Machine Learning in Gamma-Ray Astronomy

More than just Background Suppression

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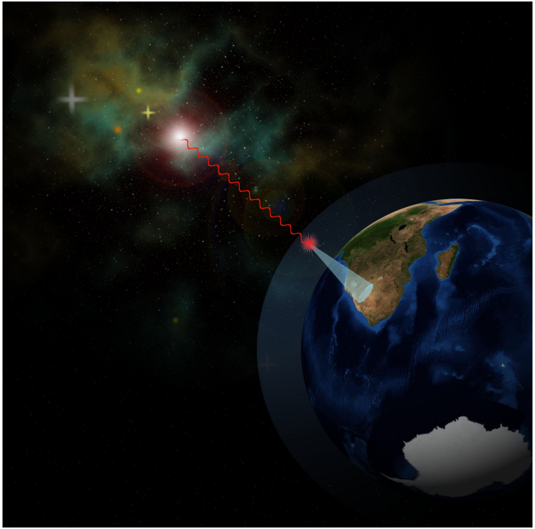
Overview

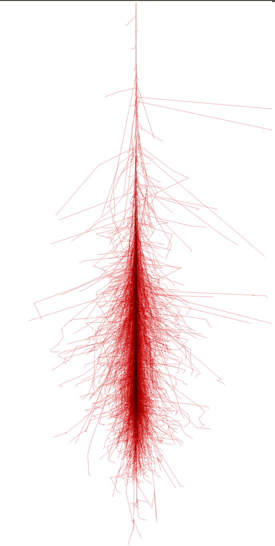
Imaging Air Cherenkov Telescopes

- Gamma-rays and hadrons produce extensive air showers
- Telescopes detect the Cherenkov light on the ground
- Usually 1000–10000 hadrons per gamma-ray
- Reconstruction tasks:
  - Particle type (γ / hadron)
  - Energy
  - Origin

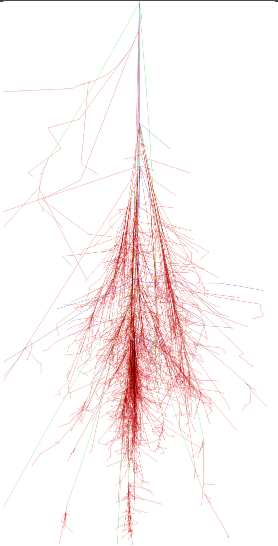


[www-ucjf.troja.mff.cuni.cz/~hess/img/sprska4.jpg]

Feature extraction



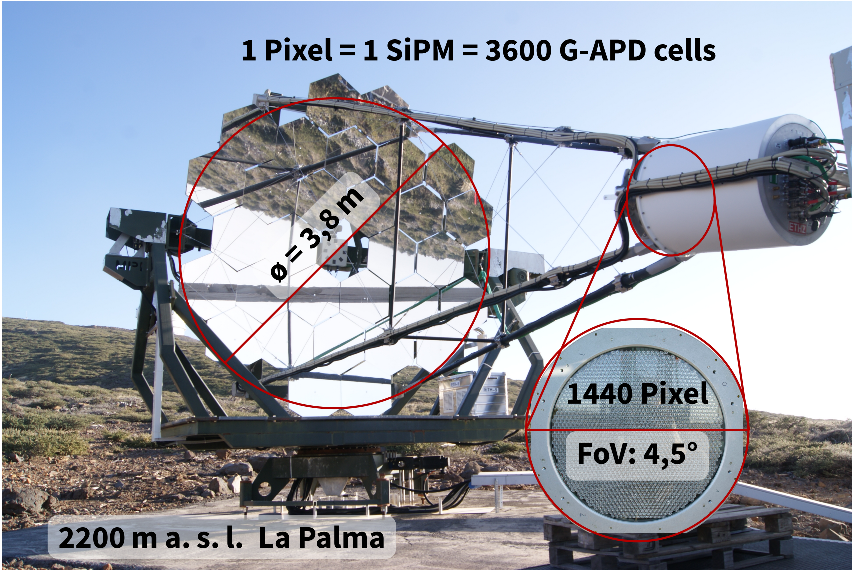
$100\,\mathrm{GeV}$ Gamma Shower



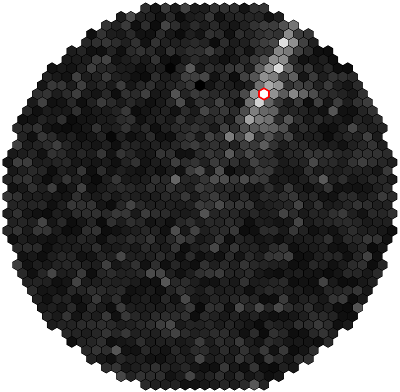
$100\,\mathrm{GeV}$ Proton Shower

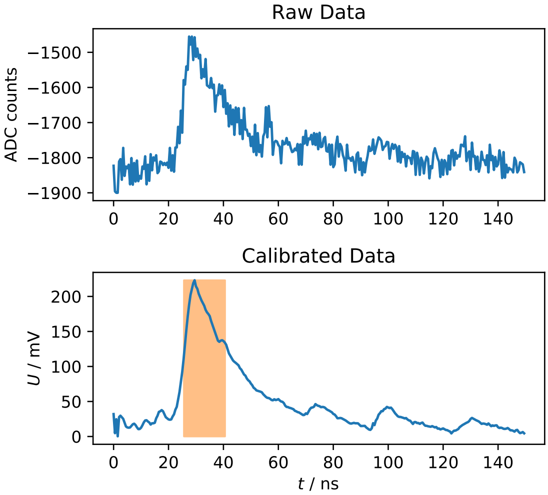
[from: `www.ikp.kit.edu/corsika`]

FACT – The First G-APD Cherenkov Telescope



Raw Data





Either measured telescope data or `CORSIKA` plus detector simulation.

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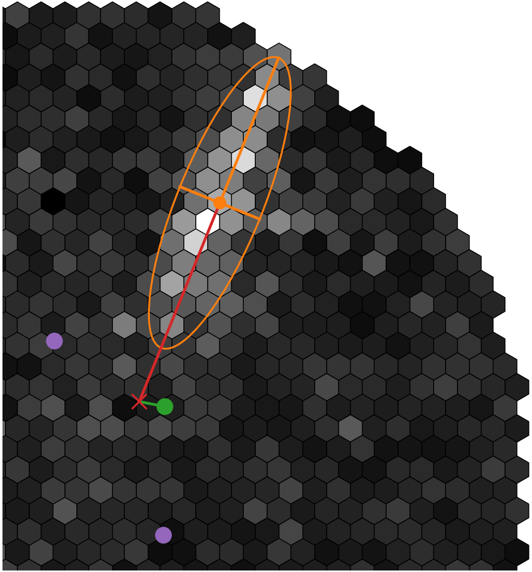

- → Further data reduction from photons and arrival times to features
- → Classical Hillas features describing the light distribution
- → Descriptive statistics of the light and time distributions
- → 40–60 features in the end
- → Source dependent features are calculated also for “off” postions

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[portal.cta-observatory.org/PublishingImages/Sites/Spain]

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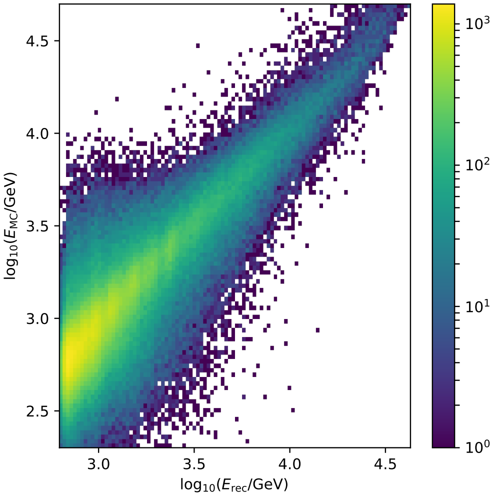
[www.cta-observatory.org/about/array-locations/la-palma]

Energy regression

- We use `scikit-learn`'s `RandomForestRegressor`
- Trained on gamma-ray Monte Carlo data
- Use Standard Deviation of tree answers for Separation



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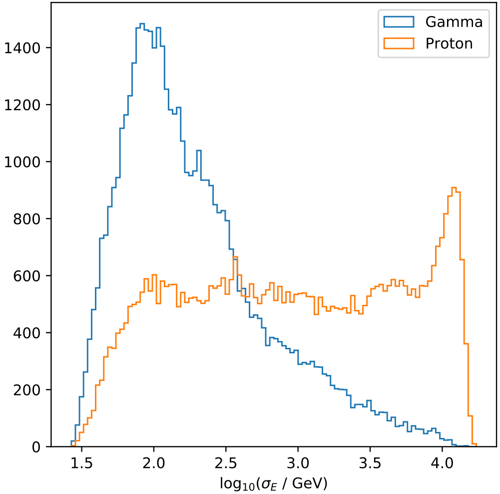
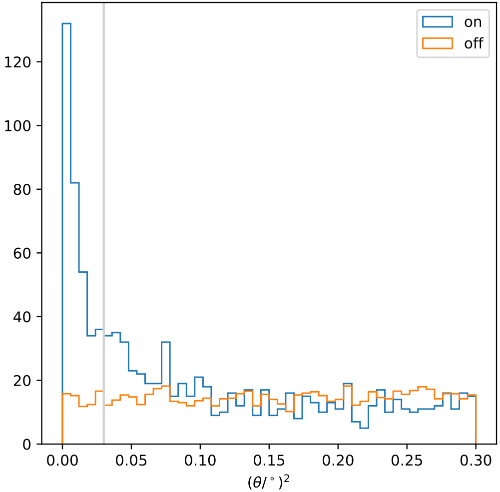


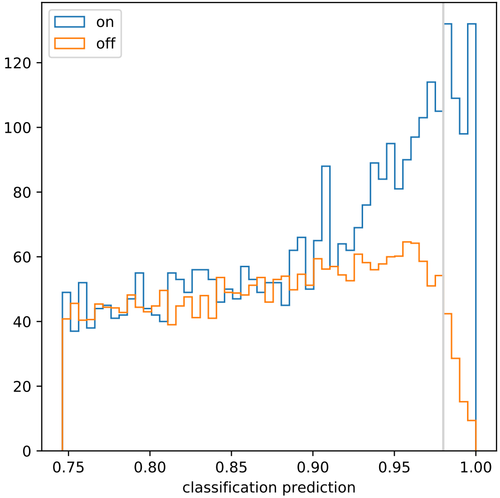
Particle Classification – Classical Approach

- → Leave out any features dependent on source position
- → Target class: gamma-rays
- → Source detection with θ^2 using on/off data
- → `RandomForestClassificator`



Particle Classification – New Approach

- Target class: gamma-rays from the source
- Source detection with classification output
- Requires application of the model for each off position
- only possible for known point sources



Online application of machine learning models

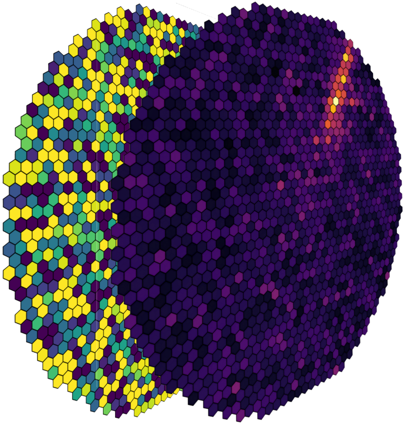
- Online application of models trained with scikit-learn in our `java` analysis framework
- Export models to `PMML`
- Apply models in `java`

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

SFB 876 Providing Information by Resource-Constrained Data Analysis

Deep Learning

- → Improve on our separation & regression tasks
- → Reduce runtime for live analysis → Alert other experiments
- → Directly go from Photons and Arrival Times to target variables
- → Maybe even directly from the raw data?
- → Current problems:
  - → No support for hexagonal grids
  - → How to deal with hexgrids?



$[1440 \times 2]$

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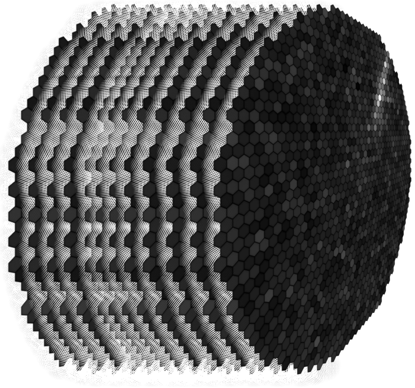
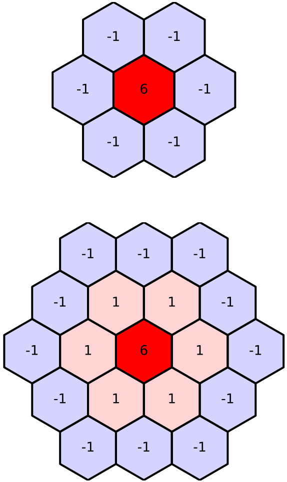


$[1440 \times 300]$

Difficulties with hexgrids

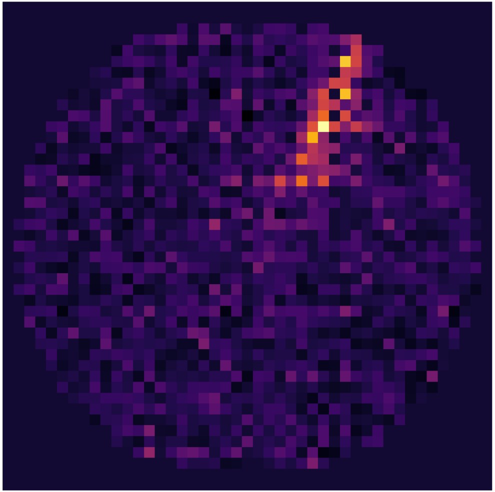
- → Borders of the camera not regular
- → Going from $\mathrm{height} \times \mathrm{width}$ to radius for the filter
- → Whitch coordinate system to use?
- → Can we contribute hexgrid support to `keras` / `tensorflow`?

If you want to learn more about hexgrids:
`www.redblobgames.com/grids/hexagons/`



Square pixel image approximation

→ We want to start first experiments with square pixel approximations
→ Not taking full advantage of the geometry
→ Probably do not gain much runtime performance



Conclusion

→ Classical machine learning approaches work very well
→ We are working on expanding the use of ML models to more reconstruction tasks
→ Constantly improve our shallow learning methods
→ We just started to look into Deep Learning