

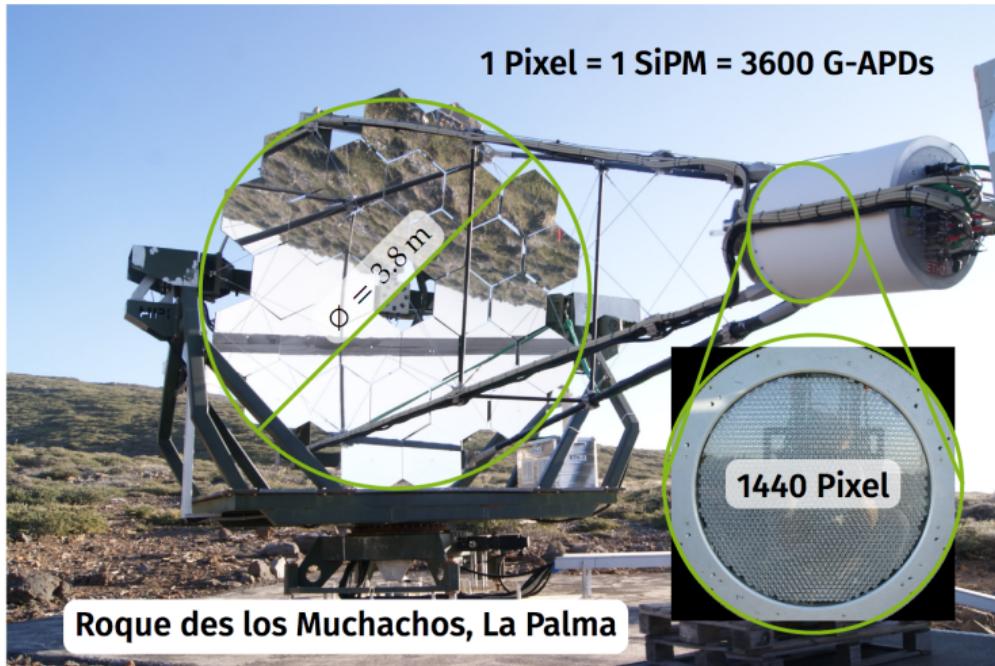
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# Analysis Of The Crab Nebula Using FACT's Photon Stream Data

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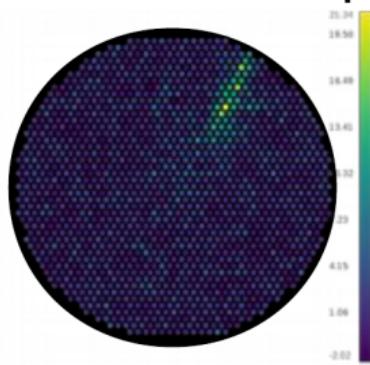
Kevin Sedlaczek, Maximilian Nöthe for the FACT-Collaboration  
DPG-Frühjahrstagung 2018 Würzburg

# The First G-APD Cherenkov Telescope

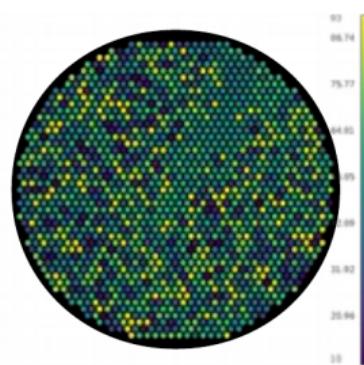


## The Photon Stream Data

### Main-Pulse Event Representation



Photon-equivalents of main pulses  
 $c$  /p.e.



Arrival times of main pulses  
 $t$  /ns



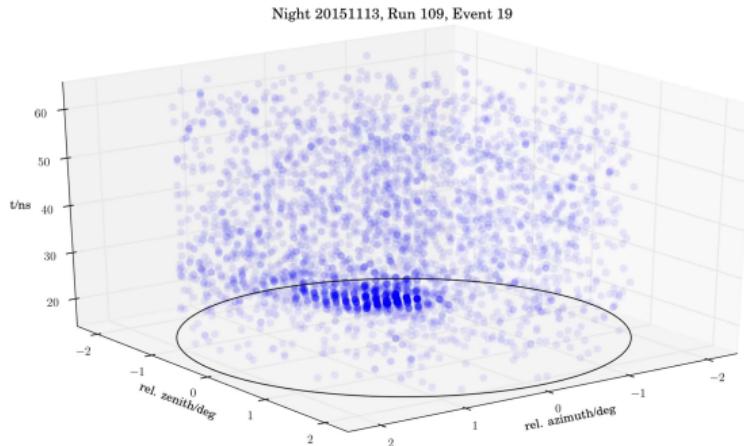
- FACT records data in format close to readout hardware
- superposition of multiple photon signals
- not intended as physics format  
→ **Photon Stream**
- list of individual photons (arrival times)

## The Photon Stream Data

$$\begin{bmatrix} [59, 84] \\ [102, 93, 103] \\ [58] \\ [65, 79, 97] \\ [] \\ [125, 43, 68] \\ [102] \\ [68, 100, 123] \\ \dots \end{bmatrix}$$

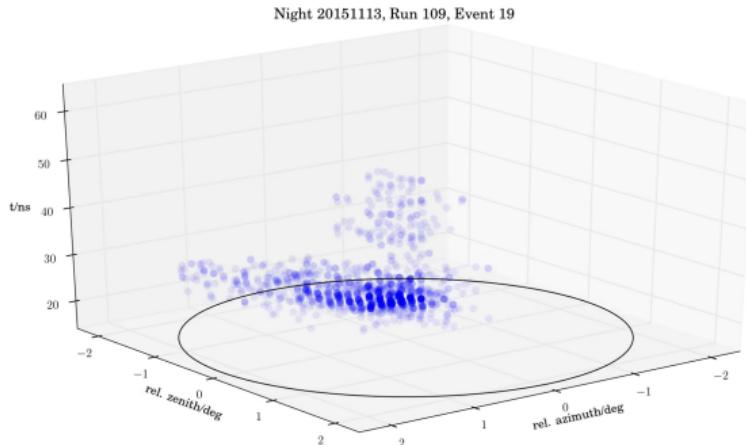
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## The Photon Stream Data



- smaller file size: possible to compress all FACT data to fit on one 10TB drive
- simplify *exchange* and *analysis*, gain timing knowledge
- DBSCAN: cluster based image cleaning
- exptected improvement for cleaning

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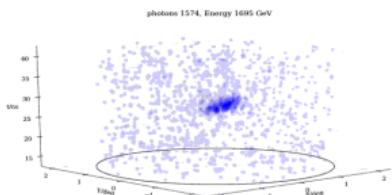


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# The Data set: FACT open data crab sample

## Photon-Stream (phs)

Single photon event representation for Imaging Atmospheric Cherenkov Telescopes (IACTs)



## Public

### Crab Nebula

High quality observations of the Crab Nebula in November 2013. Free to use for everyone. Please cite our [photon-1](#) on [GitHub](#).

### Simulations (sim)

The FACT responses to simulated air-shower observations. This is the diffuse [ceres\\_12\\_rc](#) simulation pass.

## Private

### Observations (obs)

All observed air-shower events of FACT. About 1e9 air-shower records containing about 3e12 single photons. See [2](#)

## About

- [ICRC2017 proceeding](#)
- [photon-stream Python](#)
- [photon-stream C++](#)
- [production tools](#)

FACT collaboration, Sebastian A. Mueller, 2017

- <https://fact-project.org/data>
- Crab Nebula observations from November 2013
- including gamma-ray and proton simulations
- 17.7 hours of observations

## Analysis

**aim** proof of concept: generate preliminary physics results

**Crab Nebula** well measured source of cosmic gamma rays → standard candle analysis

### Photon Stream Analysis chain

**calibration** extracting single photons

**image cleaning** DBSCAN

**parametrization** parameter set A

**separation**

**reconstruction**

### Standard Analysis chain

**calibration** identifying large pulses

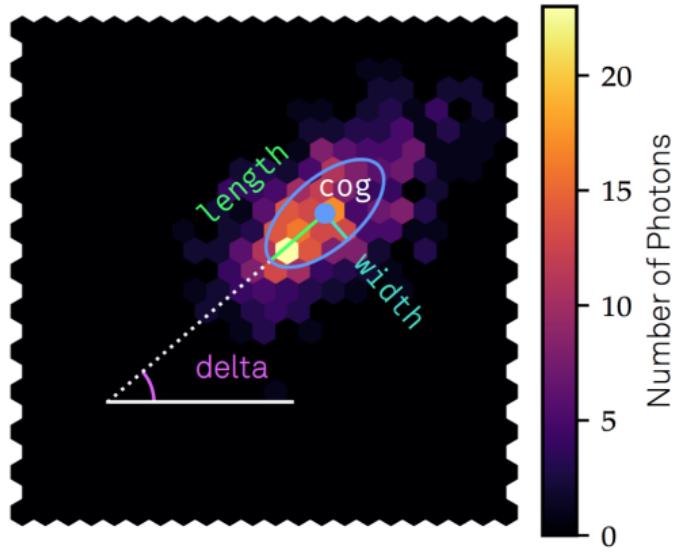
**image cleaning** time and pixel thresholds

**parametrization** parameter set B

**separation**

**reconstruction**

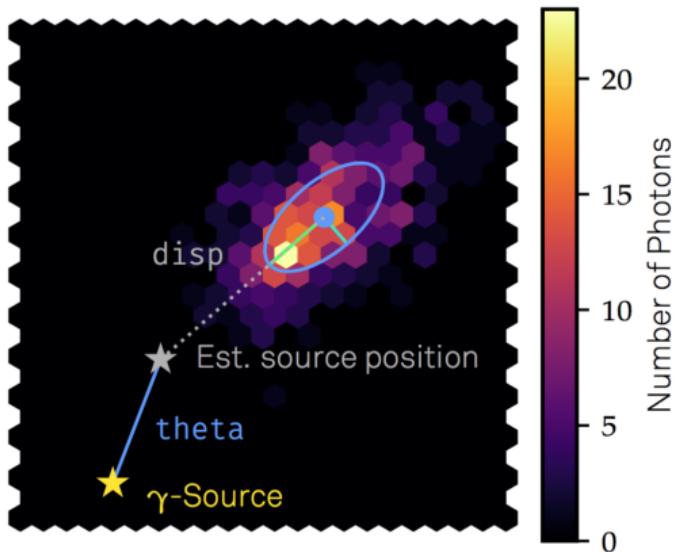
## Parameterization



Hillas parameters (projected back to 2D):

- **size**: number of photons in cluster
- **length**: std. dev. along long half-axis
- **width**: std. dev. along short half-axis
- **delta**: angle between length and disp
- **skewness/ kurtosis**: higher order statistical moments along half-axes in cluster system

## Parameterization



Source position reconstruction via disp-method:

- **|displ|**: distance from centre of gravity to target
- **sgn(displ)**: Head/Tail-Disambiguation
- **theta**: distance between reconstructed and true origin

## Tools

Machine learning with FACT classifier-tools, using 5-fold cross validation

<https://github.com/fact-project/classifier-tools>

### Energy estimation:

- random forest regressor (30 estimators)

### Gamma-hadron-separation:

- random forest classifier (50 estimators)

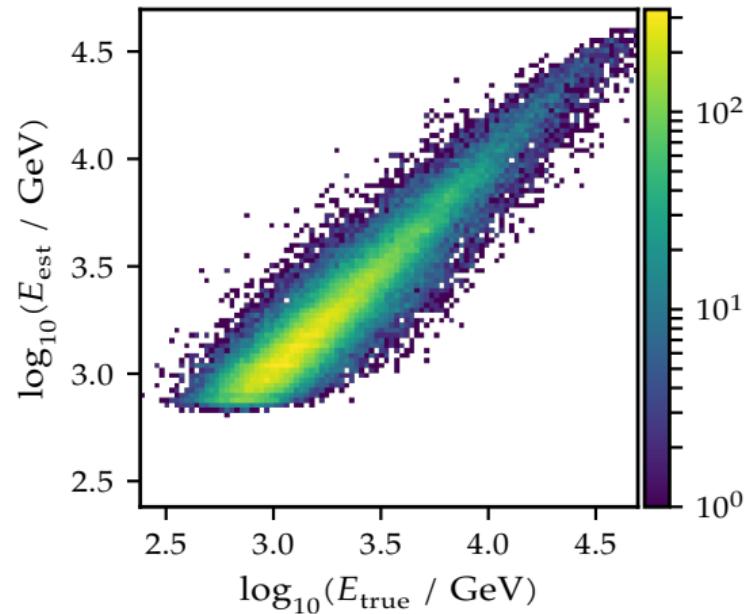
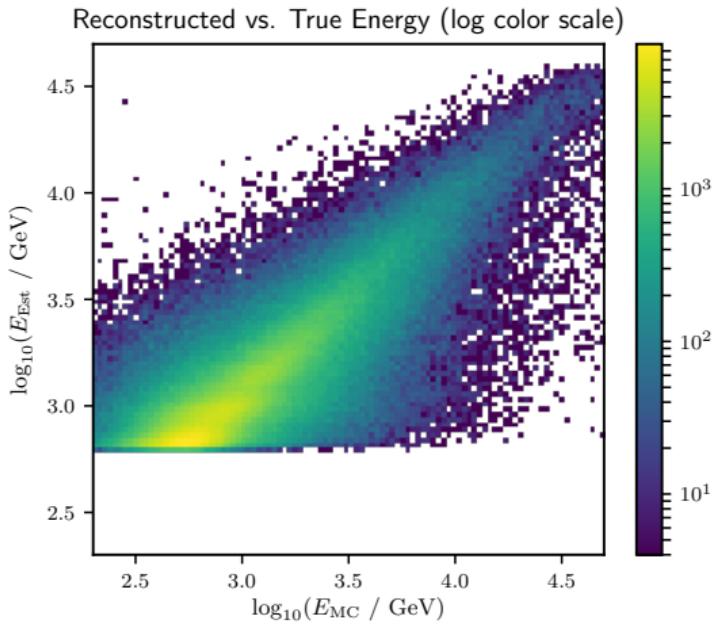
### Origin reconstruction:

- two step task: regression of  $|displ|$  and classification of  $\text{sgn}(\text{disp})$
- random forest regressor and classifier

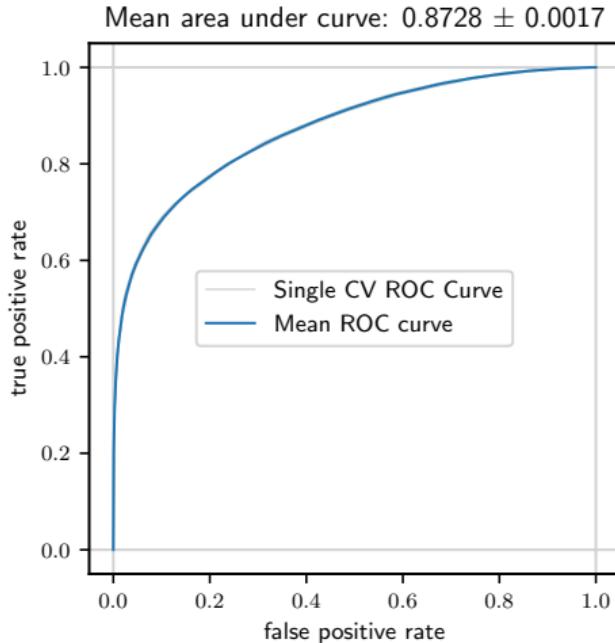
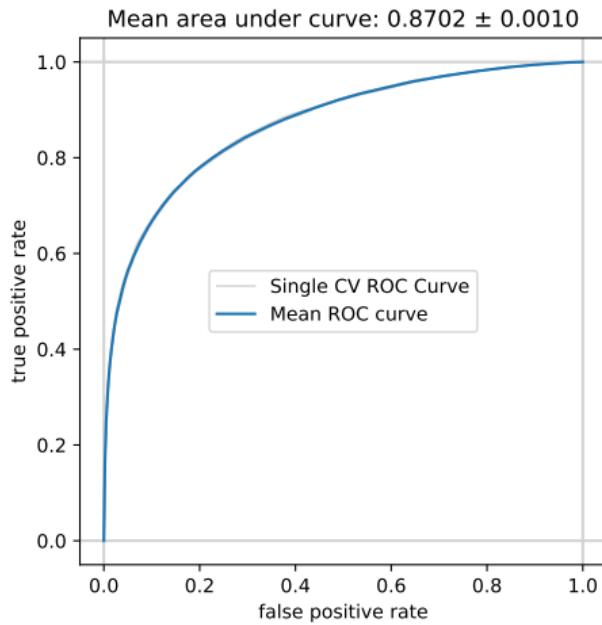
## Open Crab Sample Analysis

[https://github.com/fact-project/open\\_crab\\_sample\\_analysis](https://github.com/fact-project/open_crab_sample_analysis)

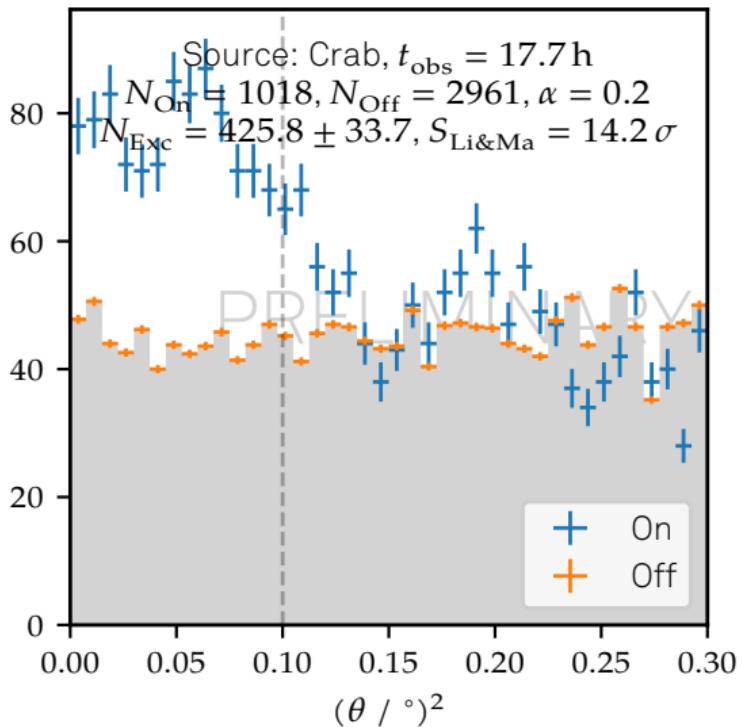
## Energy estimation



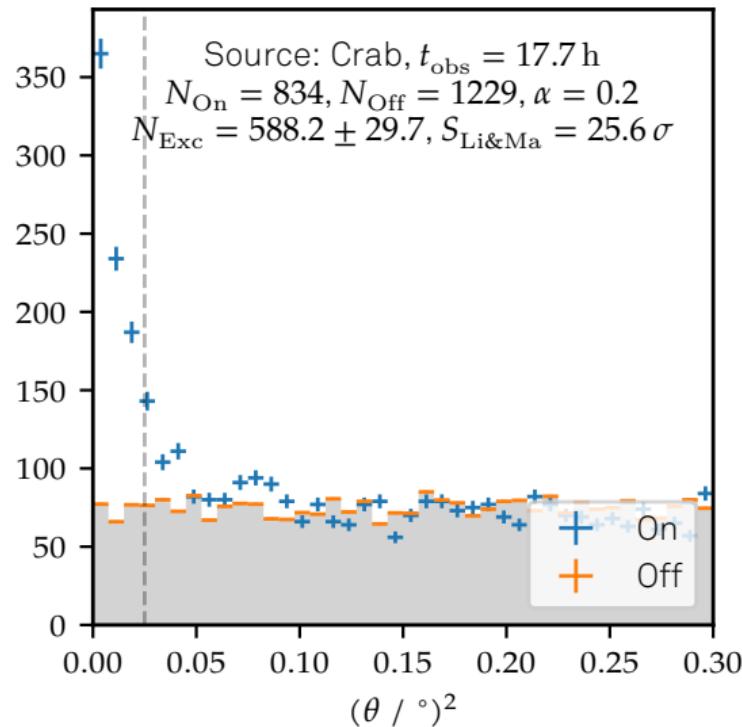
## Separation



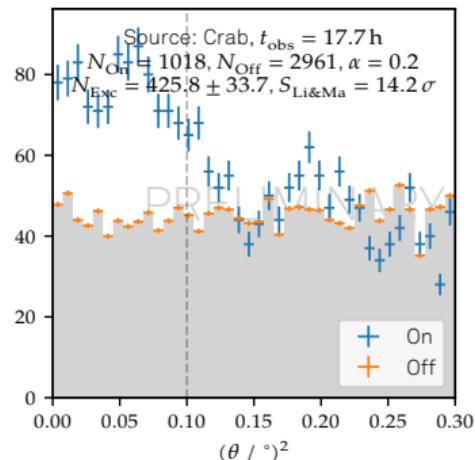
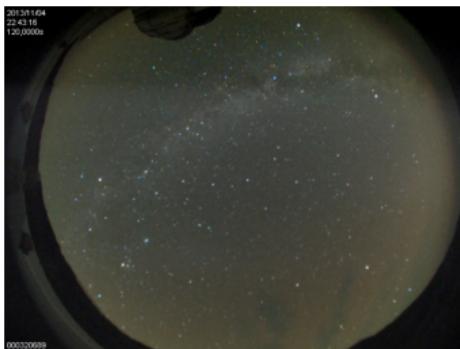
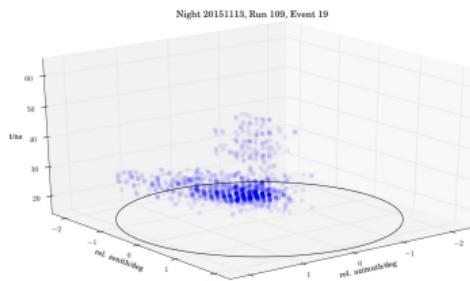
## Origin reconstruction



Results



## Summary

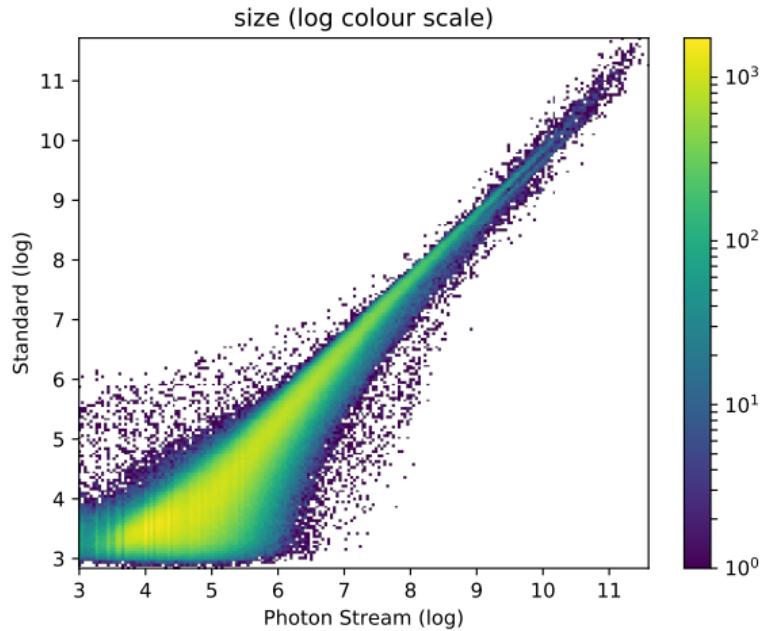


## Outlook

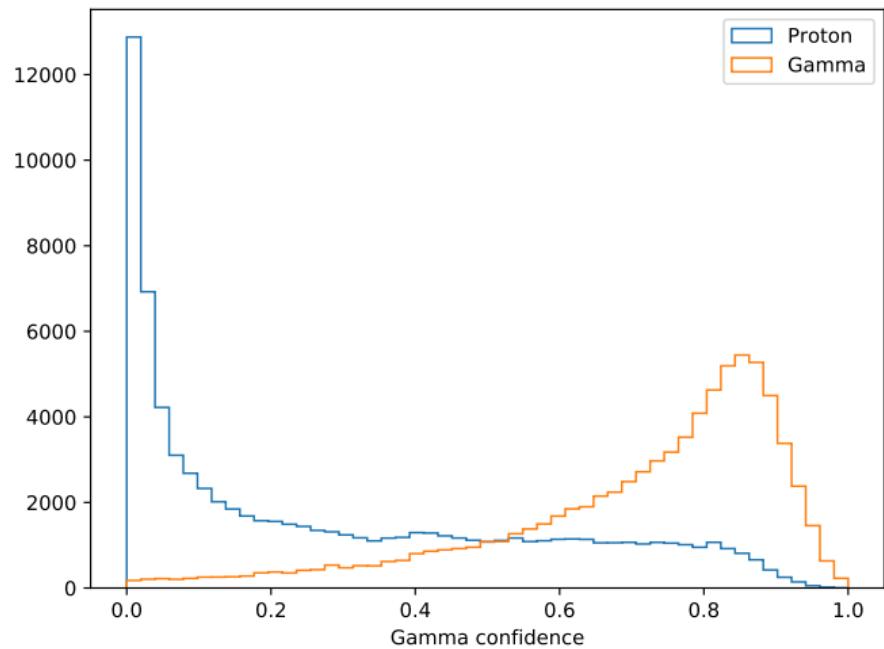
This is just the beginning!

- feature engineering
  - implement more "standard" features
  - timing information (3-dimensional point-cloud)
- improve cuts on data, hyper-parameters of classifier-tools and clustering

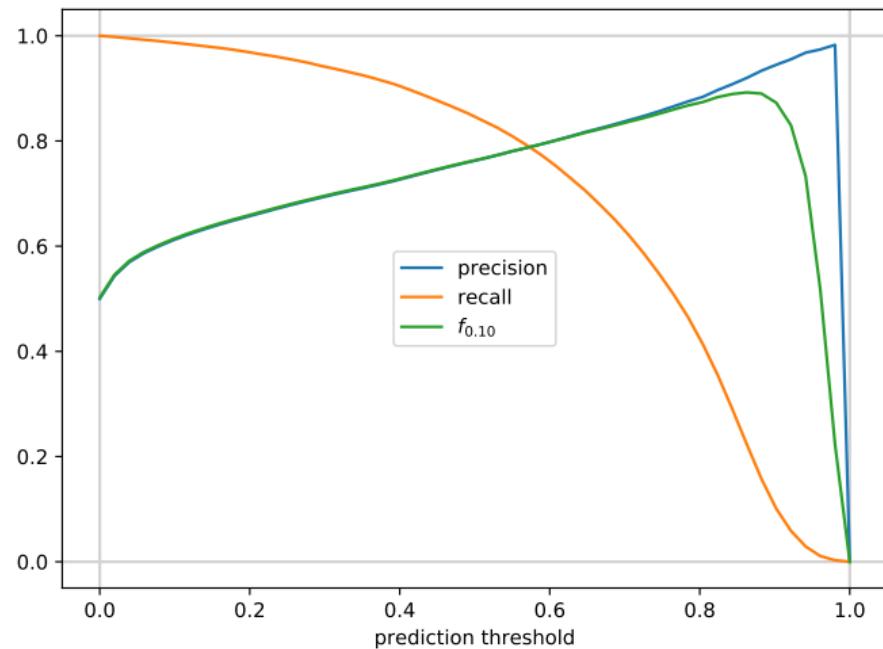




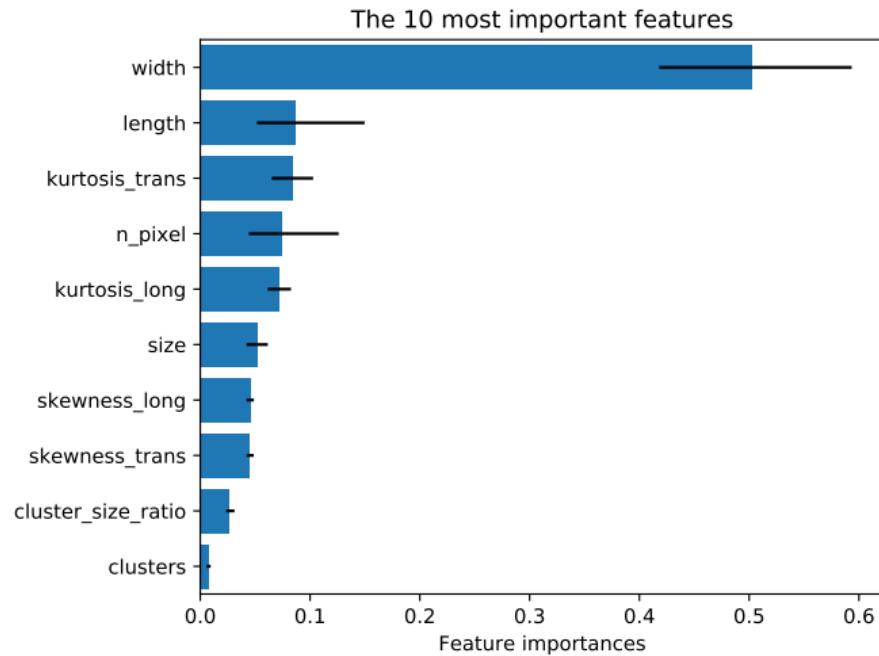
## Separation



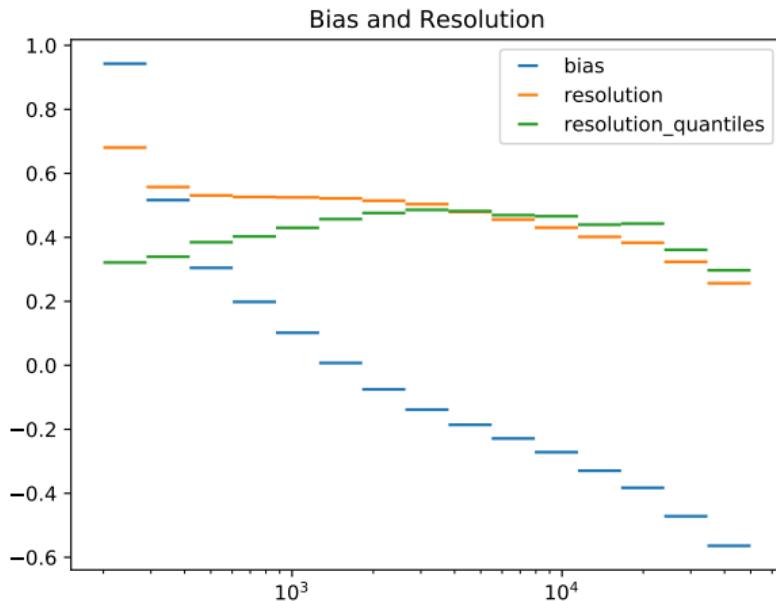
## Separation



## Separation



# Energy



# Energy

