# Airborne Inter-Calibration of H.E.S.S. Telescopes

Jacques Muller • Cosmic Explosions 2019 • 27 May – 6 June 2019

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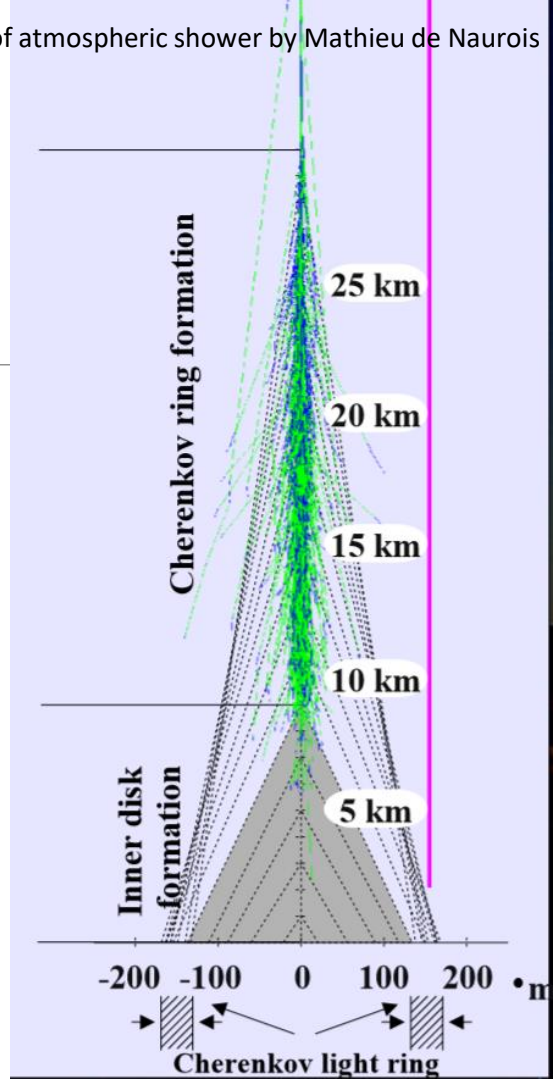
# Introduction

# Gamma-Ray Astronomy

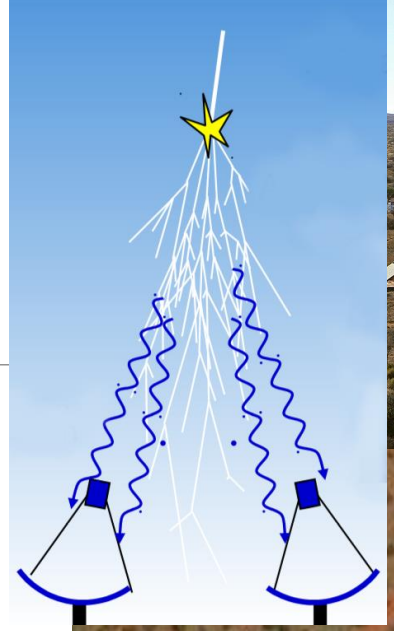
- Gamma-Ray: Photon (γ) with energy above 100keV
- Atmosphere = Calorimeter
  → “atmospheric shower” of secondary particles
- Relativistic $e^-$ / $e^+$ in atmospheric showers emit Cherenkov radiation
  (γ emitted by charged particles faster than speed of light in medium)
- Background: Hadrons & $e^-$ / $e^+$ entering atmosphere
  - Hadrons: More irregular showers & might contain muon
  - e- / e+ (& hadrons): Reaching earth almost uniformly from all direction (due to turbulent galactic magnetic fields)

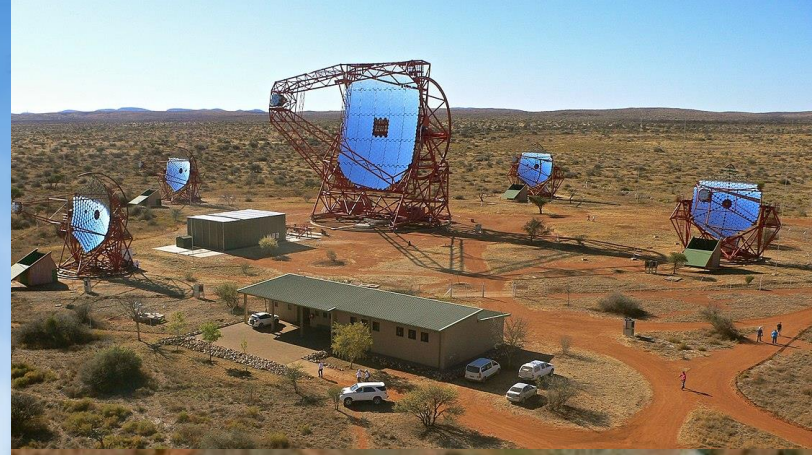
Simulation of atmospheric shower by Mathieu de Naurois

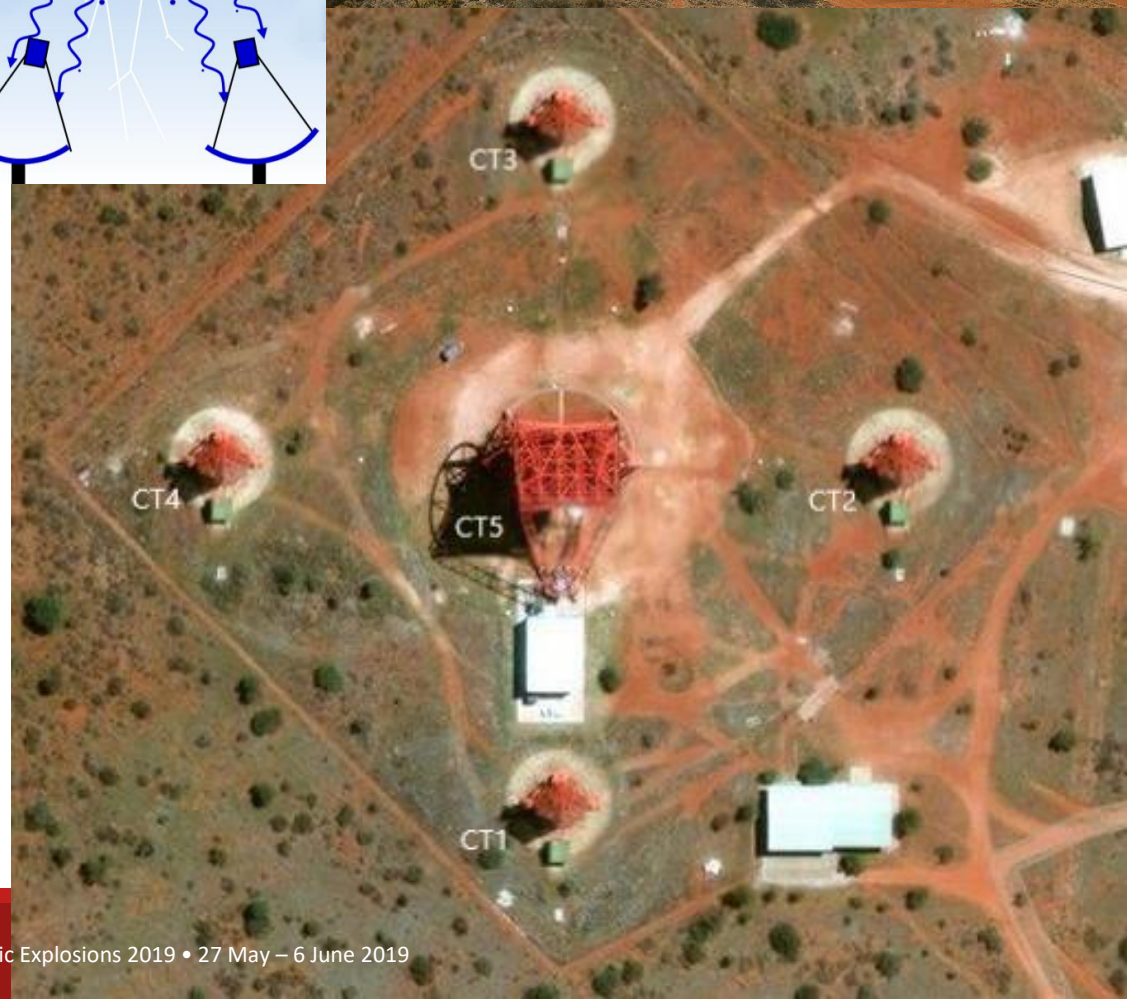


# Cherenkov Telescopes

- Showers detected by large Cherenkov telescope arrays such as H.E.S.S., MAGIC & Veritas
- H.E.S.S. constituted of 4 small telescopes on square (CT1-4) and 1 big telescope in centre (CT5)
- Planned Cherenkov Telescope Array (CTA): > 100 telescopes over 2 sites

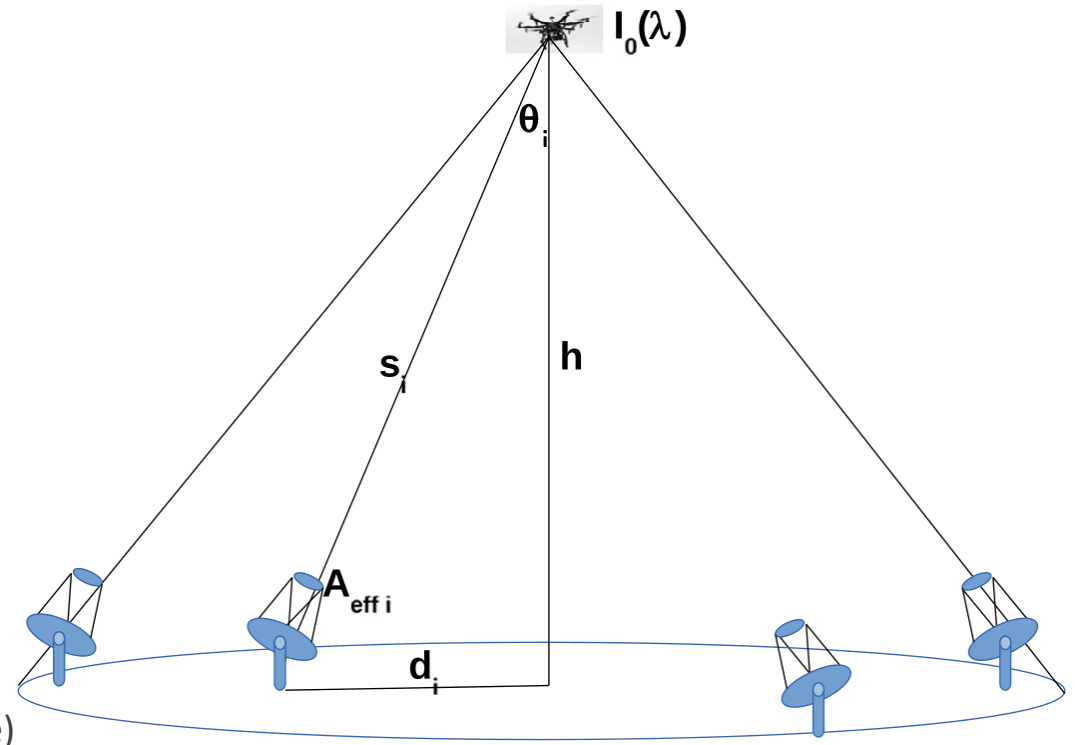






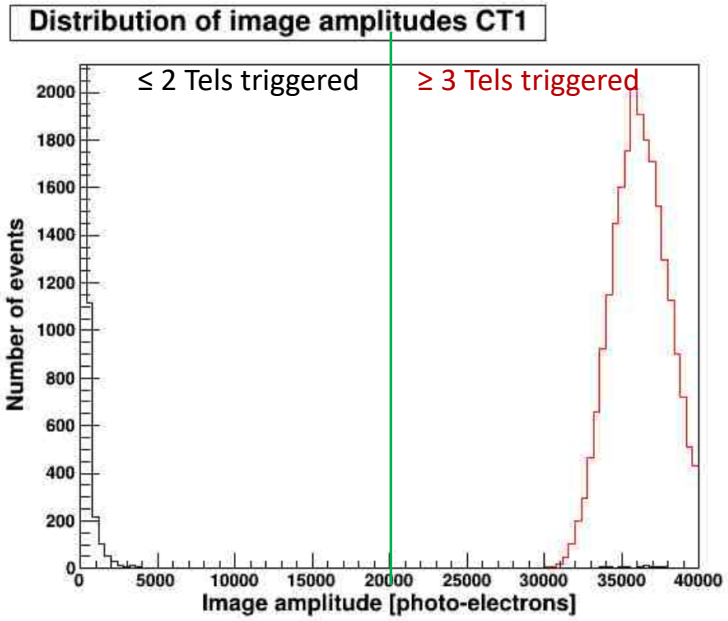
# Inter-Calibration of Cherenkov Telescope Arrays

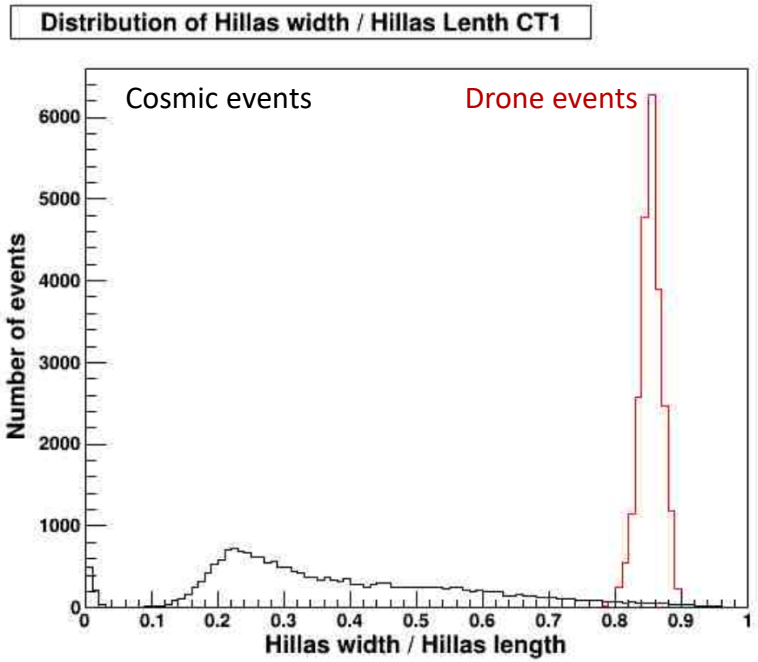
- Multiple telescopes → cross-calibration necessary
- Currently: Atmospheric muons (single track)
  - Very similar spectrum than γ
  - Ring shaped events
- Well enough for current arrays
- Future instruments such as CTA:
  - Higher precision
  - Multiple telescopes sensitive to different energies
  - → Wavelength dependent effects
  - Not possible with muons as spectrum fixed (Cherenkov at low altitude)




- Solution: Drone with LED emitting pulses flying above telescope array
  - Calibrate telescopes by comparing images in camera of different telescopes
  - First inter-calibration of Cherenkov telescopes with single light source
  - cf. A.M. Brown, "On the prospects of cross-calibrating the Cherenkov Telescope Array with an airborne calibration platform", Astroparticle Physics 97 (2018)

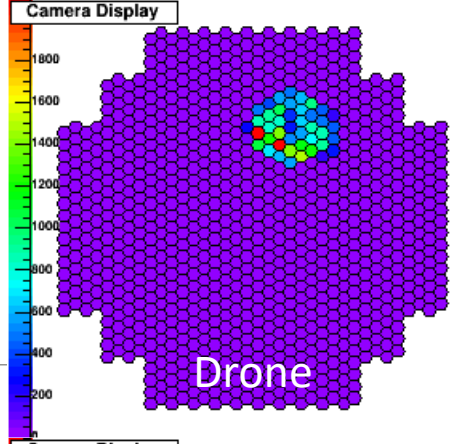
# Drone Measurements

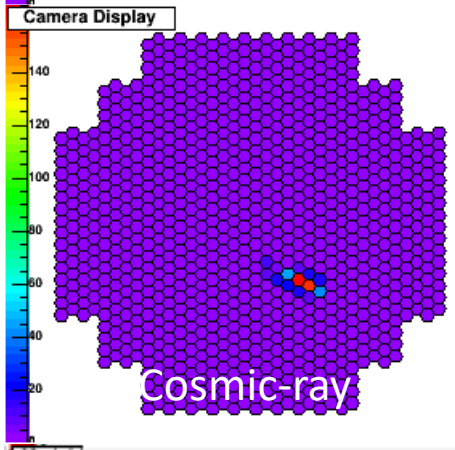


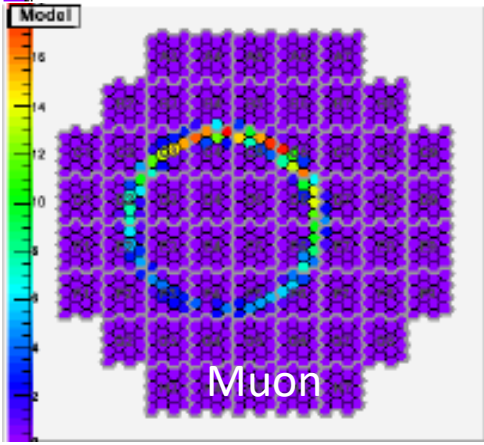




# Event Selection

- Three types of events in data: Drone events, cosmic-ray events and muon rings
- Selection of drone events based on 2 criteria:
  - 3 or more telescopes triggered
  - Minimum image amplitude
- Less than 0.3% of events classified differently for 2 criteria → very consistent results, even though no big correlation in categories expected
- Worse separation with other possible selection variables

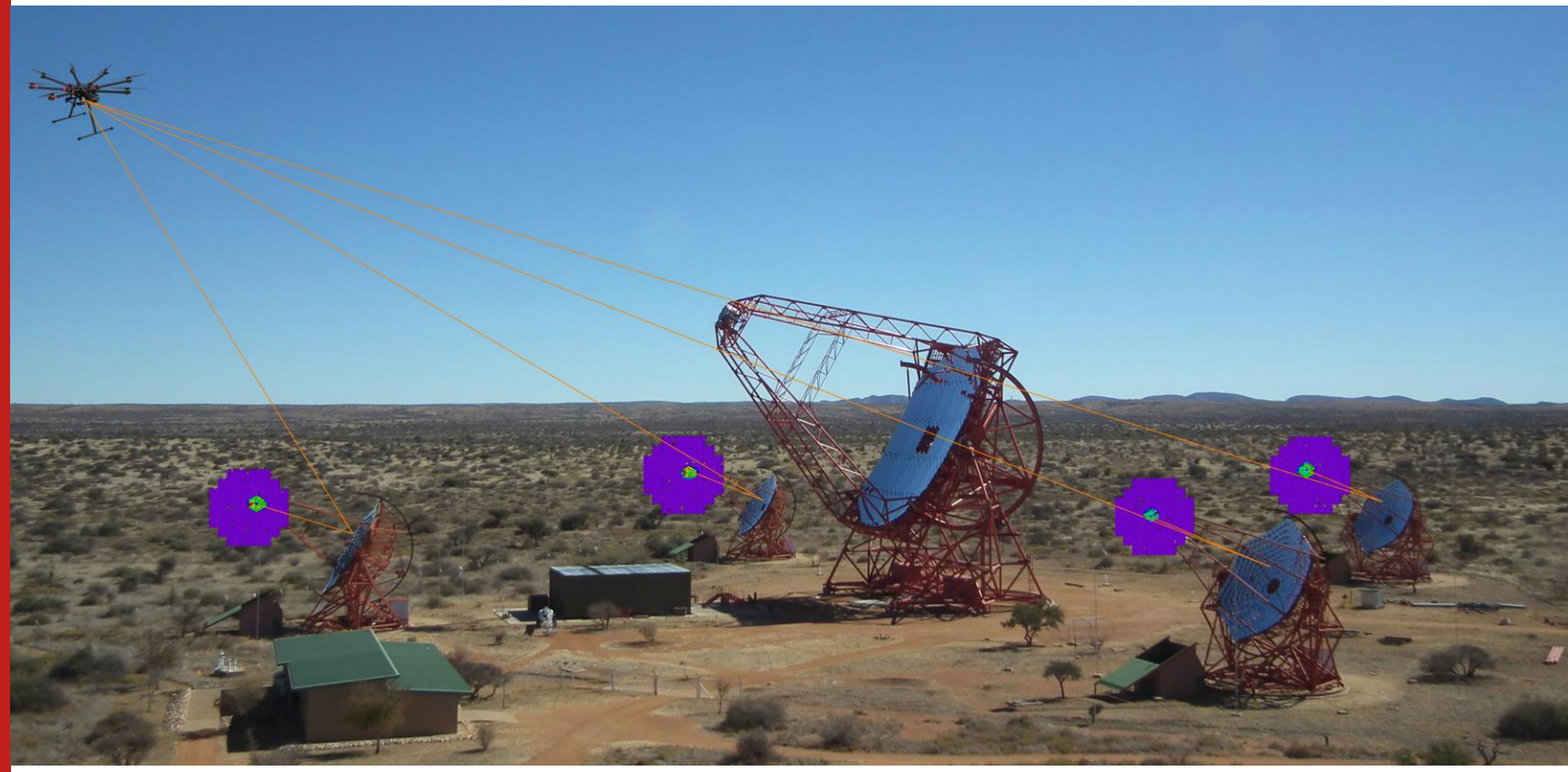


# Position Determination of Drone

- Precise position crucial for inter-calibration to work ($I$ dependent on $d$)
- Direction w.r.t. each telescope: From pointing direction & centre of gravity of image in camera
- Drone at "intersection"(point with minimal sum of squared distances to the lines: $\chi^2$ analytically minimized)
- Statistical uncertainty: 0.1m perpendicular to pointing direction & 0.65m in pointing direction



$$\chi^2 = \mathrm{d}(\mathrm{l}_1, \mathrm{D})^2 + \mathrm{d}(\mathrm{l}_2, \mathrm{D})^2 + \mathrm{d}(\mathrm{l}_3, \mathrm{D})^2 + \mathrm{d}(\mathrm{l}_4, \mathrm{D})^2$$

# Inter-Calibration of Telescopes

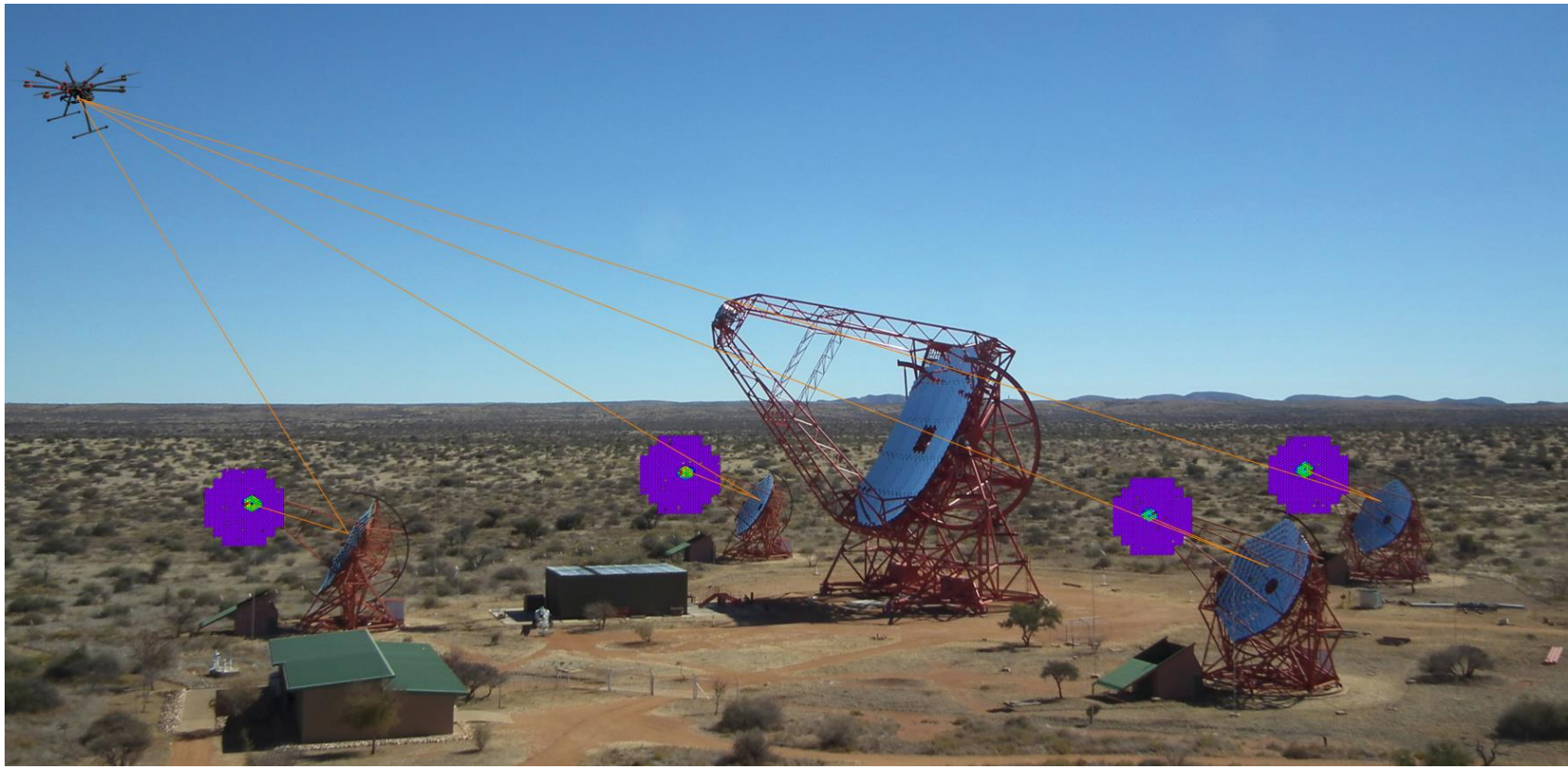
- $I \propto \frac{1}{d^2}$ (Change due to atmospheric absorption negligible for small differences of $d$)
- Relative efficiency of telescope $i$: $\epsilon_i = \frac{(Id^2)_i}{<(Id^2)_j>}$
- Statistical uncertainty from uncertainty on $Id^2$ in each telescope and uncertainty propagation
- Telescopes inter-calibrated within 4.1% (w.r.t to previous muon inter-calibration)
- Best consistency ever achieved with two methods without common uncertainties

| Telescope | Relative efficiency | Uncertainty on relative efficiency |
|---|---|---|
| CT1 | 1.0288 | 0.0003 |
| CT2 | 0.9732 | 0.0003 |
| CT3 | 1.0414 | 0.0004 |
| CT4 | 0.9567 | 0.0003 |

# Other Advantages of Drone

# Pointing Corrections

- Bending of telescope mast due to weight leads to mispointings of telescopes
- Mispointings lead to shift of position of image in camera
- Effect corrected for with pointing corrections derived from mechanical model of structure
- Can also be measured using residuals in triangulation of position determination
- Verify and ameliorate H.E.S.S. pointing corrections



# Outlook

- Monitor lowest layers of atmosphere (absorption)
- Use drone for flatfielding (inter-calibration of the different pixels of a telescope) too

- In future campaigns:
  - Inclusion of CT5 to test real cross-calibration of different telescope types
  - Mount multiple LEDs emitting at different wavelengths on drone (Investigating wavelength dependency of inter-calibration)

- Further information:
  - A.M. Brown, "On the prospects of cross-calibrating the Cherenkov Telescope Array with an airborne calibration platform", Astroparticle Physics 97 (2018)
  - H.E.S.S. source of the month of February: https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2019/02/