FACT – Public Gamma-Ray Crab-Nebula Observations and Simulations

Maximilian Nöthe, Kai Brügge for the FACT-Collaboration

DPG Frühjahrstagung 2018, Würzburg

technische universität dortmund

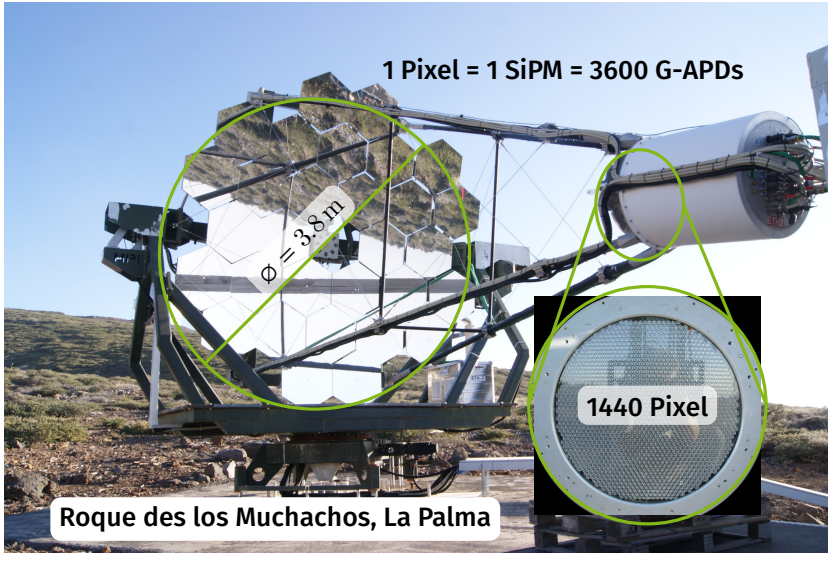
ETH zürich

ISDC DATA CENTRE FOR ASTROPHYSICS

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

Overview

[Miguel Claro]


1 Pixel = 1 SiPM = 3600 G-APDs
$\phi = 3.8\,\mathrm{m}$
1440 Pixel
Roque des los Muchachos, La Palma

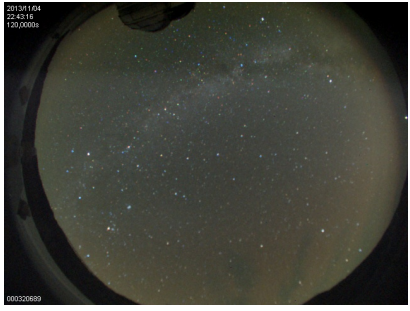
The Dataset

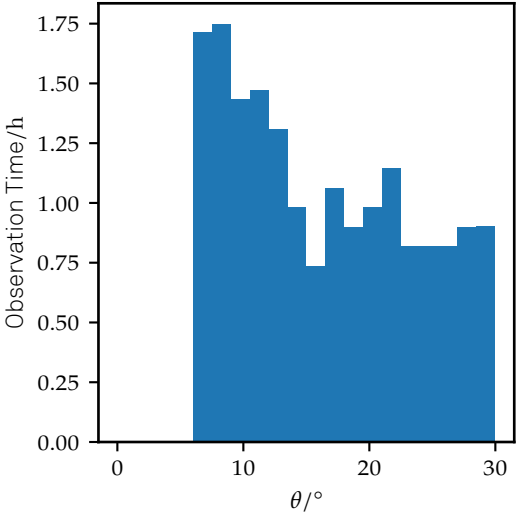
- Crab Observations from November 2013
- Point-source gamma-ray simulations
- Diffuse gamma-ray simulations
- Diffuse proton simulations
- Available in different formats and multiple analysis stages

https://fact-project.org/data

Observations

- 17.7 hours of Crab Nebula observations
- Good environmental conditions
- Zenith distance between 6° and 30°





Simulations

- CORSIKA for air shower simulations
- CERES for FACT detector response simulations

Gammas

Energy Range	$200\,\mathrm{GeV} - 50\,\mathrm{TeV}$
Spectral Slope	-2.7
Max. Impact	$270\,\mathrm{m}$
Zenith Distance	$0° - 30°$
CORSIKA Events	$12\,000\,000$
Triggered Events	$1\,914\,812$

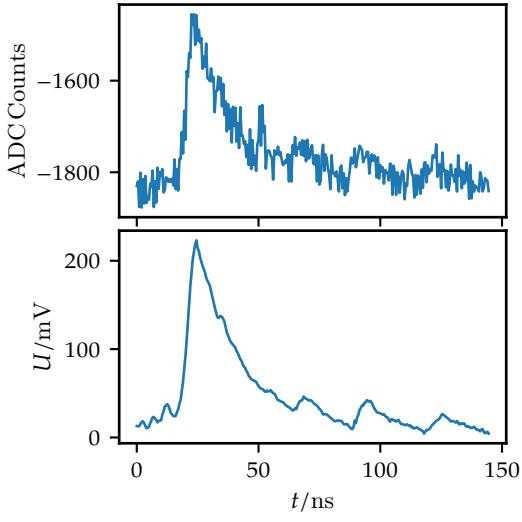
Protons

Energy Range	$100\,\mathrm{GeV} - 200\,\mathrm{TeV}$
Spectral Slope	-2.7
Max. Impact	$400\,\mathrm{m}$
Zenith Distance	$0° - 30°$
CORSIKA Events	$780\,046\,520$
Triggered Events	$509\,652$

A FACT Analysis

Classical IACT Analysis Chain

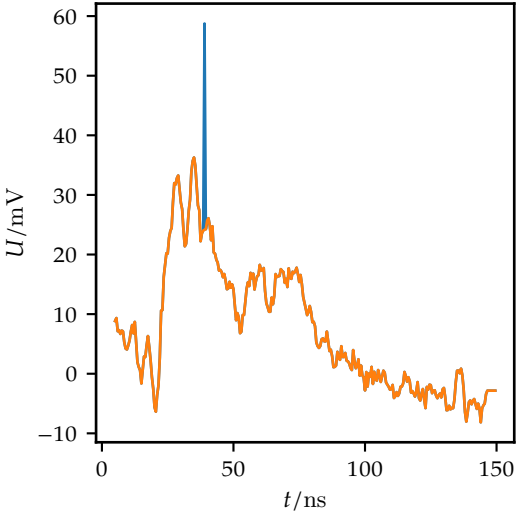
1. Raw Data Calibration
2. Removal of electronic artifacts
3. Extraction of number of photons and mean arrival times for each pixel
4. Image parameterization
5. Reconstruction of particle properties
   - Energy
   - Origin
   - Particle type (γ, p, μ)



A FACT Analysis

Classical IACT Analysis Chain

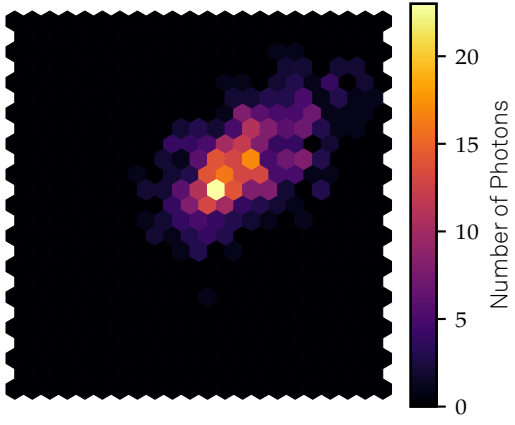
1. Raw Data Calibration
2. Removal of electronic artifacts
3. Extraction of number of photons and mean arrival times for each pixel
4. Image parameterization
5. Reconstruction of particle properties
   - Energy
   - Origin
   - Particle type (γ, p, μ)



A FACT Analysis

Classical IACT Analysis Chain

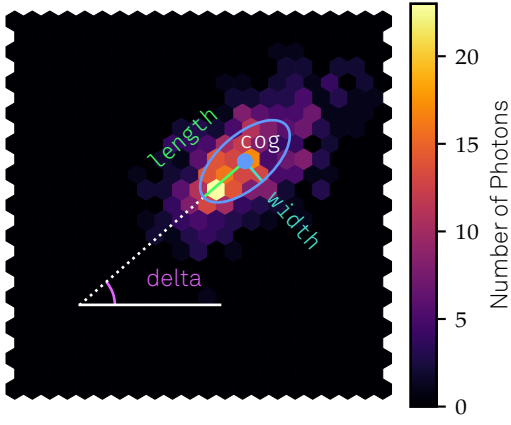
1. Raw Data Calibration
2. Removal of electronic artifacts
3. Extraction of number of photons and mean arrival times for each pixel
4. Image parameterization
5. Reconstruction of particle properties
   - Energy
   - Origin
   - Particle type (γ, p, μ)



A FACT Analysis

Classical IACT Analysis Chain

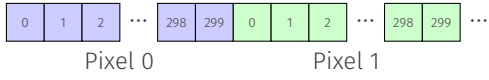
1. Raw Data Calibration
2. Removal of electronic artifacts
3. Extraction of number of photons and mean arrival times for each pixel
4. Image parameterization
5. Reconstruction of particle properties
   - Energy
   - Origin
   - Particle type (γ, p, μ)



Raw Data

- FACT observations are stored in custom compressed FITS Files called `zfits`
- Readers are available for

  Python `https://github.com/fact-project/zfits`
  Java `https://github.com/fact-project/fact-tools`
  C++ (ROOT) `https://trac.fact-project.org/browser/trunk/Mars`
- FACT-Tools can be easily used to convert `zfits` to standard FITS
- Simulations are stored in standard, gzipped FITS Files
- Raw Data consists of a single array of length 1440×300 ($N_{\text{Pixels}} \times N_{\text{Slices}}$)



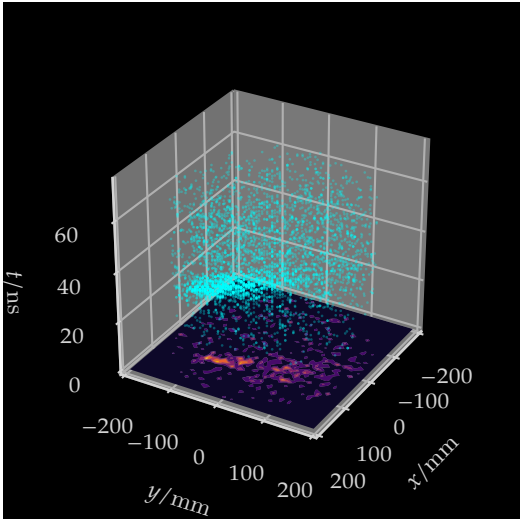
0.9 TB observations, 1.1 TB simulations

See: Max Ludwig Ahnen et al. “Data compression for the first G-APD Cherenkov Telescope”. In: *Astronomy and Computing* 12 (2015), pp. 191–199

Photon Stream

- The FACT Camera has single photon resolution
- Each photon produces a known pulse shape
- Multiple photons just superimpose
- → Reconstruct the arrival time of each individual photon by subtracting pulses until a flat line is reached
- *Much* smaller file size compared to raw data
- All FACT Data ≈ 8 TB

See: Sebastian Achim Mueller et al. "Single Photon Extraction for FACT's SiPMs allows for Novel IACT Event Representation". In: *Proceedings of the 35th ICRC*. 2017



FACT-Tools

- Extension of the `streams`-Framework to analyze FACT data
- Developed at TU Dortmund and ETHZ
- Also performs photonstream extraction

`https://github.com/fact-project/fact-tools`

Higher-Level Analysis

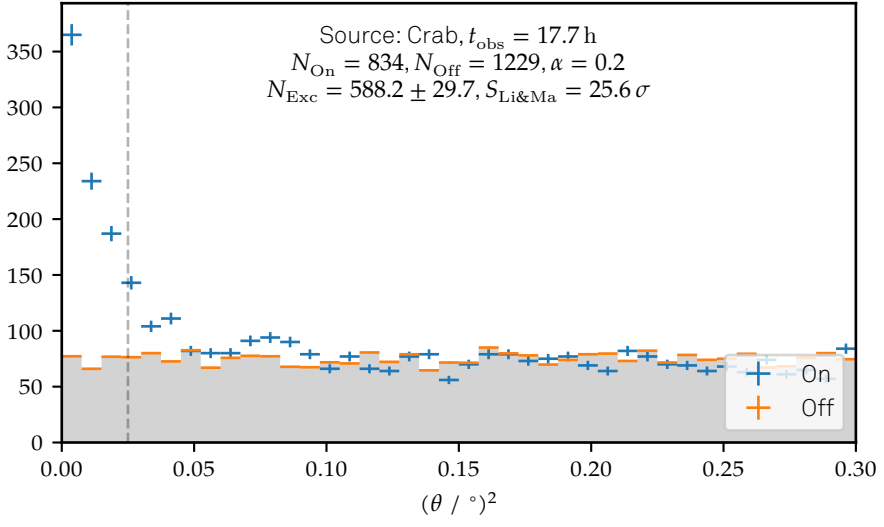
- We use the Scientific Python Stack
- `scikit-learn` models for particle classification, energy estimation and reconstruction of origin

Example analysis on the open data sample:

```
$ git clone https://github.com/fact-project/open_crab_sample_analysis
$ pip install -r requirements.txt
$ make
```

This will download the data, train models, apply them and produce a θ^2 plot for the source detection.

Result


Source: Crab, $t_{\mathrm{obs}} = 17.7\,\mathrm{h}$
$N_{\mathrm{On}} = 834, N_{\mathrm{Off}} = 1229, \alpha = 0.2$
$N_{\mathrm{Exc}} = 588.2 \pm 29.7, S_{\mathrm{Li\&Ma}} = 25.6\,\sigma$
On
Off
0
50
100
150
200
250
300
350
0.00
0.05
0.10
0.15
0.20
0.25
0.30
$(\theta\ /\ ^\circ)^2$

Conclusions

- From the start, FACT made results of he Quick Look Analysis publicly available `https://fact-project.org/monitoring`
- In November, FACT released a dataset of Crab observations, from the raw data up.
- Accompanied by extensive simulations.
- FACT-Tools standard analysis has 25.6 on this dataset
- Use it for education and outreach!
- Many possibilities including Deep Learning, Spectrum Estimation, etc.
- We are planning on releasing more data in the future.