IRON-SPECTRUM.

The Template Method for Measuring the Cosmic Iron Spectrum with IACTs

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HELMHOLTZ ASSOCIATION
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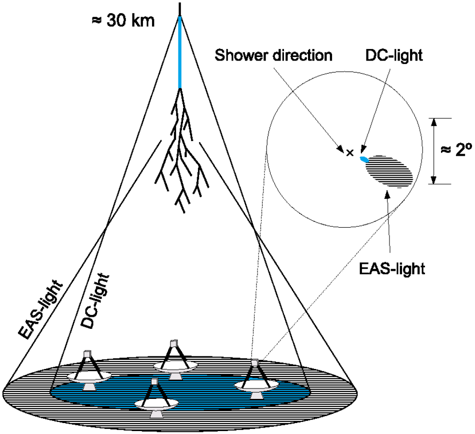
Cherenkov telescopes

- Cherenkov radiation from extended air showers.
- Gamma-ray astronomy; main background: cosmic rays.
- Measure shower core; direction and energy of primary particle.
- Direct Cherenkov light (from primary particle):
  - Very concentrated.
  - Sensitive to a small fraction of the iron's flight path.
  - Intensity $\propto Z^2 \cdot \sin(\theta_c)$.
  - Identification of heavy nuclei, eg. iron, in the TeV range.
  - Cf. Kieda et al. (2001); Aharonian et al. (2007).



Source: Aharonian et al. (2007)

VERITAS

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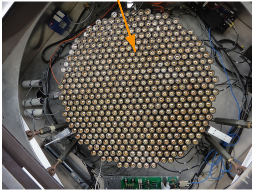
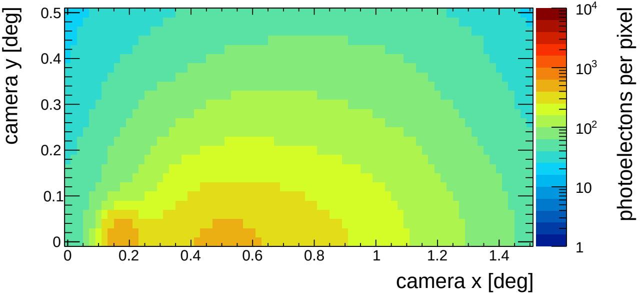


The template method for shower reconstrution

Idea: Predict light intensity per pixel, depending on direction, energy, first interaction height, core position cf. Le Bohec et al. (1998); compare to measured values.

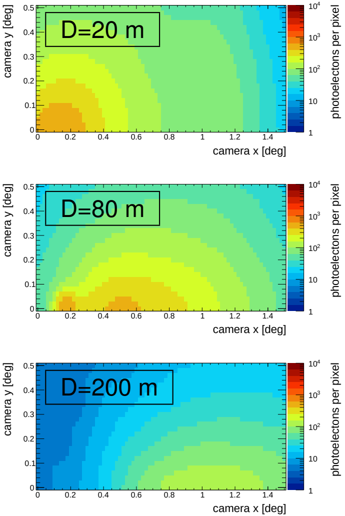
- Can be used for iron showers as well as gamma showers.
- Use MC simulations of shower development and light propagation in atmosphere and telescope.
- Simulations for fixed points in energy, distance to telescope, first interaction heigt; interpolate between those points.



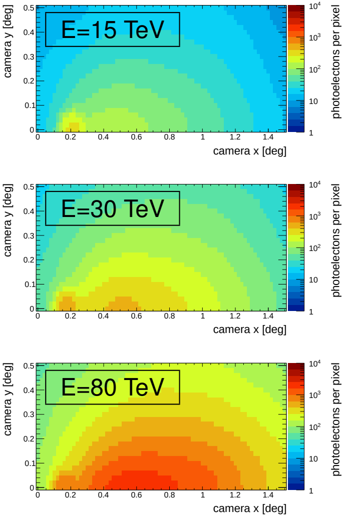
Iron
Ze=0°
E=30 TeV
D=80 m
H=33 km

More iron templates

E=30 TeV, H=33 km



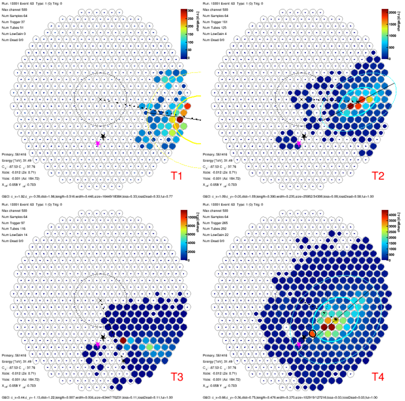
D=80 m, H=33 km



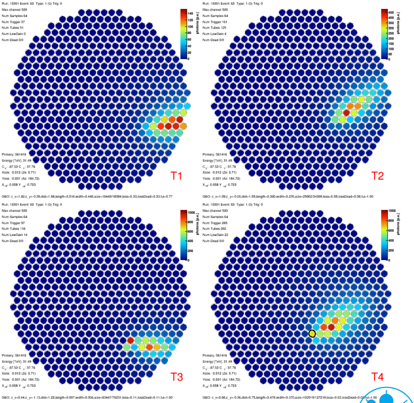
Using the templates for reconstruction

- Simultaneous Fit of direction, core position, energy, and first interaction height to data in the four telescopes using likelihood method.
- Validation of the templates using iron showers (after detector simulation) Example: 31 TeV shower.

Simulation

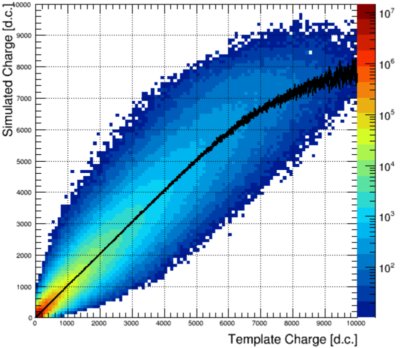


Best fit template prediction



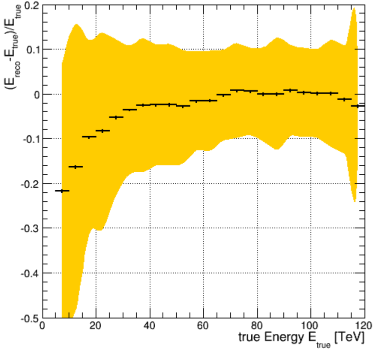
Template validation

- Compare template predictions with simulated showers after detector simulation.
- Use true values, no fit, no B-field.
- Charge per pixel well predicted for Q $\leq$ 6000 d.c. (saturation effects for large signals).

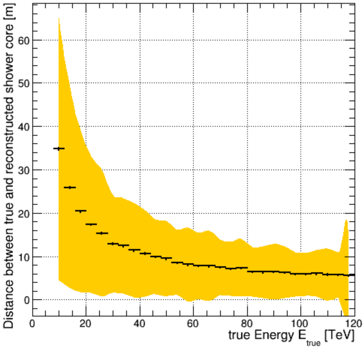


Fit procedure validation

- Fit of the template predictions to simulated iron showers after detector simulation.
- True values as starting points, fix first interaction heigt.



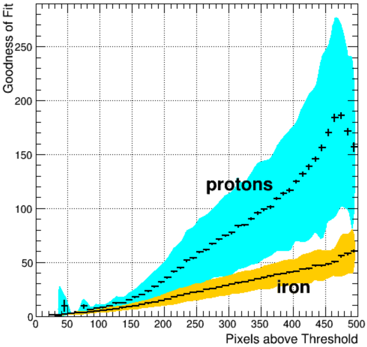
Energy resolution



Reconstruction of core position

Goodness of fit for proton separation

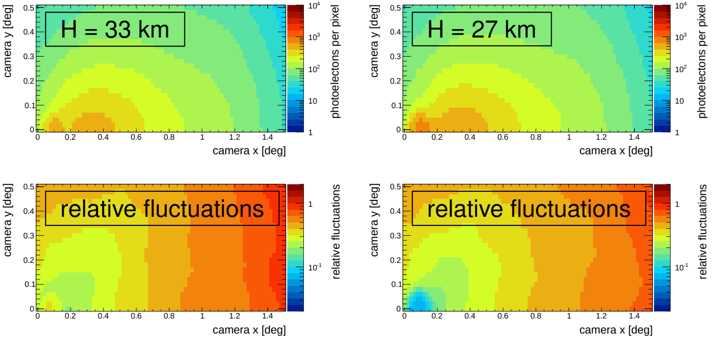
- Fit of the template predictions to simulated iron showers after detector simulation.
- True values as starting points, fix first interaction heigt.
- Distance of shower core to detector between 30 and 140 m.
- Selection not final/optimized yet!



Shower-to-shower fluctuations

- Right now: Likelihood function includes photon statistics, dc-to-pe uncertainty, and NSB-induced noise (optimised for gamma showers)
- Shower-to-shower fluctuations more important for iron showers.
- Different for DC light vs shower light, dependance on energy, first interaction height.
- Will include this in likelihood calculation in the future.

D=50 m, E=30 TeV



Status and Plans

> Adapted template analysis for iron-induced showers.
> Energy, direction and core position well reconstructed.
> Simultaneous fit of first interaction height problemactic.
> Separation of proton showers possible using goodness of fit.
> Starting values?
> Working on including shower-to-shower fluctuations in likelihood.

Sources

Thank you for the attention!

Aharonian, F. et al. (2007). First ground based measurement of atmospheric Cherenkov light from cosmic rays. *Phys.Rev.*, D75:042004.

Kieda, D., Swordy, S., and Wakely, S. (2001). A high resolution method for measuring cosmic ray composition beyond 10 TeV. *Astroparticle Physics*, 15(3):287 – 303.

Le Bohec, S. et al. (1998). A new analysis method for very high definition imaging atmospheric cherenkov telescopes as applied to the cat telescope. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 416(2 - 3):425 – 437.

Backup.

Details

> Shower simulation: CORSIKA 6.99, bernlohr package.

> Ray tracing, detector simulation: GrISU2012April20

> Templates:

- Zenith angle: 0°.
- Energy 11 steps, $E_0 =$10 TeV, $\Delta E = 0.1$, $\log_{10}(E_i) = \log_{10}(E_0) + i \cdot \Delta E$.
- Detector distance: 31 steps, 0 m to 300 m, $D_i = i \cdot 10\,\text{m}$.
- First interaction height: N=11 steps, $\chi_i = \lambda \cdot \ln\left(\frac{N-i-\Delta}{N}\right)$, $\lambda = 13\,\frac{g}{cm^2}$, $\Delta = 0.5$ (even coverage of first interaction heights).