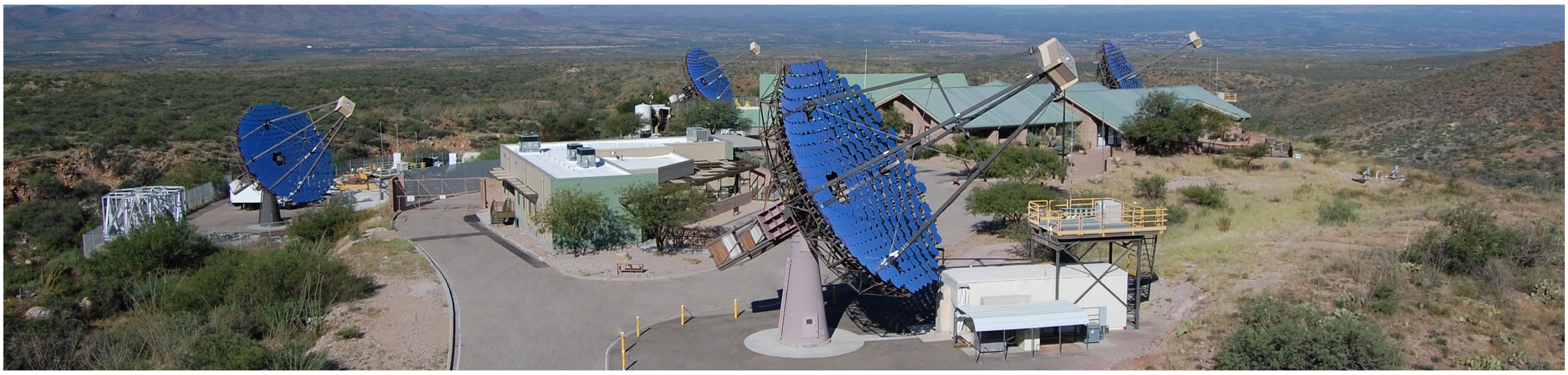

A template method for measuring the iron spectrum in cosmic rays with Cherenkov telescopes.

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Introduction

> Cosmic rays known for 100 years.
> Make-up: Mainly protons, nuclei.
> Energy spectrum: ∼smooth power law.
> Origin, composition not fully understood.

Direct detection experiments[1]:
> Balloons/space borne detectors.
> Detection area ∼1 m^2.
> Good at small Z, MeV to TeV energies.

Indirect detection — EAS arrays[2, 3]:
> Detect air shower on ground.
> Detection area ∼ 10^{12} m^2.
> Best at energies of 10^{13} eV and above.

Indirect detection — IACTs[4]:
> Detect Cherenkov light from air showers
> Detection area ∼ 10^4 m^2.
> Intermediate energies (TeV range).

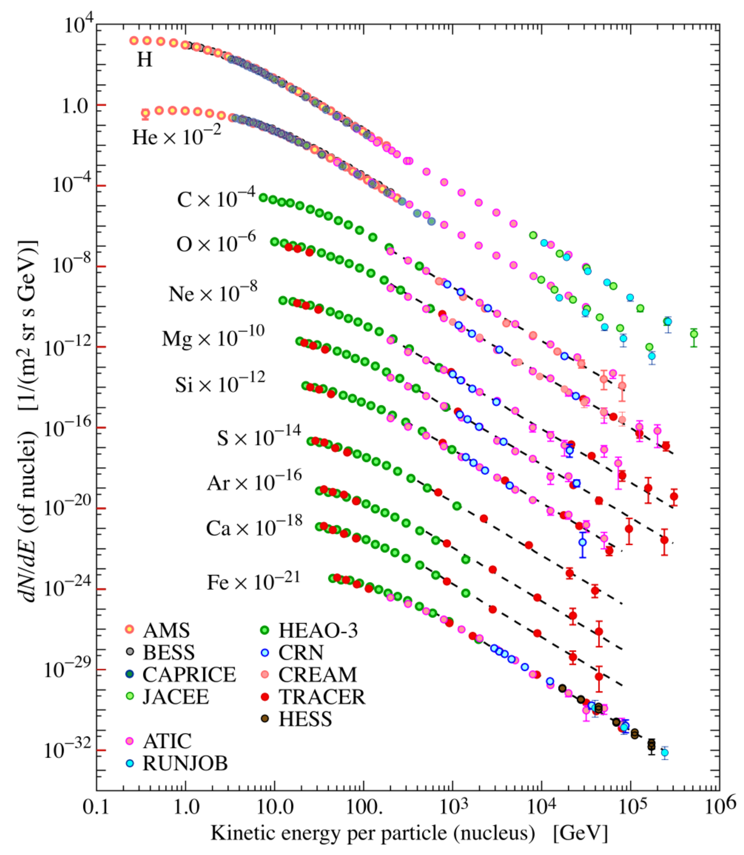

Figure 1: Energy spectra of various elements in cosmic rays, measured by different experiments over a large energy range, from [5].

Imaging Air Showers & Direct Cherenkov Technique

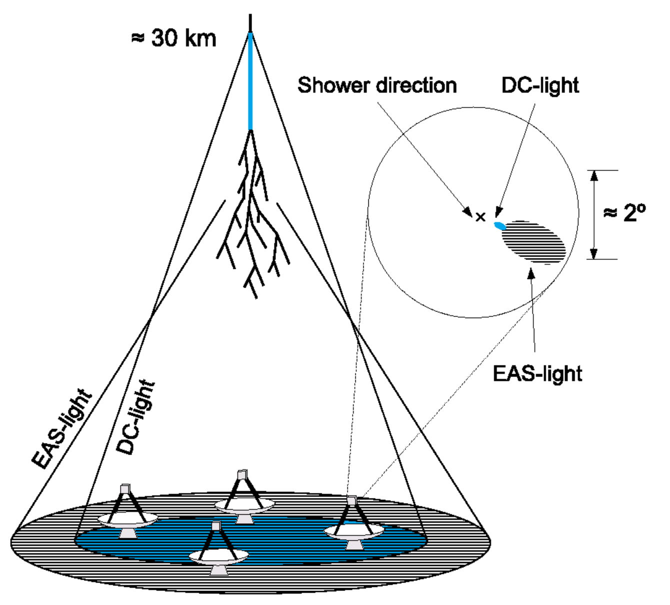

Figure 2: Cherenkov light pool, adapted from [4].

Imaging of Air Showers:
> Charged particles → Cherenkov light.
> Light pool: few 100 m radius at ground.
> Extension in camera: ∼1°.
> Reconstruct energy, direction, primary particle from size, shape, orientation.
> Telescope arrays → stereoscopy.
> γ-ray astronomy, large background of CRs.

Direct Cherenkov Technique[4, 6]
> Charged primary particles: direct Cherenkov (DC) light before first interaction.
> Very concentrated in camera.
> DC Intensity ∼ Z^2 → separation of heavy and light nuclei.
> Combine IACT data on all targets.
> Complementary to EAS, direct detection.

The VERITAS instrument

> Very Energetic Radiation Imaging Telescope Array System [7].
> Array of four imaging atmospheric Cherenkov telescopes at the Fred Lawrence Whipple Observatory (FLWO) in southern Arizona (31 40N, 110 57W, 1.3km a.s.l.).
> Field of view 3.5° per camera, consisting of 499 pixels each.

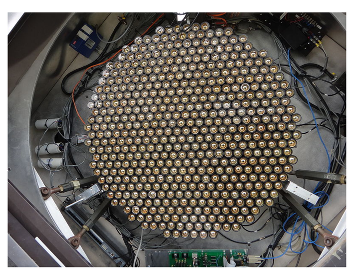

Figure 3: One of the VERITAS cameras.

Template Likelihood Reconstruction

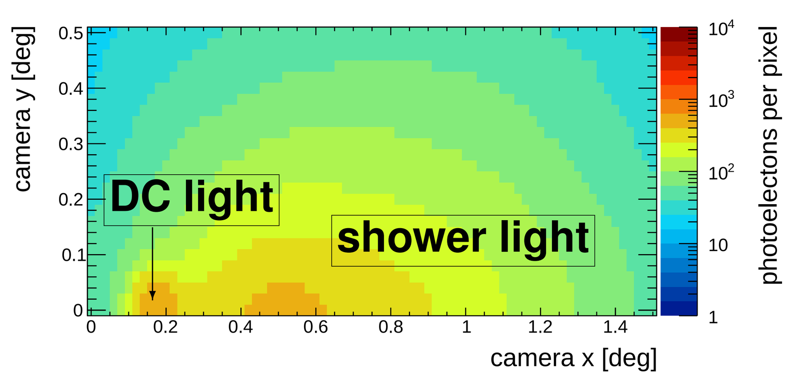

Figure 4: Template: Iron shower, E = 30 TeV, D =80 m (detector to shower core), H = 33 km.

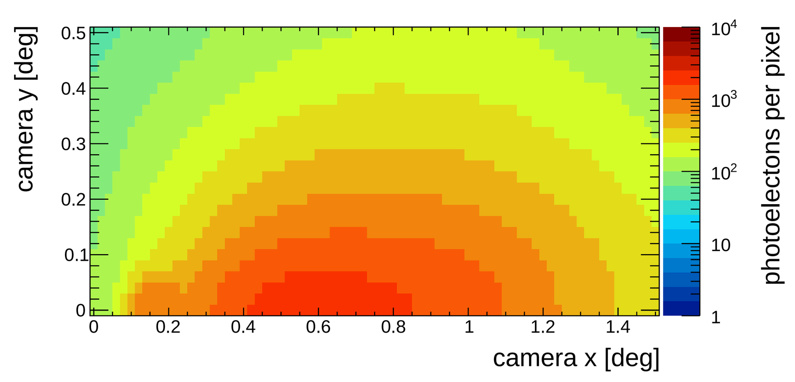

Figure 5: Template: Iron shower, E = 80 TeV, D =80 m, H = 33 km.

Probability distribution of signal, given
> direction X_S, Y_S,
> energy E of the primary particle,
> height of first interaction H
> position of shower core X_P, Y_P.
> uncertainty of pixel gain
> pedestal variance.

> Likelihood optimization to estimate parameters for a given shower by fitting camera images to model [8, 9].
> Goodness of fit: background separation.
> CR analysis: include shower-to-shower fluctuations in likelihood. [10].

Performance

> Reconstruction tested on simulated iron showers.
> Select very bright showers only, no cut on goodness of fit.
> Reconstruction works well, safe energy threshold ∼ $10^{1.5}$ TeV ≈ 30 TeV.
> Energy bias ($E_{rec}/E_{true} - 1$) flat above energy threshold.
> Offset-dependent energy bias, need to correct for that.
> Energy resolution and angular resolution improved compared to geometrical reconstruction.
> Angular resolution still larger than pixel diameter below 100 TeV.

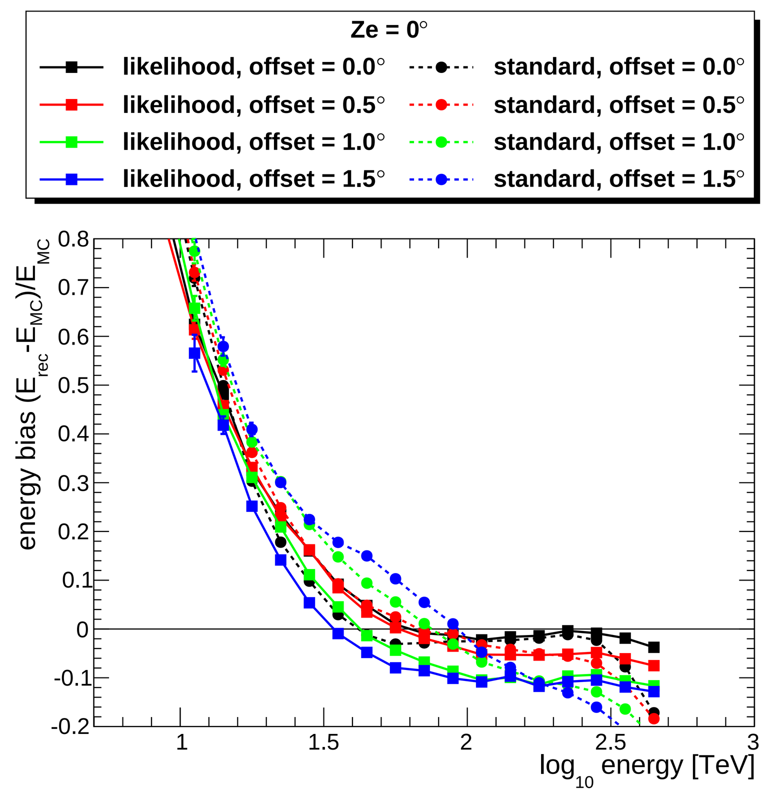

Figure 6: Energy bias for showers from zenith, different offsets from the camera center.

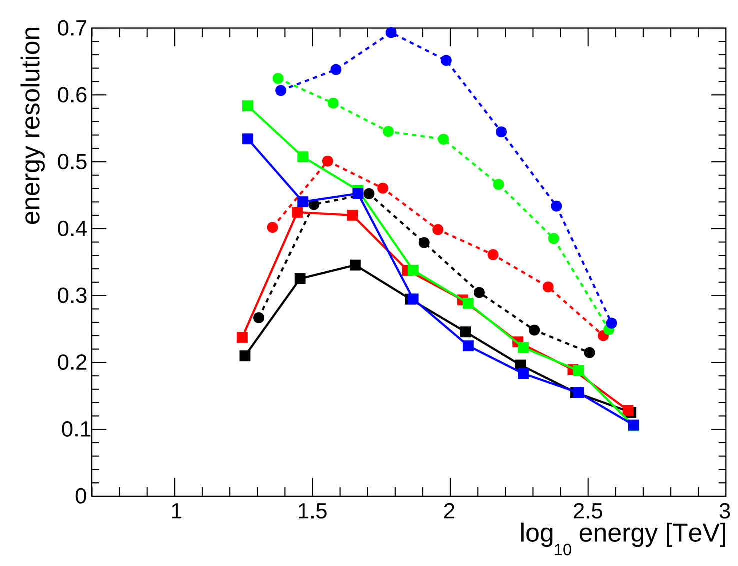

Figure 7: Energy resolution for showers from zenith, different offsets from the camera center.

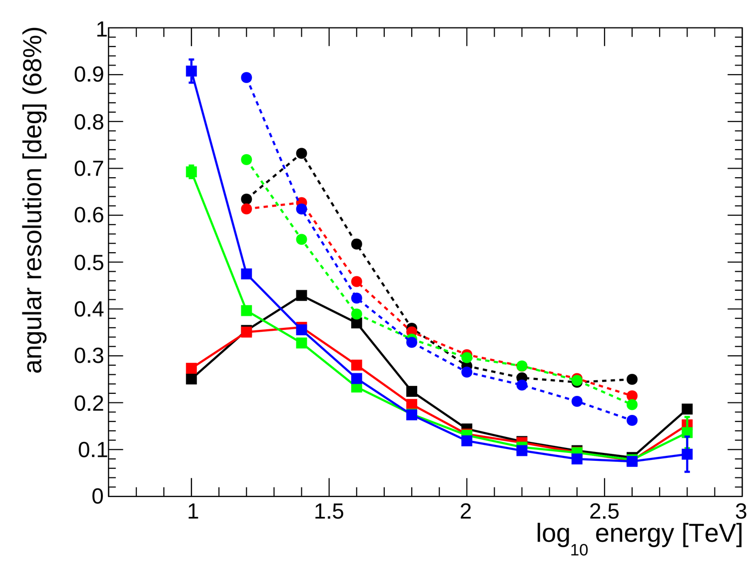

Figure 8: Angular resolution for showers from zenith, different offsets from the camera center.

Conclusions

> Have adapted template likelihood reconstruction to reconstruct iron-induced showers.
> Reconstruction works well for iron-induced showers with energies of ∼30 TeV – ∼300 TeV.
> Future plans: Use goodness-of-fit to separate iron-induced showers from background (showers induced by protons and light nuclei).
> Eventually: Spectrum of cosmic ray iron in the TeV range.

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See PoS(ICRC2015)264 for more details.

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