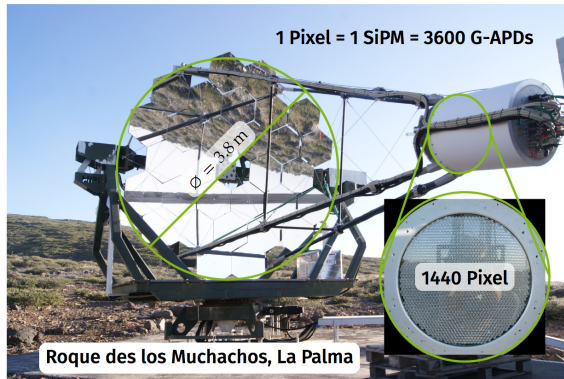

Analysis Of The Crab Nebula Using FACT's Photon Stream Data

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DPG-Frühjahrstagung 2018 Würzburg

The First G-APD Cherenkov Telescope



- located on Roque des los Muchachos, La Palma
- build to demonstrate novel light sensors *silicon photo multipliers* (SiPM)
- offer possibility to operate under much brighter light conditions
- camera has single photon resolution

The Photon Stream Data

Main-Pulse Event Representation

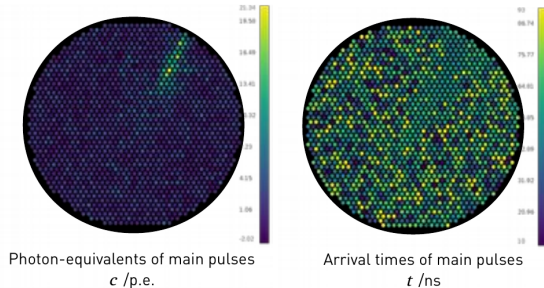
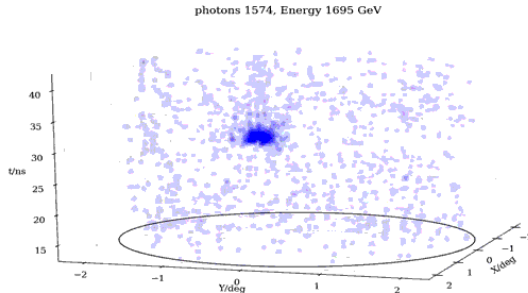


Figure: Standard FACT events.

Photon Stream:

- FACT records data in format close to readout hardware
- not intended as physics format
→ **Photon Stream**
- superposition of multiple photon signals
- reconstruct arrival time of single photons by subtracting their pulse shapes
- list of lists of arrival times

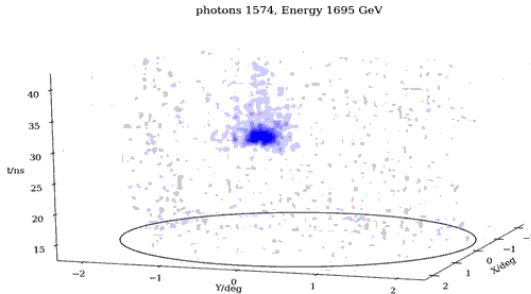
The Photon Stream Data



- smaller file size: possible to compress all FACT data to fit on one 10TB drive
- simplify *exchange* and *analysis*, gain timing knowledge
- do cluster based image cleaning
- do physics analysis on an SiPM based IACT

Figure: Represent Imaging Atmospheric Cherenkov Telescope events using single photons

The Photon Stream Data



- smaller file size: possible to compress all FACT data to fit on one 10TB drive
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Figure: Represent Imaging Atmospheric Cherenkov Telescope events using single photons

The Data set: FACT open data crab sample



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

Analysis

aim test the Photon Stream data in a physics analysis

Crab Nebula well measured source of cosmic gamma rays → comparative analysis

FACT Analysis chain:

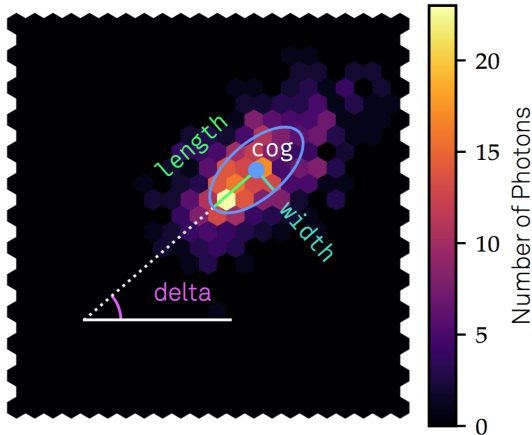
1. calibration of data
2. image cleaning → pure shower image remains

This Analysis so far:

3. Parametrization: calculate useful parameters
4. distinguish protons (background) from gammas
5. reconstruct direction and energy of particles

This is only the classical analysis approach so far!

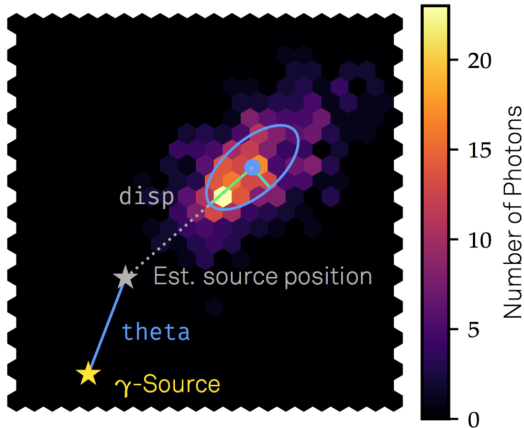
Parameterization



Hillas parameters:

- **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

Parameterization



Source position reconstruction via disp-method:

- **|disp|**: distance from centre of gravity to target
- **sgn(displ)**: Head/Tail-Disambiguation
- **theta**: distance between reconstructed and true origin
- **skewness/ kurtosis**: higher order statistical moments along half-axes in cluster system

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): `klaas_energy_regressor`

Gamma-hadron-separation:

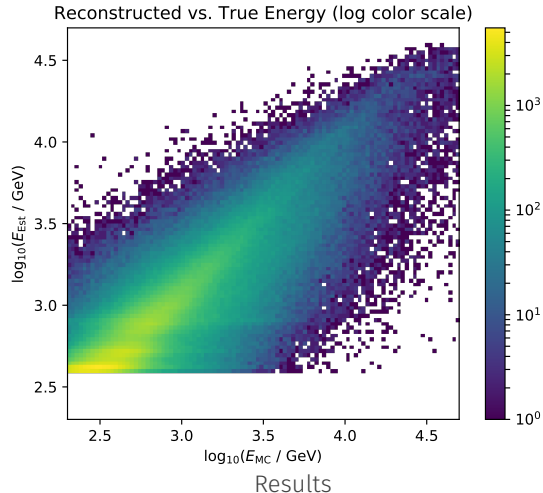
- random forest classifier (50 estimators): `klaas_separation_model`

Origin reconstruction:

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

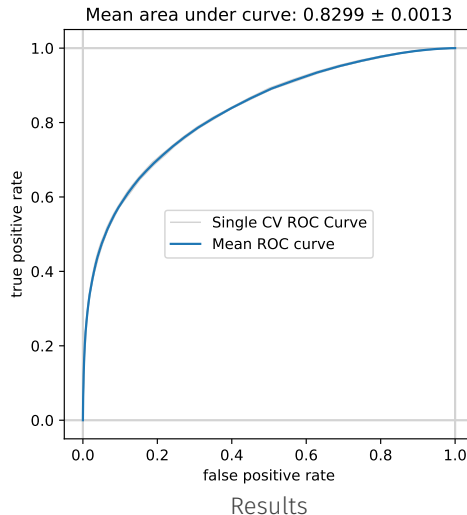
Energy estimation

Mean R^2 score from CV: 0.6065 ± 0.0092



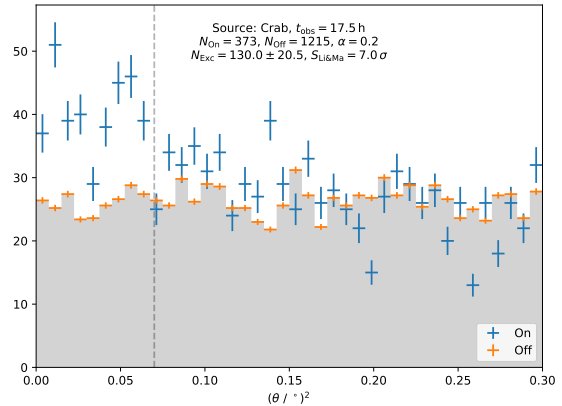
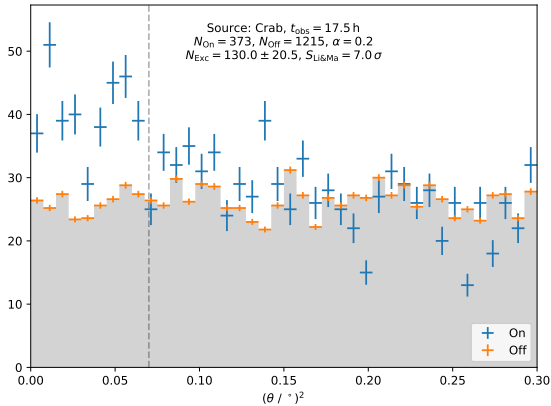
Separation

Trained on 100 000 signal and background events



Origin reconstruction

- mean accuracy for $\text{sgn}(\text{disp})$: $(75,99 \pm 0,22) \%$
- mean R^2 score for disp: 0.5429 ± 0.0036



Summary

Works well already!

	significance crab	separation AUC ROC	sign accuracy	disp R^2
This analysis	7.0σ	0,83	$0,7599 \pm 0,0022$	$0,5429 \pm 0,0036$
Std analysis	24.2σ	0,89	0,75	$0,6 \pm 0,2$

Outlook

- run analysis on more data
- apply cuts on data
- improve hyper-parameters of classifier-tools and clustering
- improve feature selection → feature engineering