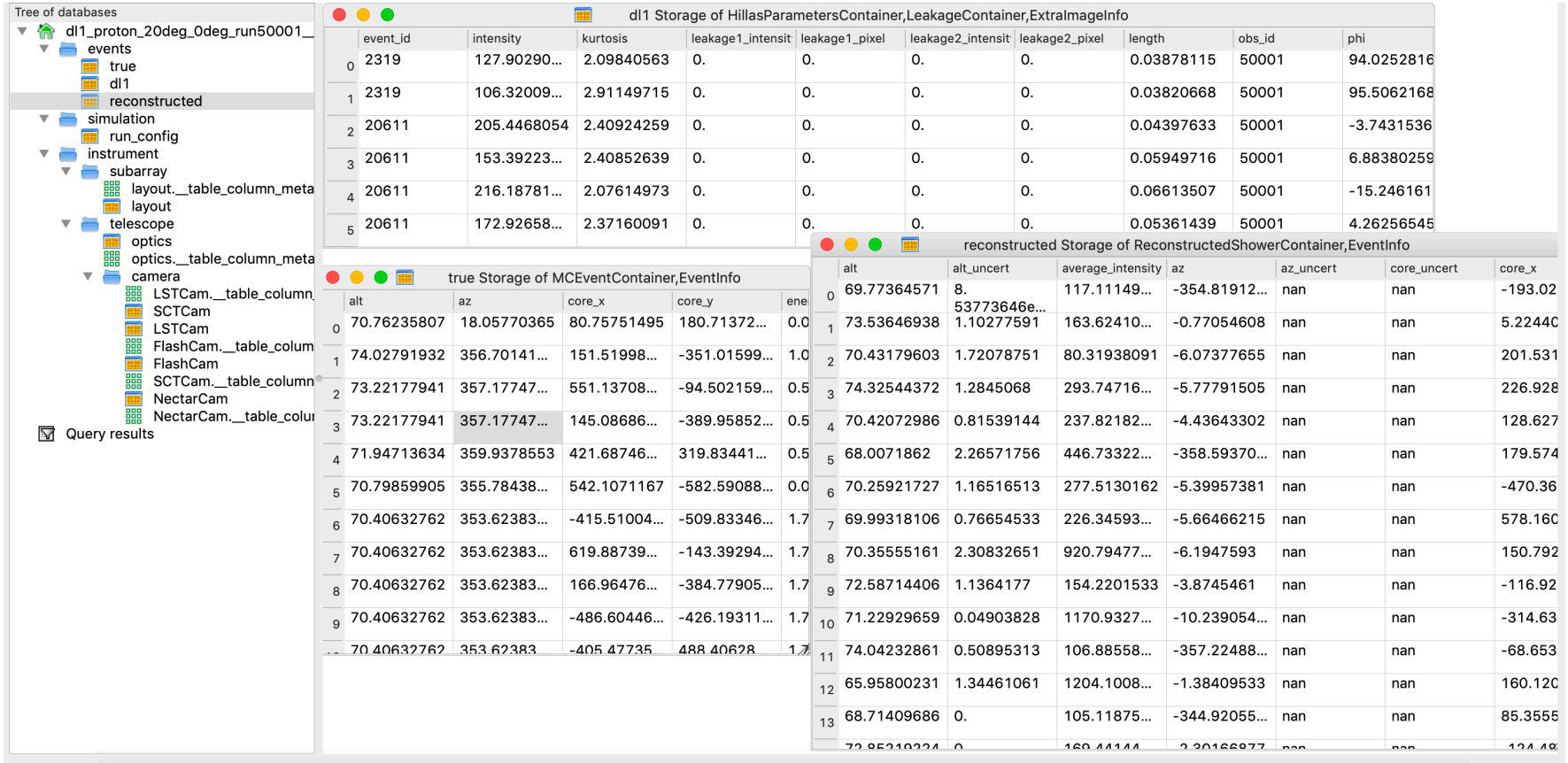
- Development of a pointing map tool started
- Based on telescope multiplicity





DL1 files

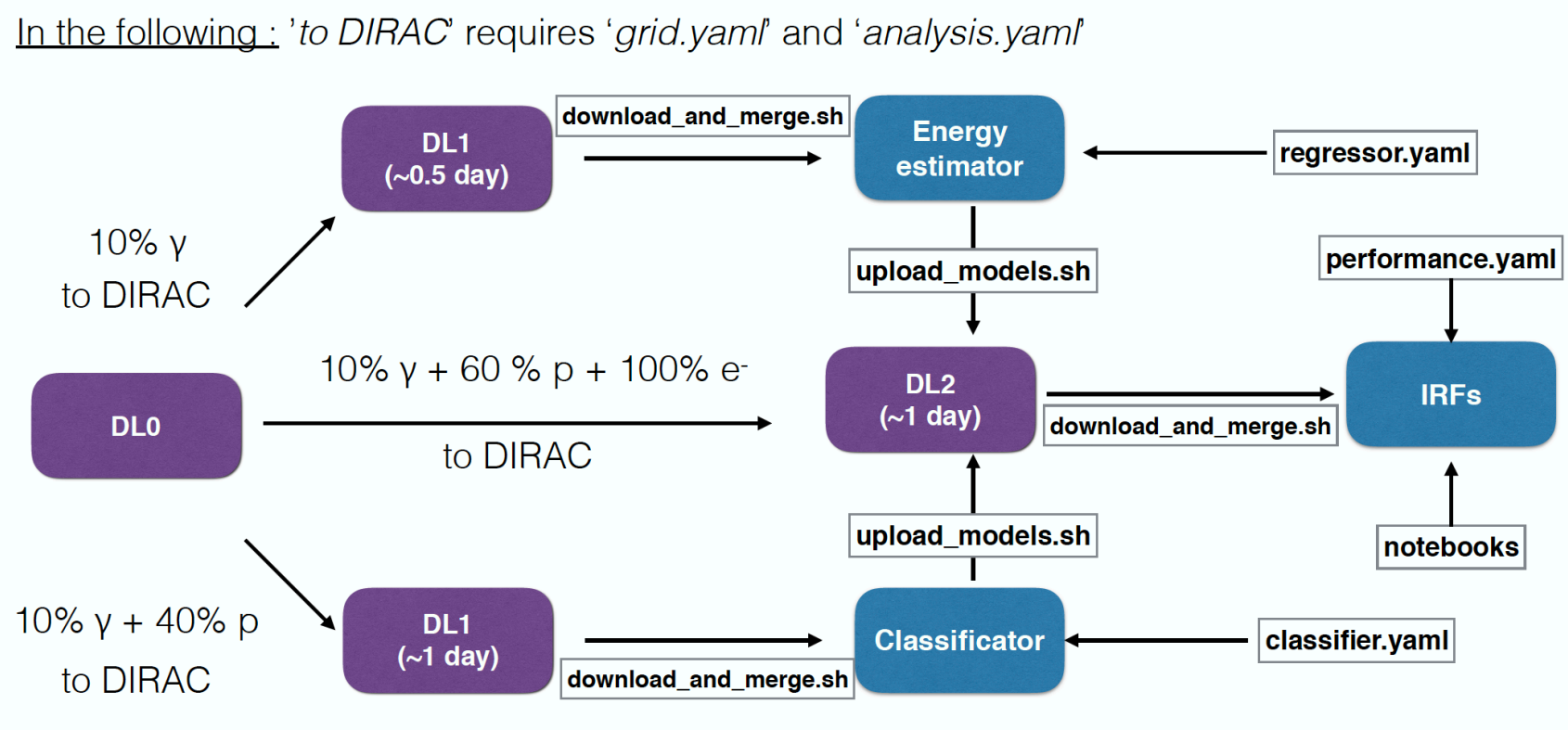
- Scripts to create DL1 files using ctapipe methods



Protopipe

- New pipeline prototype for CTA based on ctapipe library
- Installed and tested successfully at CNAF
- The pipeline provides scripts to:
  - Process simtelarray files and write DL1 or DL2 tables
  - Build regression or classification models with diagnostic plots
  - Estimate the best cutoffs which gives the minimal sensitivy reachable in a given amount of time
  - Produce instrument response functions (IRF), including sensitivity

Protopipe - Analysis



M. Peresano talk in Lugano: https://indico.cta-observatory.org/event/1995/

Data level

- **R0 (raw low-level)**: merged raw data
- **R1 (raw common)**: calibrated data

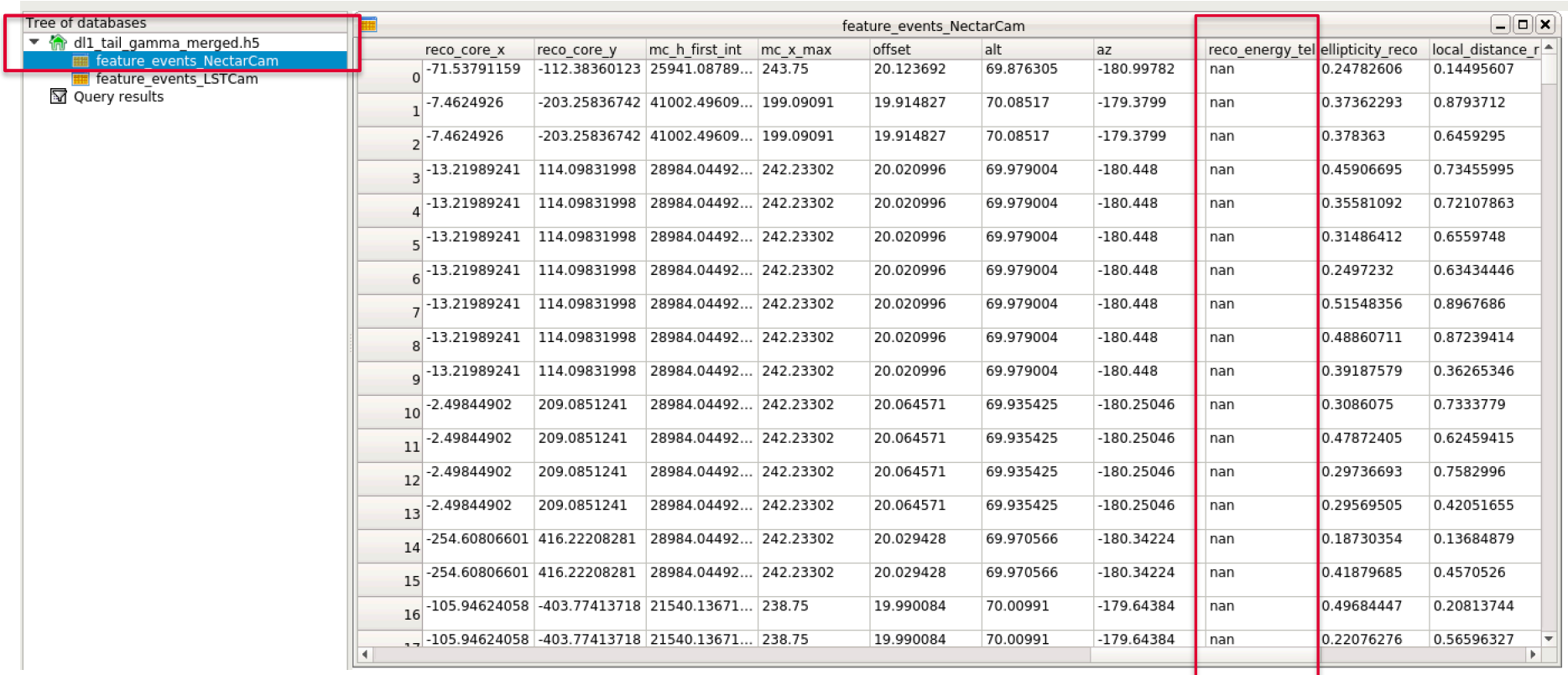
Camera precalibration

- **DL0 (raw archived)**: data volume reduced data
- **DL1 (processed)**: final calibrated image

Waveform cleaning and charge extraction

- **DL2 (reconstructed)**: reconstructed shower information
- **DL3 (IRFs)**

Protopipe – DL1 files



feature_events_NectarCam

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1	-7.4624926	-203.25836742	41002.49609...	199.09091	19.914827	70.08517	-179.3799	nan	0.37362293	0.8793712
2	-7.4624926	-203.25836742	41002.49609...	199.09091	19.914827	70.08517	-179.3799	nan	0.378363	0.6459295
3	-13.21989241	114.09831998	28984.04492...	242.23302	20.020996	69.979004	-180.448	nan	0.45906695	0.73455995
4	-13.21989241	114.09831998	28984.04492...	242.23302	20.020996	69.979004	-180.448	nan	0.35581092	0.72107863
5	-13.21989241	114.09831998	28984.04492...	242.23302	20.020996	69.979004	-180.448	nan	0.31486412	0.6559748
6	-13.21989241	114.09831998	28984.04492...	242.23302	20.020996	69.979004	-180.448	nan	0.2497232	0.63434446
7	-13.21989241	114.09831998	28984.04492...	242.23302	20.020996	69.979004	-180.448	nan	0.51548356	0.8967686
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10	-2.49844902	209.0851241	28984.04492...	242.23302	20.064571	69.935425	-180.25046	nan	0.3086075	0.7333779
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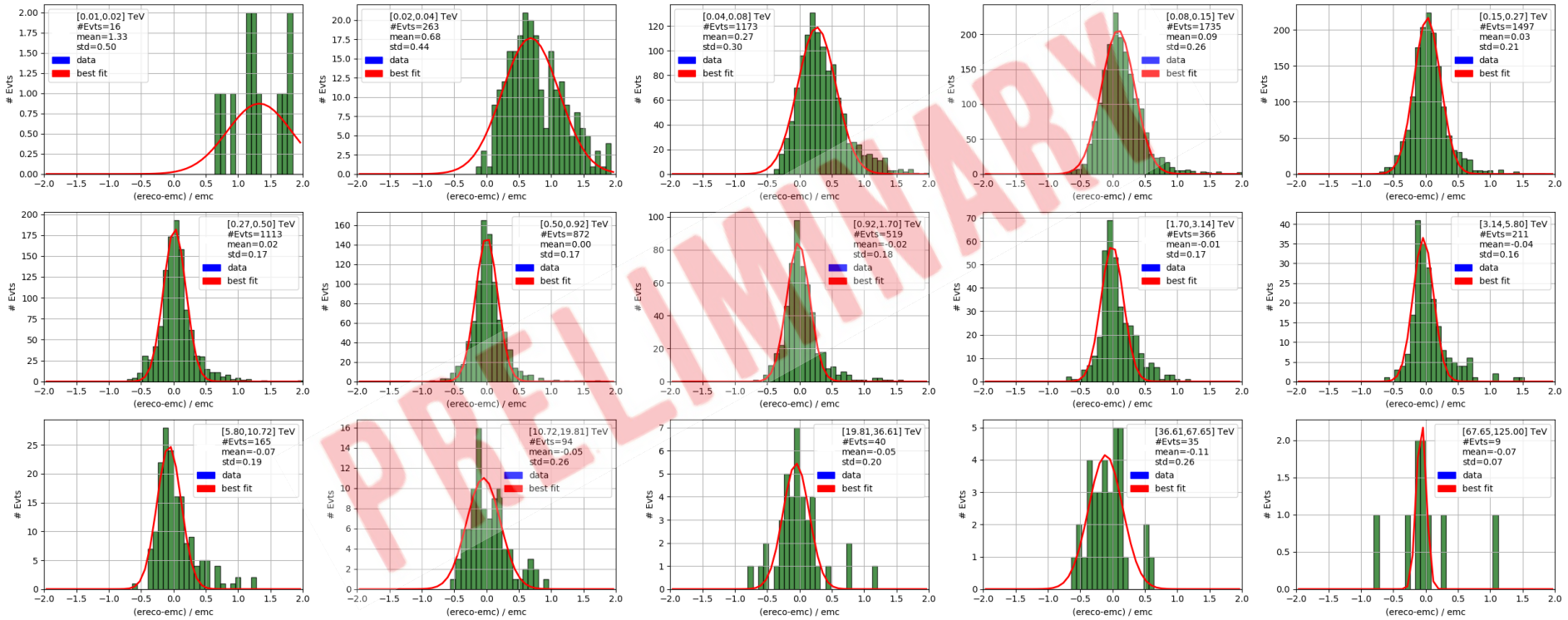
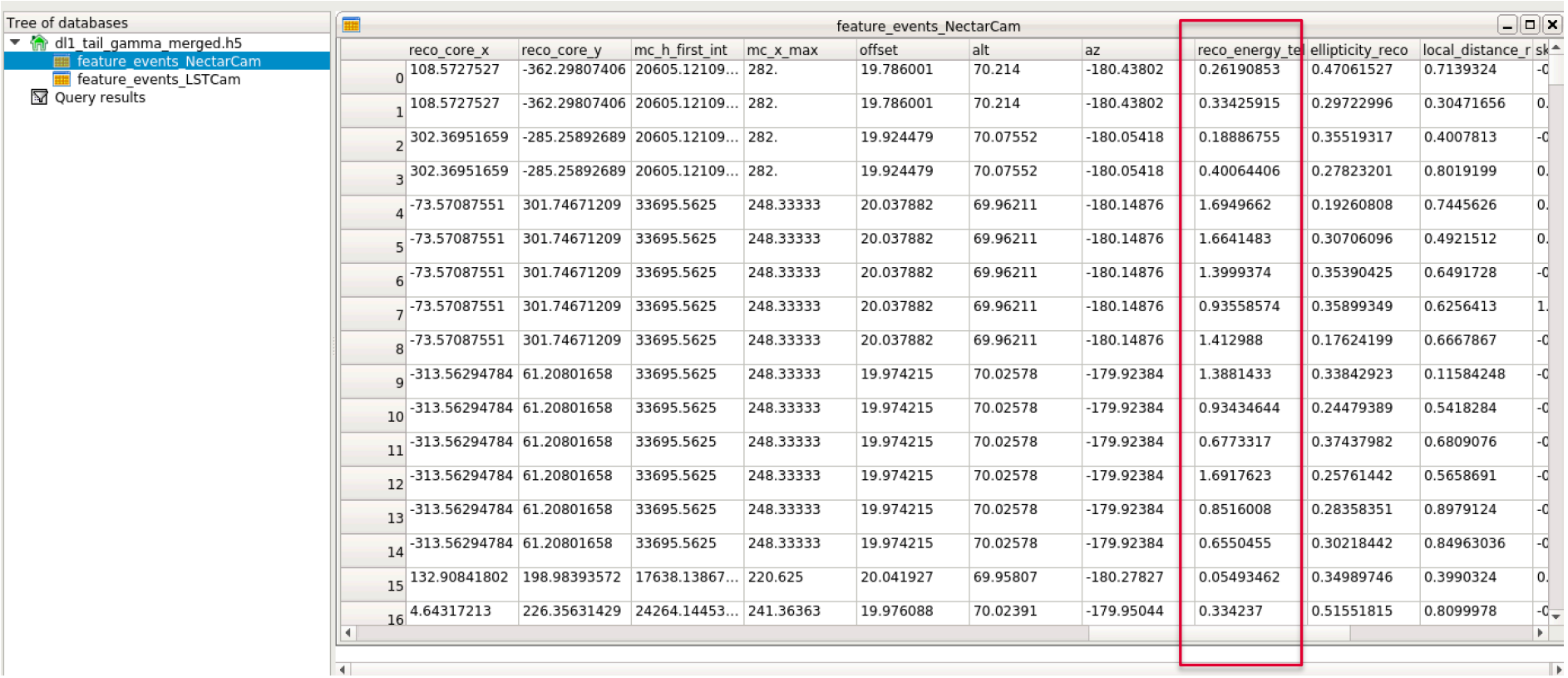
14	-254.60806601	416.22208281	28984.04492...	242.23302	20.029428	69.970566	-180.34224	nan	0.18730354	0.13684879
15	-254.60806601	416.22208281	28984.04492...	242.23302	20.029428	69.970566	-180.34224	nan	0.41879685	0.4570526
16	-105.94624058	-403.77413718	21540.13671...	238.75	19.990084	70.00991	-179.64384	nan	0.49684447	0.20813744
	-105.94624058	-403.77413718	21540.13671...	238.75	19.990084	70.00991	-179.64384	nan	0.22076276	0.56596327

Protopipe – Energy model



PRELIMINARY

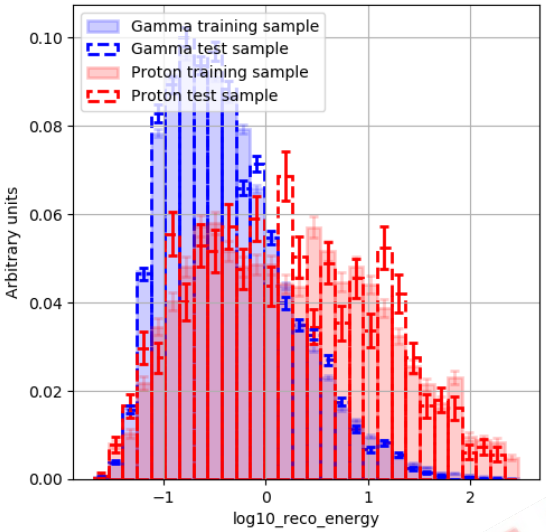
Protopipe – DL1 files

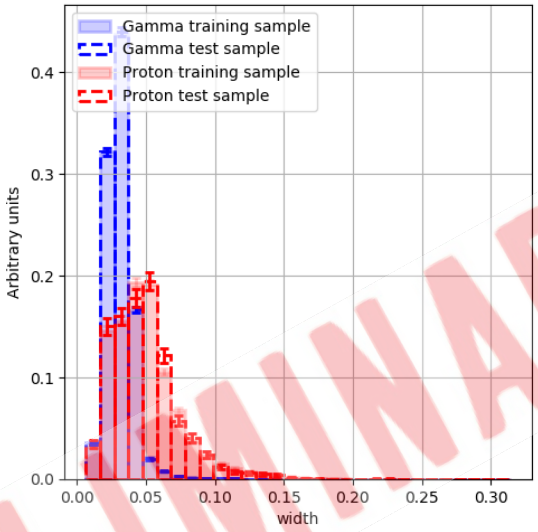


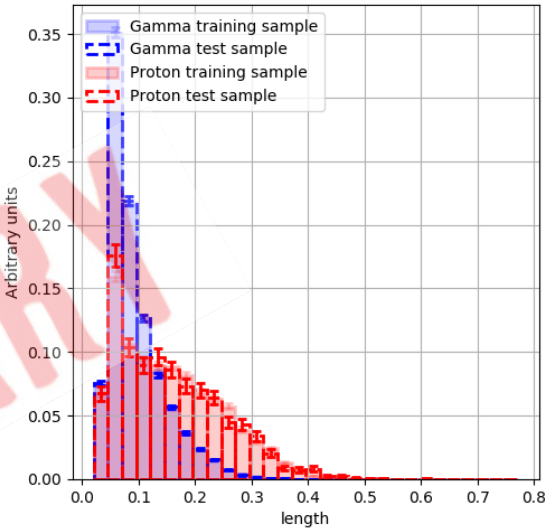
feature_events_NectarCam

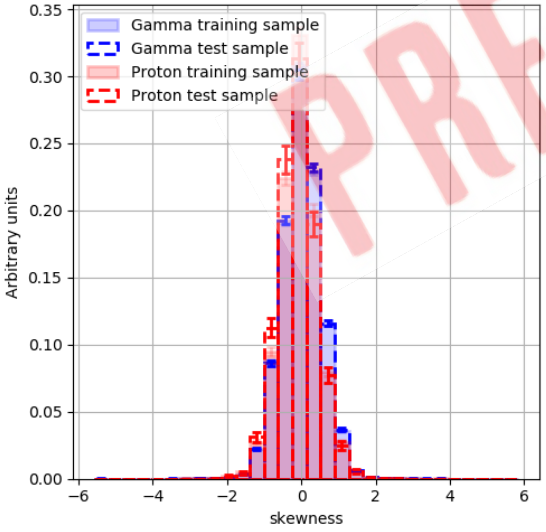
	reco_core_x	reco_core_y	mc_h_first_int	mc_x_max	offset	alt	az	reco_energy_tel	ellipticity_reco	local_distance_r	sk
0	108.5727527	-362.29807406	20605.12109...	282.	19.786001	70.214	-180.43802	0.26190853	0.47061527	0.7139324	-0
1	108.5727527	-362.29807406	20605.12109...	282.	19.786001	70.214	-180.43802	0.33425915	0.29722996	0.30471656	0.
2	302.36951659	-285.25892689	20605.12109...	282.	19.924479	70.07552	-180.05418	0.18886755	0.35519317	0.4007813	-0
3	302.36951659	-285.25892689	20605.12109...	282.	19.924479	70.07552	-180.05418	0.40064406	0.27823201	0.8019199	0.
4	-73.57087551	301.74671209	33695.5625	248.33333	20.037882	69.96211	-180.14876	1.6949662	0.19260808	0.7445626	0.
5	-73.57087551	301.74671209	33695.5625	248.33333	20.037882	69.96211	-180.14876	1.6641483	0.30706096	0.4921512	0.
6	-73.57087551	301.74671209	33695.5625	248.33333	20.037882	69.96211	-180.14876	1.3999374	0.35390425	0.6491728	-0
7	-73.57087551	301.74671209	33695.5625	248.33333	20.037882	69.96211	-180.14876	0.93558574	0.35899349	0.6256413	1.
8	-73.57087551	301.74671209	33695.5625	248.33333	20.037882	69.96211	-180.14876	1.412988	0.17624199	0.6667867	-0
9	-313.56294784	61.20801658	33695.5625	248.33333	19.974215	70.02578	-179.92384	1.3881433	0.33842923	0.11584248	-0
10	-313.56294784	61.20801658	33695.5625	248.33333	19.974215	70.02578	-179.92384	0.93434644	0.24479389	0.5418284	-0
11	-313.56294784	61.20801658	33695.5625	248.33333	19.974215	70.02578	-179.92384	0.6773317	0.37437982	0.6809076	-0
12	-313.56294784	61.20801658	33695.5625	248.33333	19.974215	70.02578	-179.92384	1.6917623	0.25761442	0.5658691	-0
13	-313.56294784	61.20801658	33695.5625	248.33333	19.974215	70.02578	-179.92384	0.8516008	0.28358351	0.8979124	-0
14	-313.56294784	61.20801658	33695.5625	248.33333	19.974215	70.02578	-179.92384	0.6550455	0.30218442	0.84963036	-0
15	132.90841802	198.98393572	17638.13867...	220.625	20.041927	69.95807	-180.27827	0.05493462	0.34989746	0.3990324	0.
16	4.64317213	226.35631429	24264.14453...	241.36363	19.976088	70.02391	-179.95044	0.334237	0.51551815	0.8099978	-0

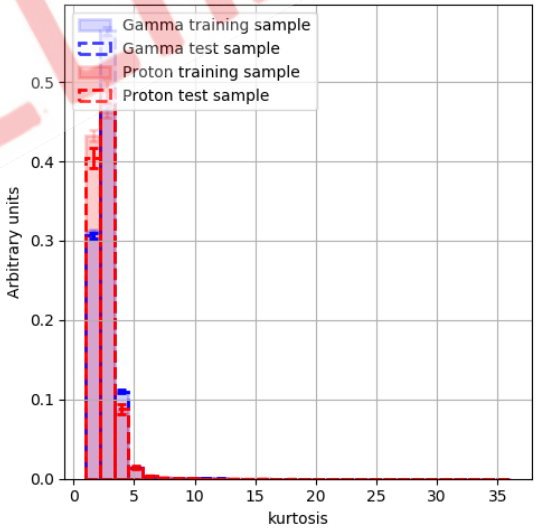
Protopipe – Gamma/hadron separation

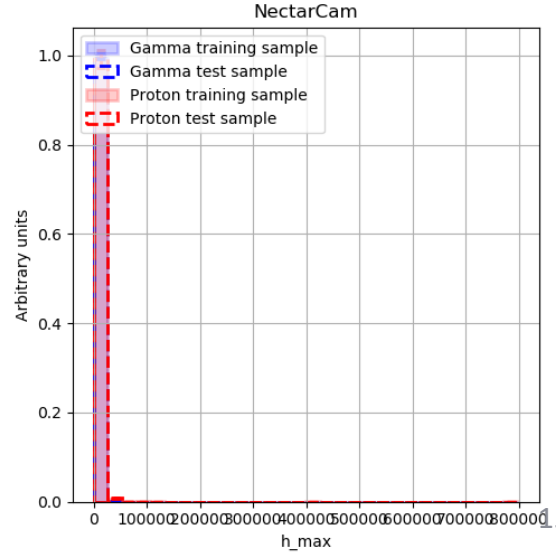








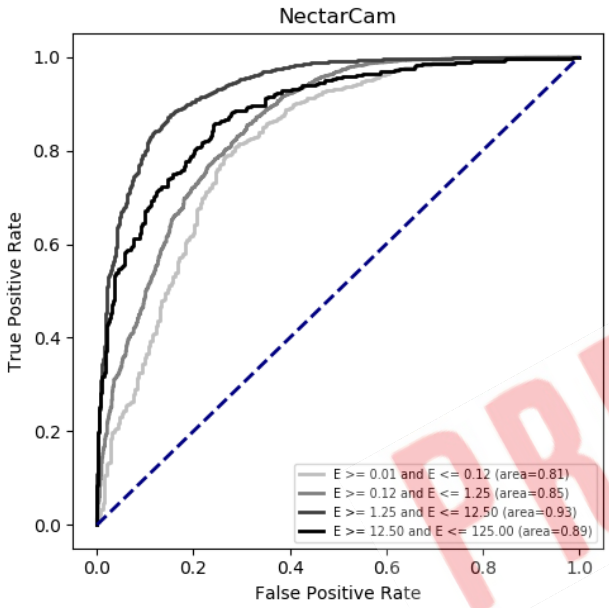


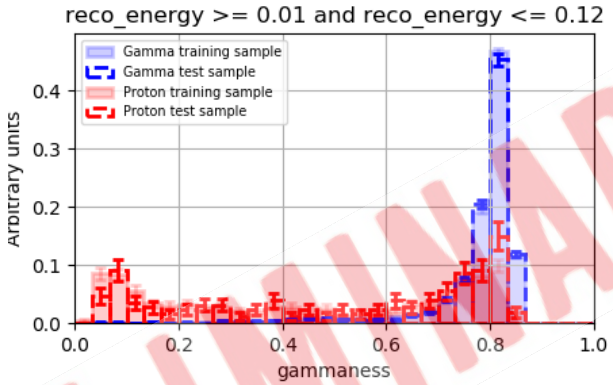


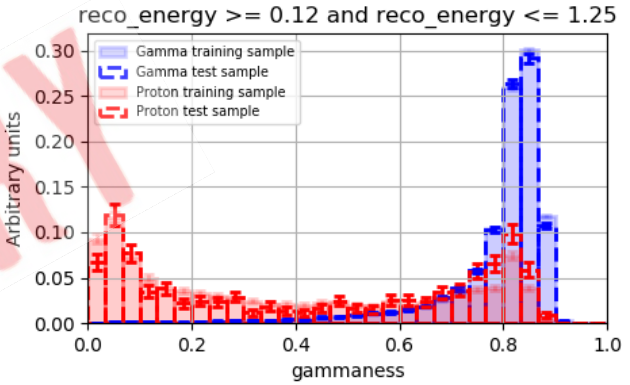
PRELIMINARY

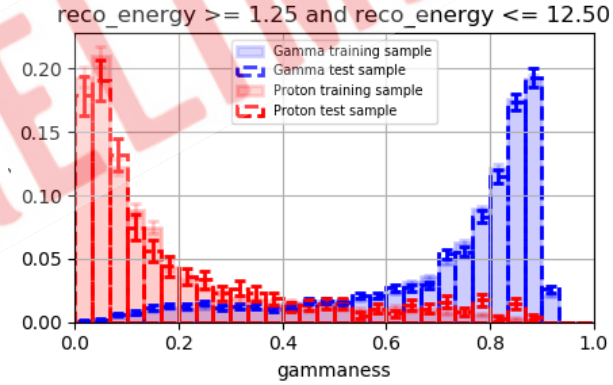
Protopipe – Gamma/hadron separation

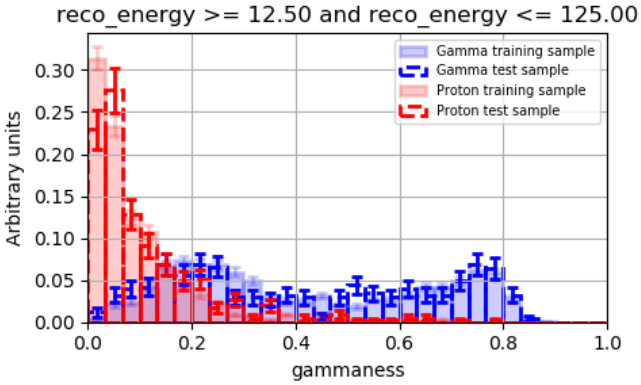
ROC Curve





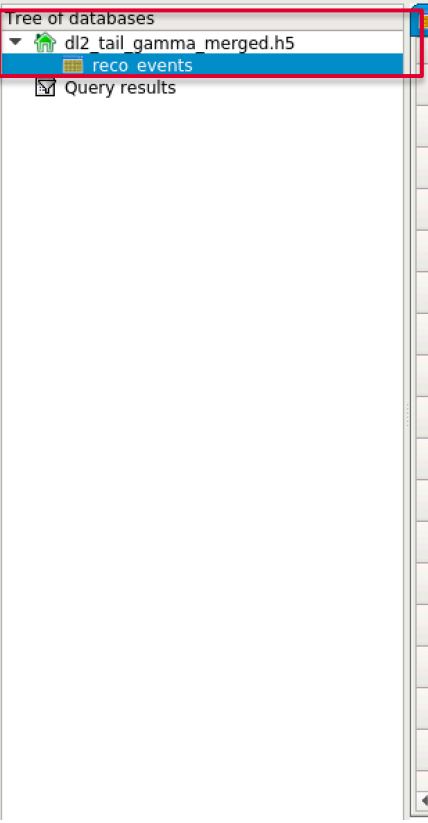






PRELIMINARY

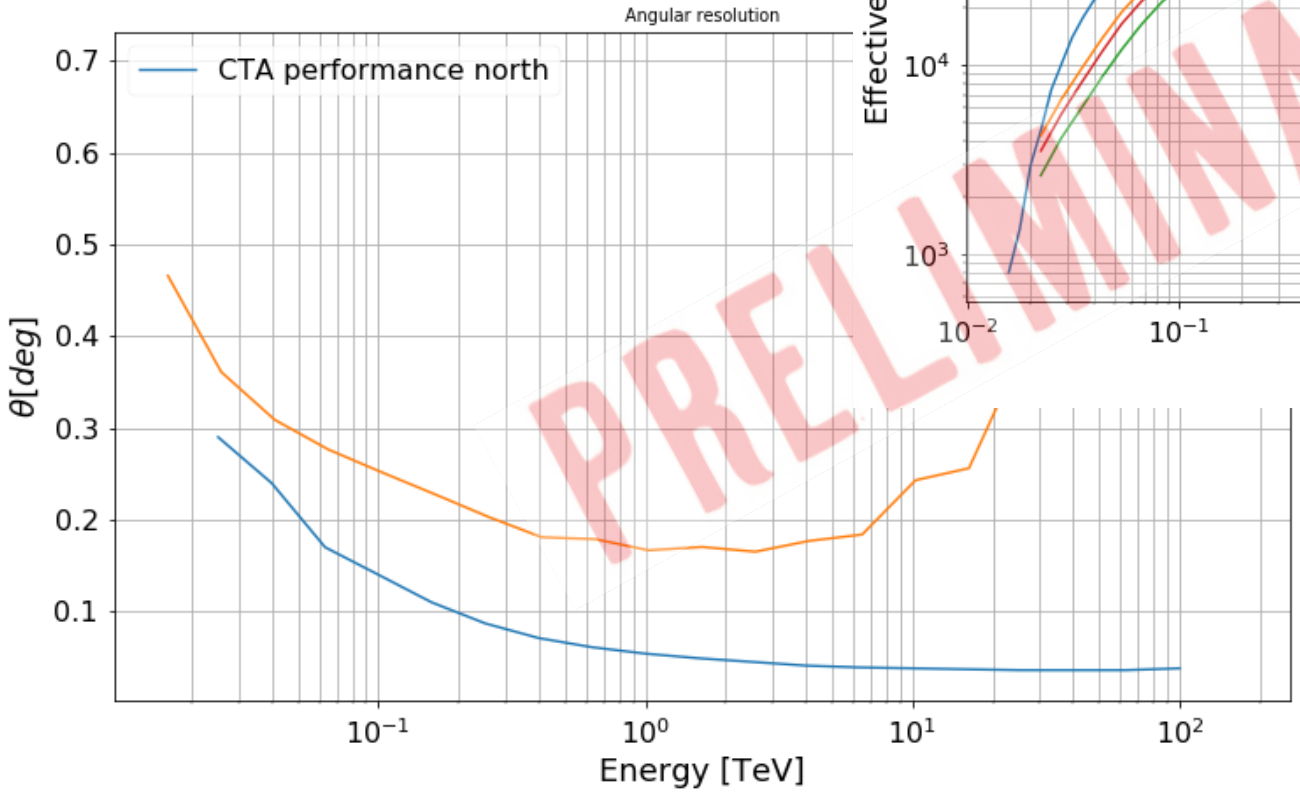
Protopipe - DL2 files

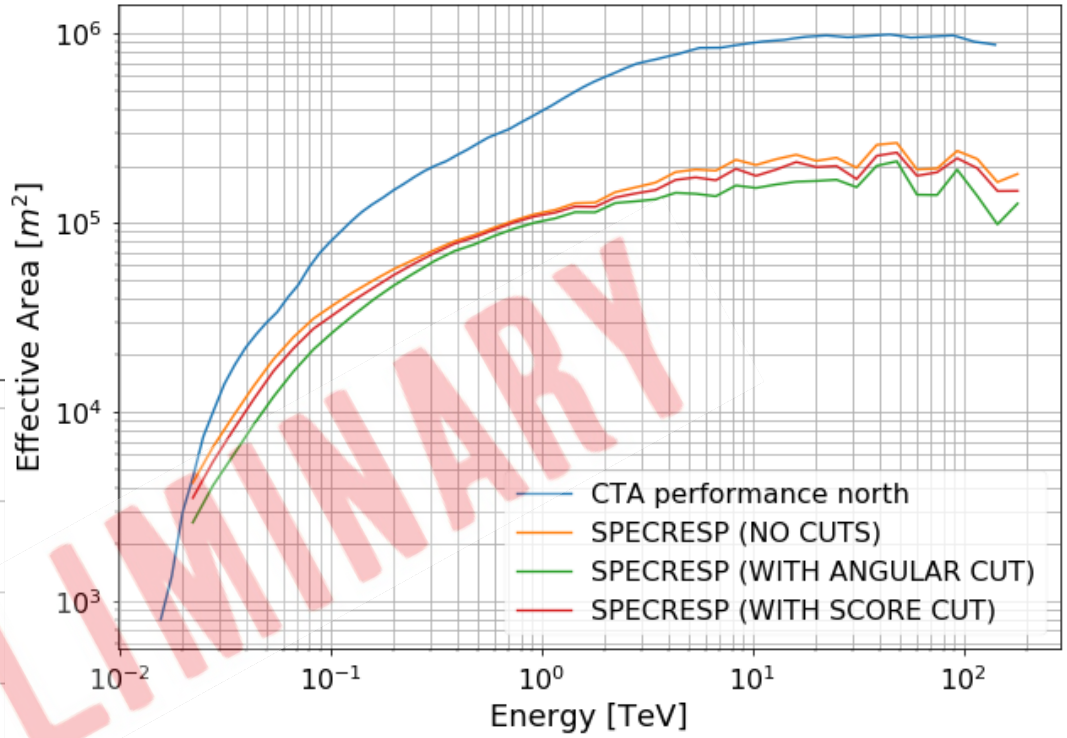


reco_events

	obs_id	event_id	NTels_trig	NTels_reco	NTels_reco_lst	NTels_reco_mst	NTels_reco_sst	mc_energy	reco_energy	reco_alt
0	2	3301	4	3	1	2	0	0.11306483	0.09901197	69.8187
1	2	14204	5	4	2	2	0	0.09049278	0.10220671	69.99206
2	2	25006	9	5	2	3	0	0.18832242	0.19523066	70.02958
3	2	25007	8	7	4	3	0	0.18832242	0.21187113	70.055336
4	2	25401	3	2	0	2	0	0.20942356	0.23906799	69.67418
5	2	27109	5	3	0	3	0	0.11683443	0.11994074	69.9287
6	2	29908	2	2	0	2	0	0.12634292	0.10671375	70.00219
7	2	30406	9	5	3	2	0	0.15606718	0.15290608	70.00522
8	2	30608	5	5	4	1	0	0.0355488	0.03903736	69.90162
9	2	30904	4	2	2	0	0	0.05010928	0.07498839	70.06539
10	2	35402	4	2	2	0	0	0.01831837	0.0159413	70.68967
11	2	40703	4	2	2	0	0	0.0317192	0.04321555	69.94814
12	2	42703	6	3	0	3	0	1.3144745	1.4499964	69.79742
13	2	42704	11	5	3	2	0	1.3144745	1.5562333	69.995094
14	2	43402	5	2	1	1	0	0.10142623	0.10566033	69.967094
15	2	44004	8	3	2	1	0	0.07901578	0.15111837	69.89622
16	2	44406	2	2	2	0	0	0.01180071	0.02545218	70.01579
17	2	44502	7	6	4	2	0	0.09912796	0.09770369	70.00026

Performances – cfg2



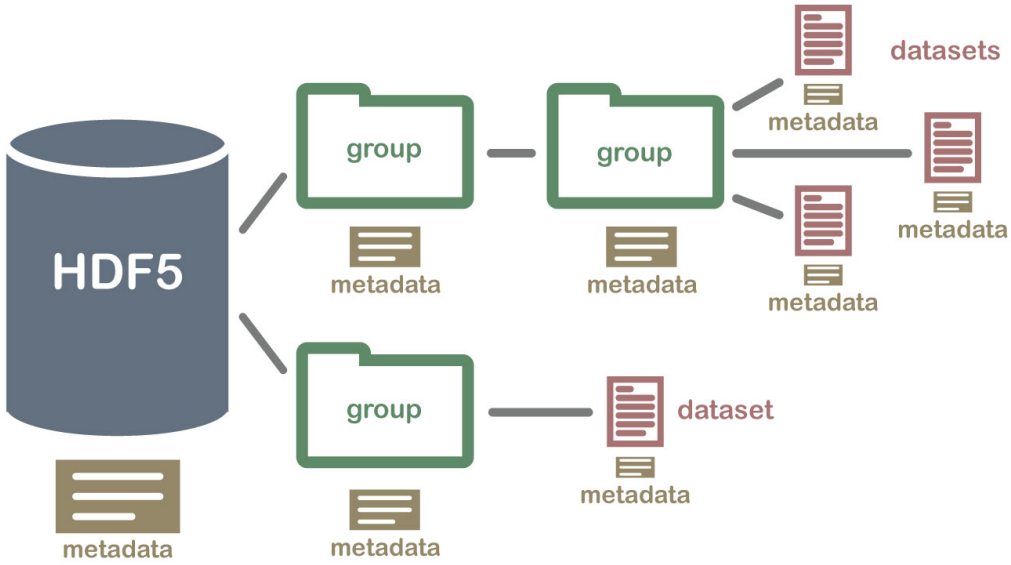


PRELIMINARY

BACKUP SLIDES

HDF5 format

- Open source file format with a "directory" like structure
  - Store a similar set of data organized in the same way you organize files and folders on your computer
    - Directories → groups
    - Folders → datasets



- Allows for embedding of metadata:
  - Self describing
  - Processing the data:
    grab information from the metadata, that are already associated with the dataset