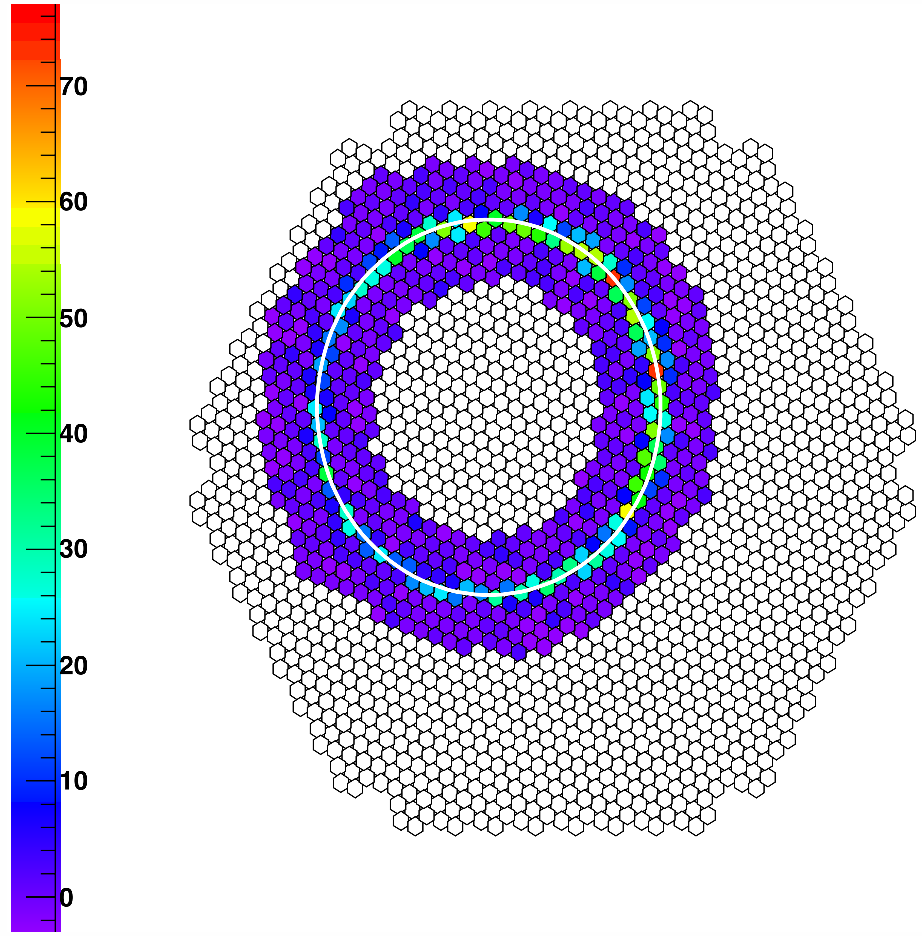
Reconstructing Muons in CTA

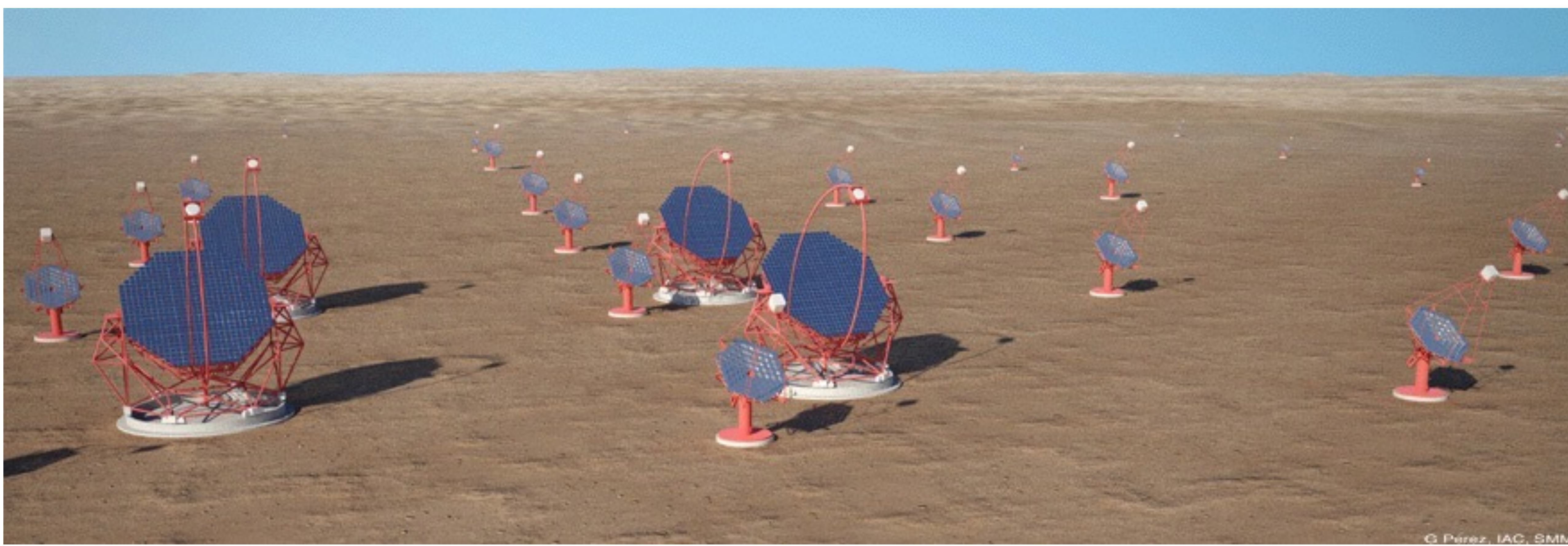


CCF Meeting, 23/06/16

A. Mitchell

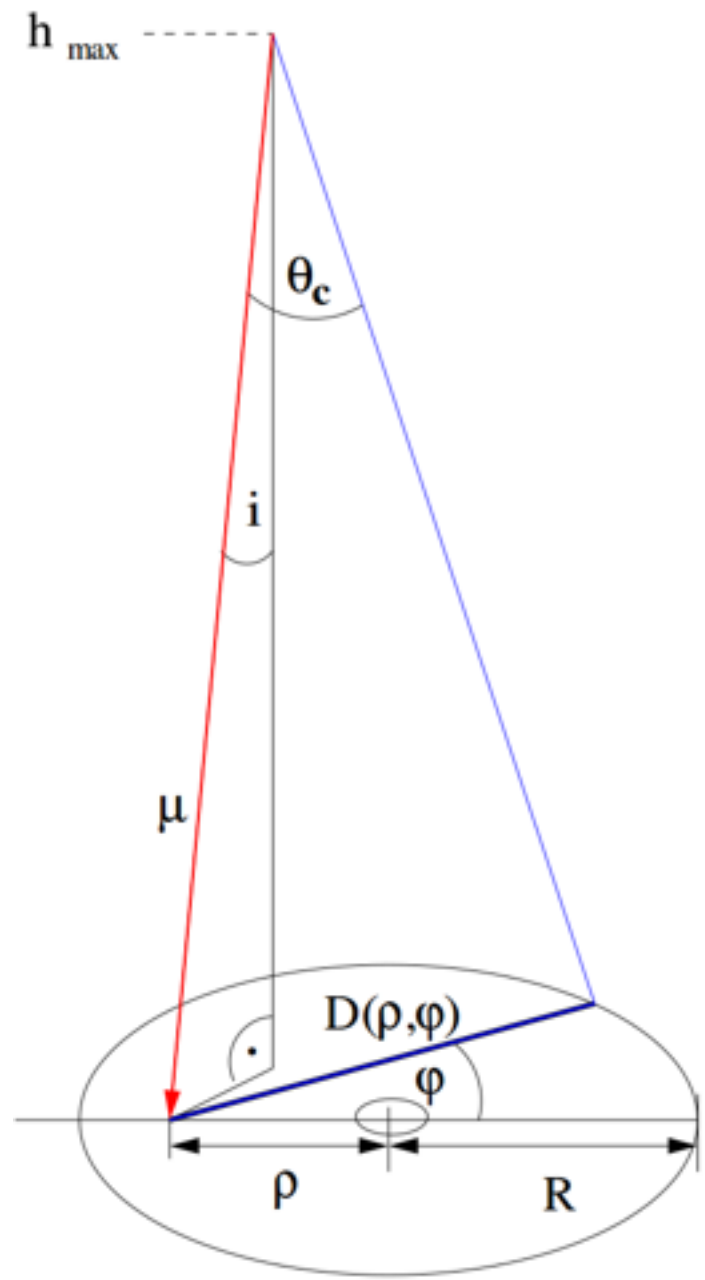
Need for Generic Algorithms

- CTA will comprise a variety of telescopes and cameras
- Don’t want every camera/telescope team to have a separate reconstruction algorithm
- Ideally a single, generic algorithm in the pipeline, which can be applied to all
- —> Need flexible/generalised approach



H.E.S.S. II Approach

- H.E.S.S. II is the only currently operational multi-sized IACT array
- Needed to rework the muon calibration code for use on both telescope types
- Amount of light from muon in one pixel depends on telescope geometry



$$I_{pe} = \varepsilon_\mu I(\theta_c, \rho, \phi, \omega) = \varepsilon_\mu \frac{\alpha}{2} \frac{\omega}{\theta_c} I \sin(2\theta_c) D(\rho, \phi)$$

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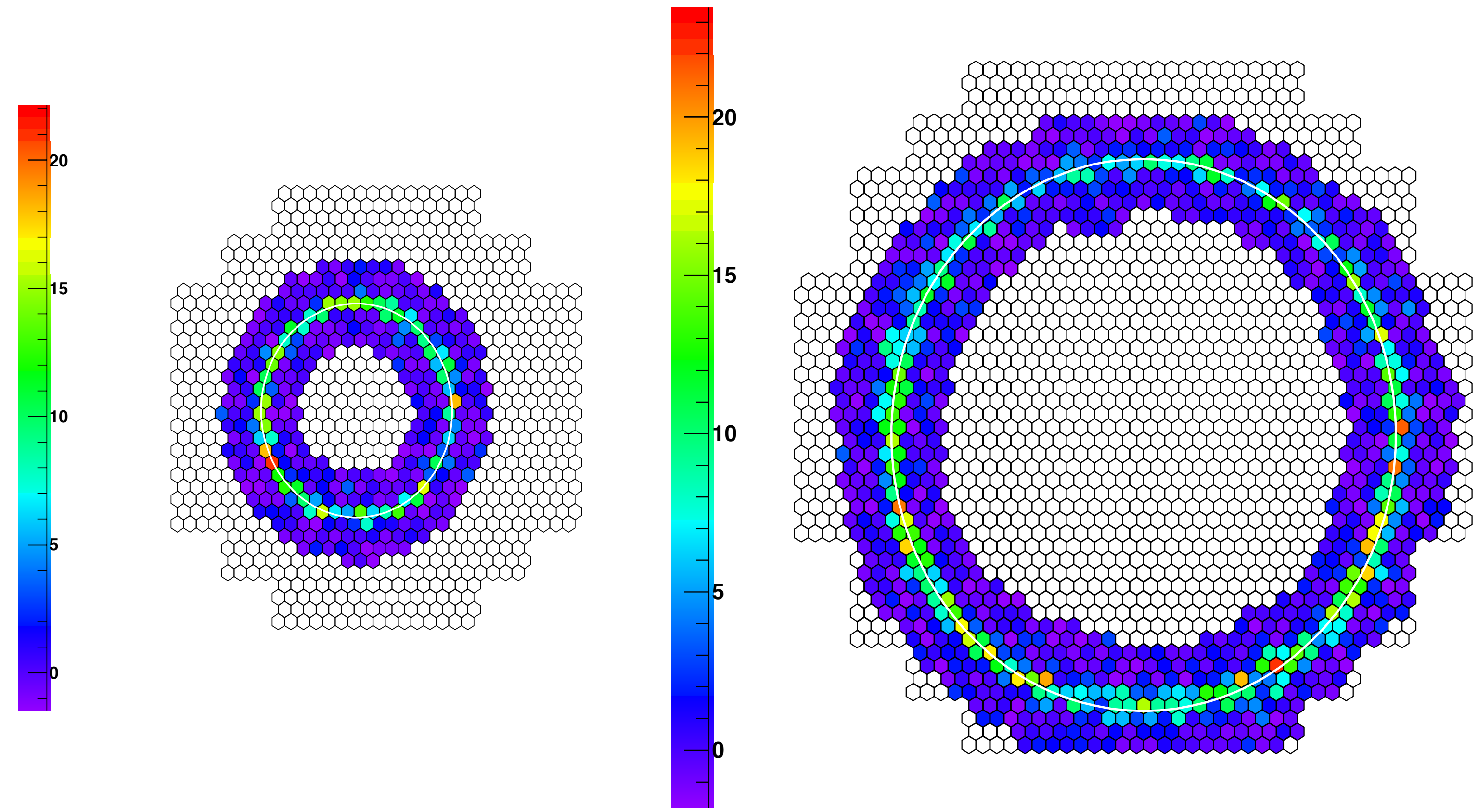

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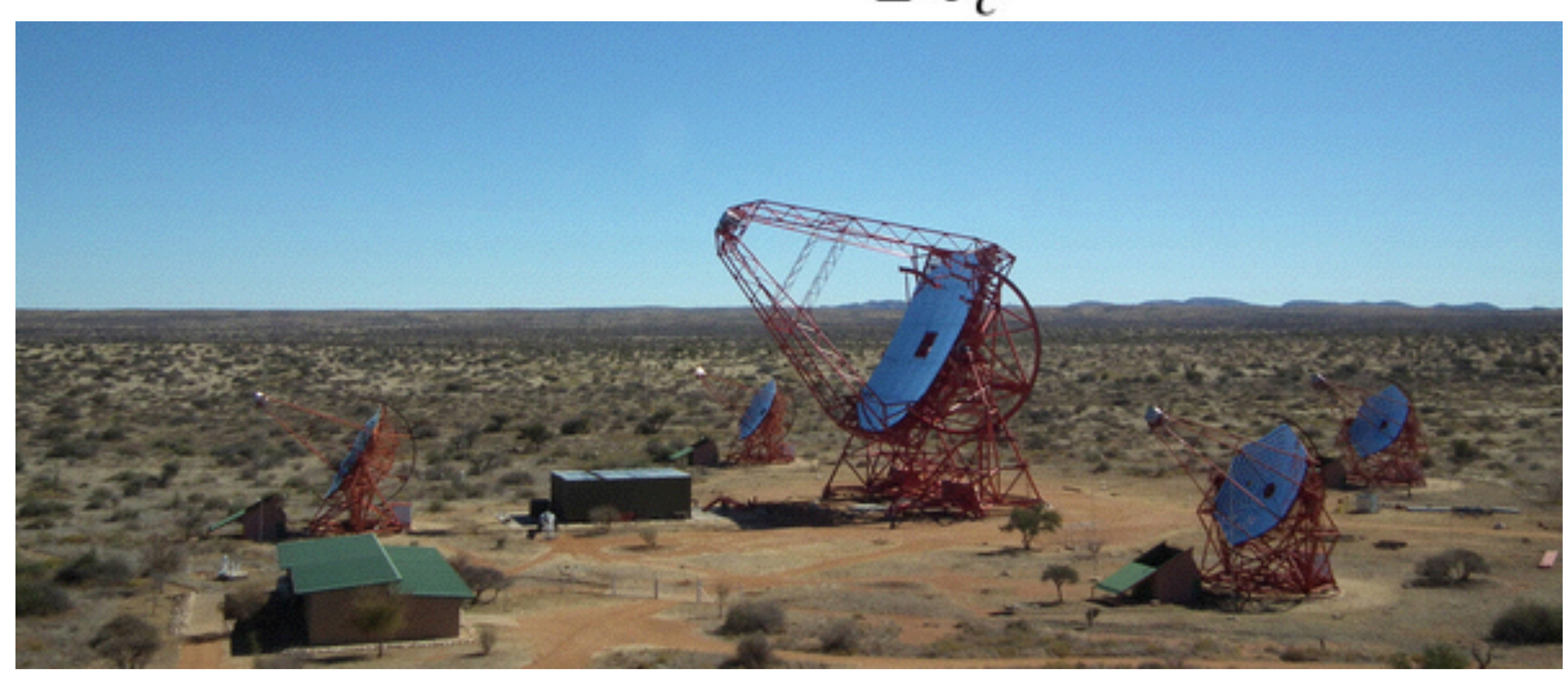

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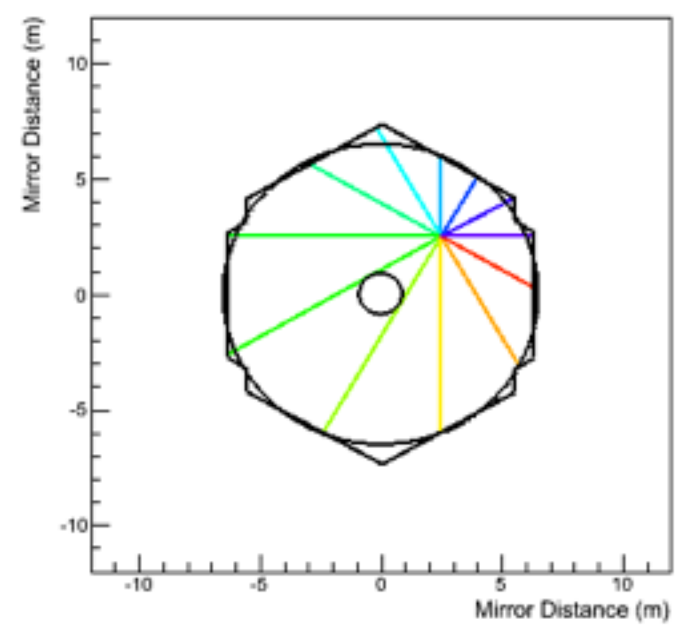

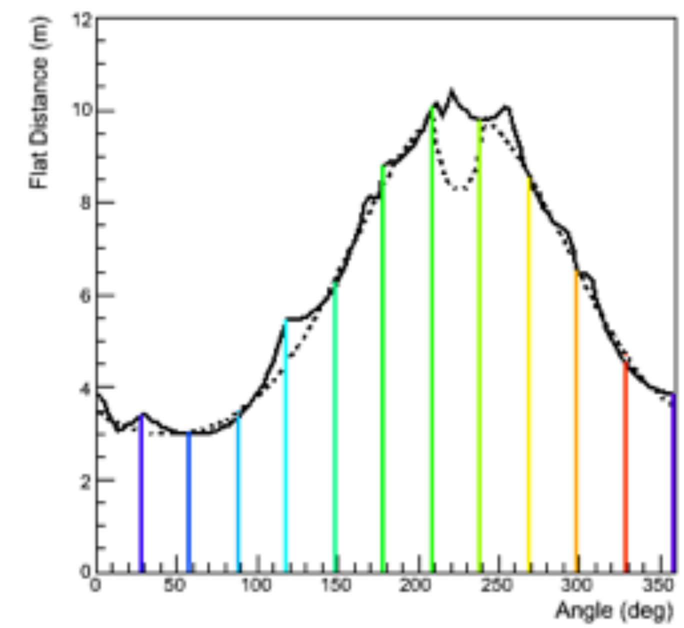

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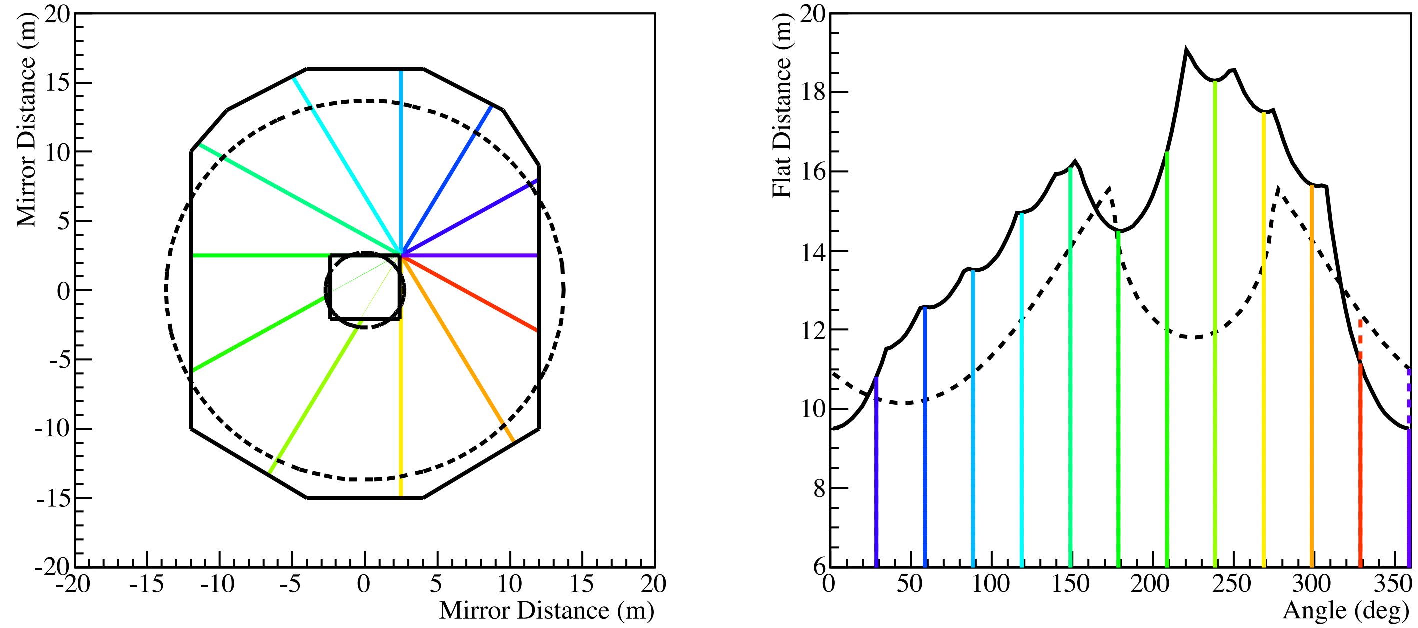
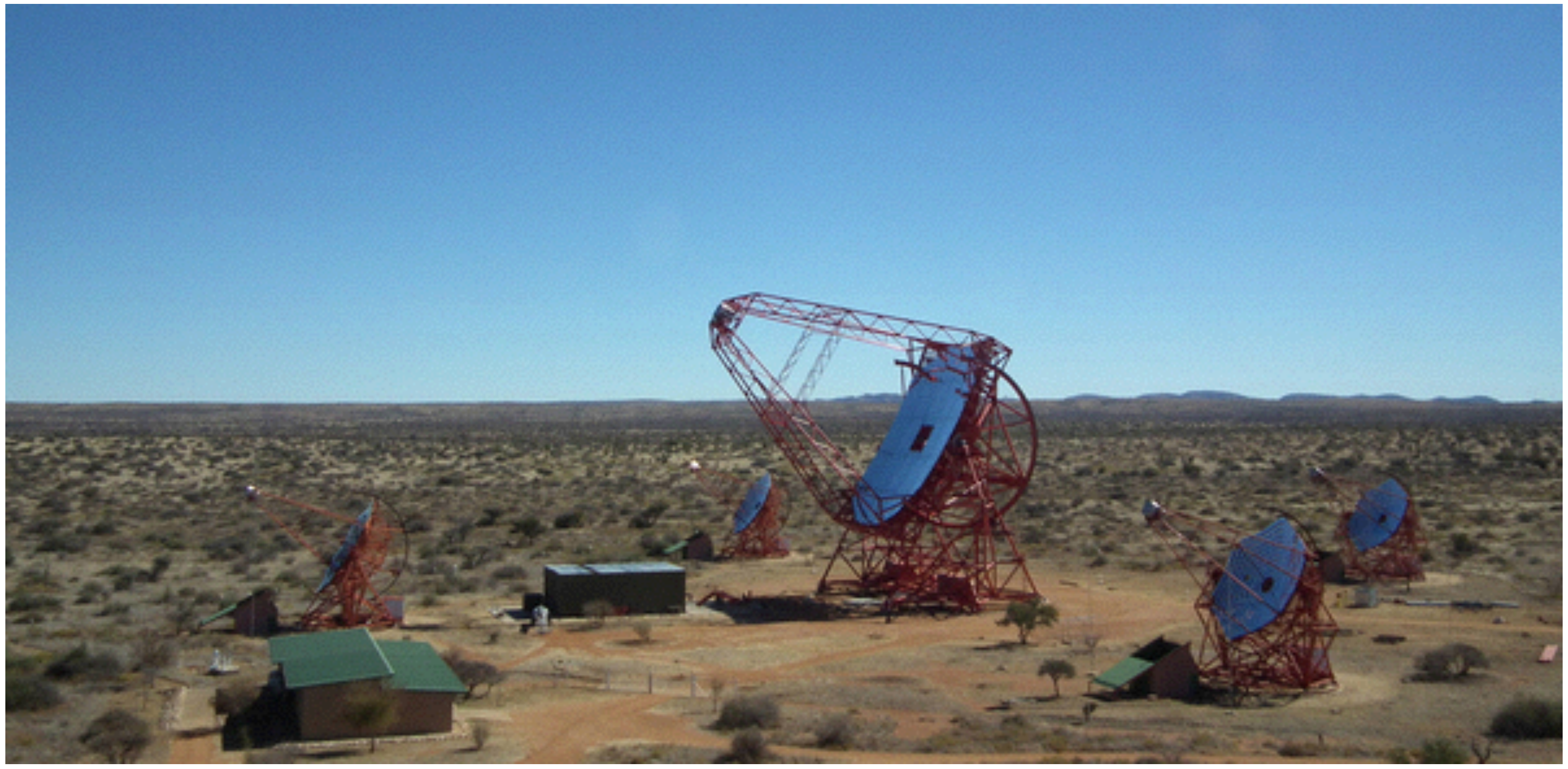
- Same code now used for all HESS telescopes; telescope configuration passed as input

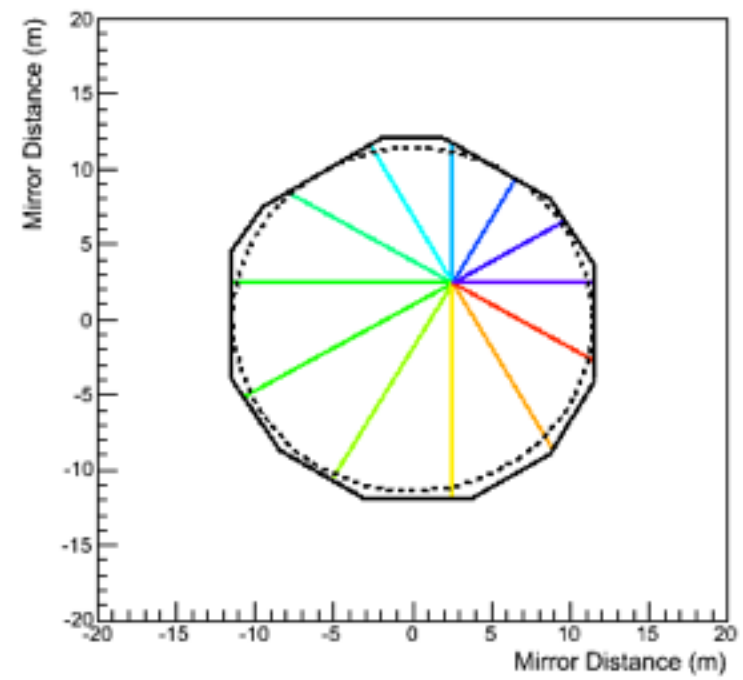


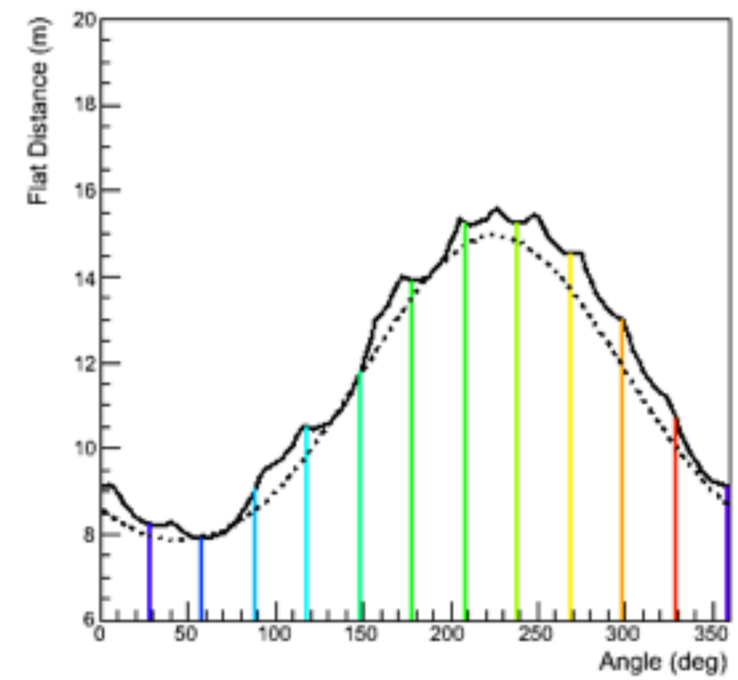


CTA simulations

- Simulated muons for all telescopes with prod-3
- Converted output into HESS readable format
- New mirror descriptions (within the muon code) required for CTA telescopes
- Cuts required optimising
- Same code now used for all HESS **and CTA** telescopes; telescope configuration passed as input

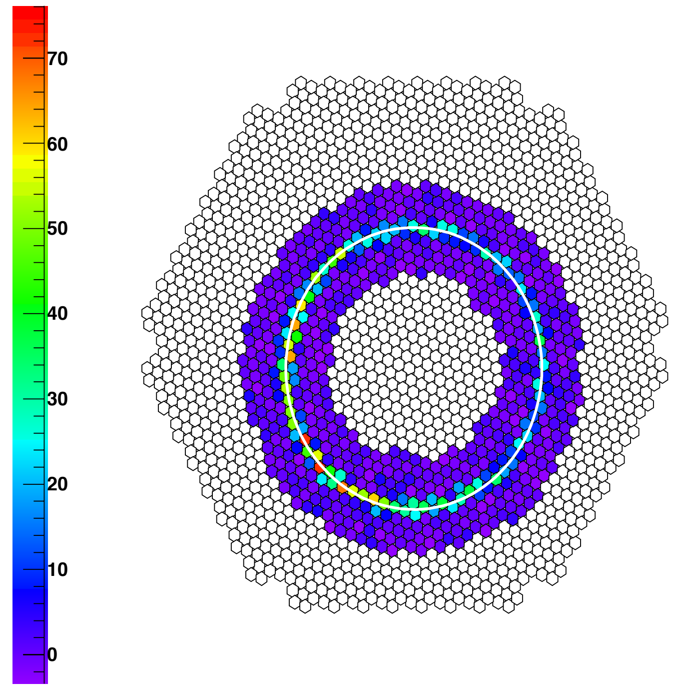
LST





CTA Muon Events

- Muon events are fitted with a circle
- A 2D analytical expectation is calculated
- A 2D pixel log-likelihood fit of the event to the expectation is performed
- Muon Efficiency is a free parameter of the fit
- ω - angular pixel size



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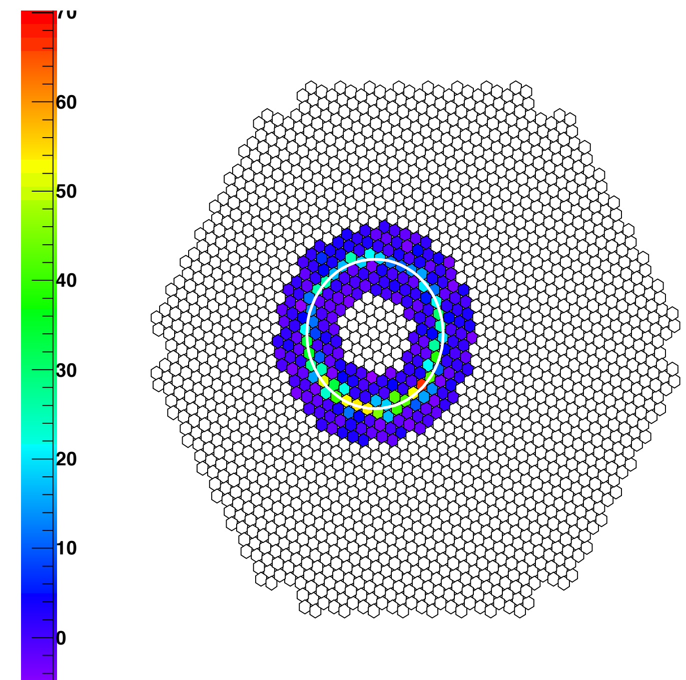

MST

$$I_{pe} = \varepsilon_\mu I(\theta_c, \rho, \phi, \omega) = \varepsilon_\mu \frac{\alpha}{2} \frac{\omega}{\theta_c} I \sin(2\theta_c) D(\rho, \phi)$$

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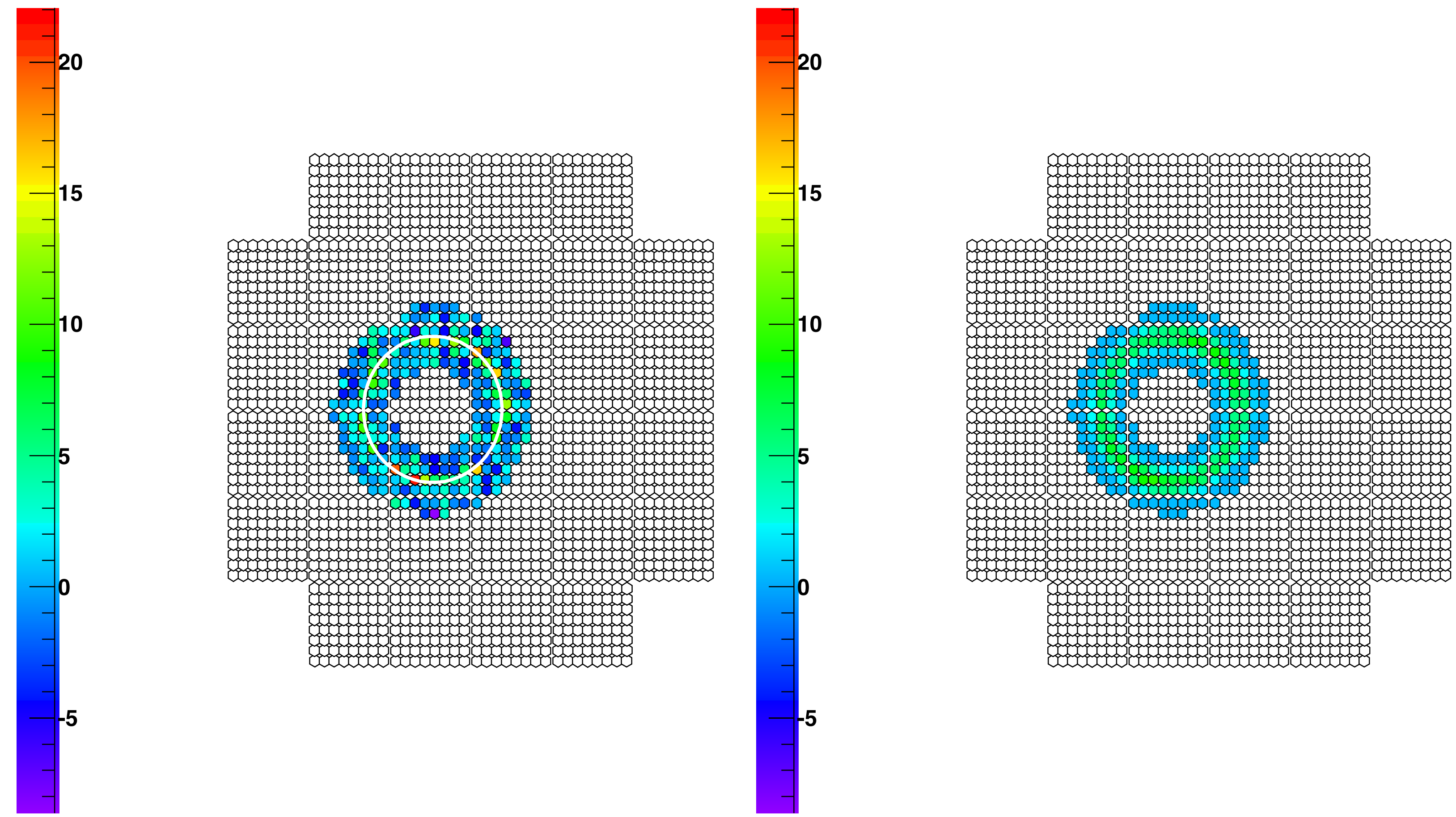


SST-GCT

$$I_{pe} = \varepsilon_{\mu} I(\theta_c, \rho, \phi, \omega) = \varepsilon_{\mu} \frac{\alpha}{2} \frac{\omega}{\theta_c} I \sin(2\theta_c) D(\rho, \phi)$$

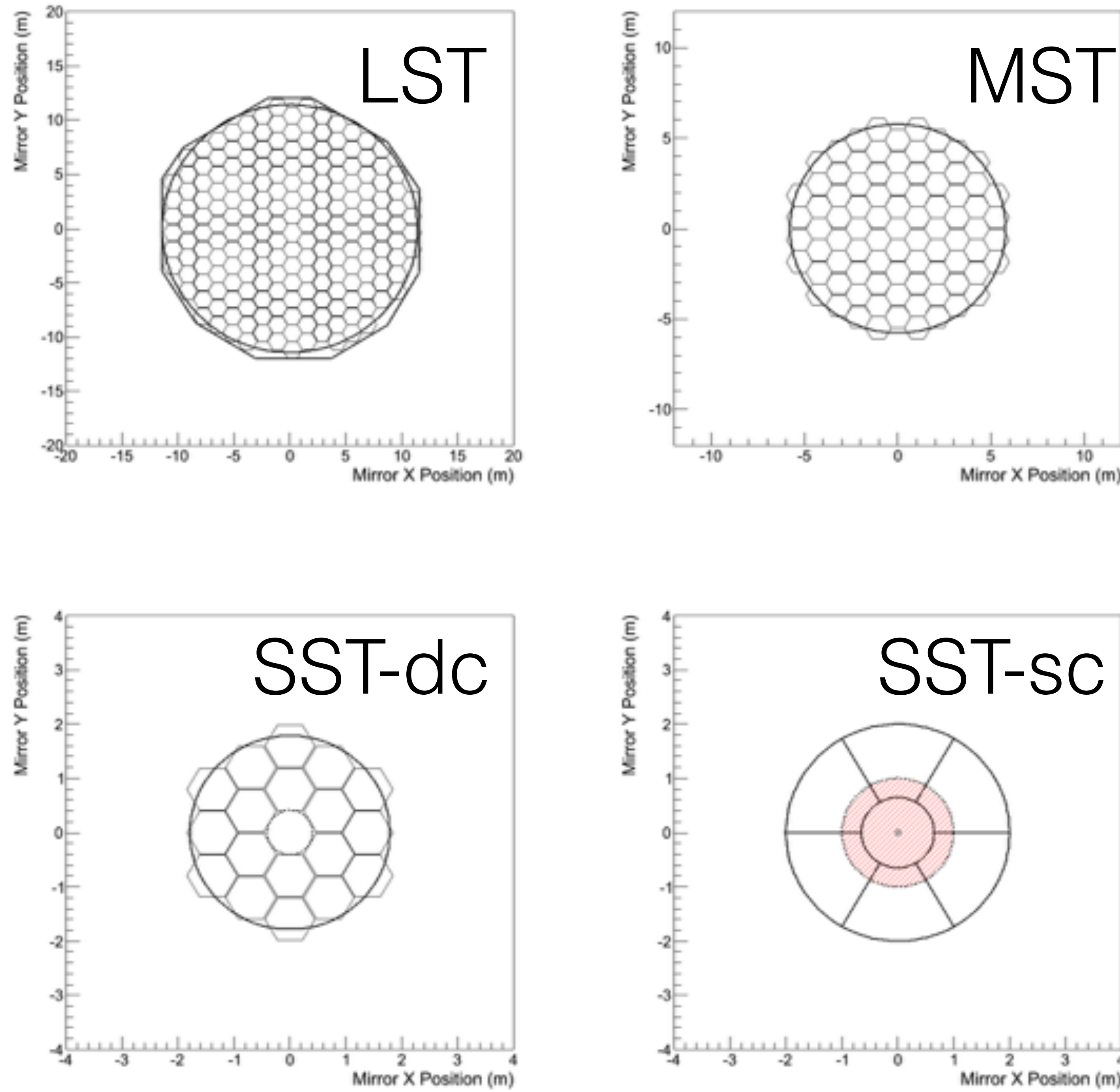
CTA Mirror Descriptions

CTA Mirrors generally well approximated by a circle

Interpolation more precise, but small corrections

Dual Mirror SSTs more complex

N.B. SST-dc ~ SST-1M, and SST-sc ~ SST-GCT , but some minor differences



Dual-Mirror telescopes

1. $\rho > R$ and $\rho \sin\phi > R'$

   $C = D$

$$D(\rho,\phi) = 2R\sqrt{1-\left(\frac{\rho}{R}\right)^2 \sin^2\phi}$$

2. $\rho > R$ and $\rho \sin\phi < R'$

   $C = D - D'$

$$D'(\rho,\phi) = 2R'\sqrt{1-\left(\frac{\rho}{R'}\right)^2 \sin^2\phi}$$

3. $\rho < R$ and $\rho \sin\phi > R'$

   $C = D$

$$D(\rho,\phi) = R\left[\sqrt{1-\left(\frac{\rho}{R}\right)^2 \sin^2\phi} + \frac{\rho}{R}\cos\phi\right]$$

4. $\rho < R$ and $\rho \sin\phi < R'$

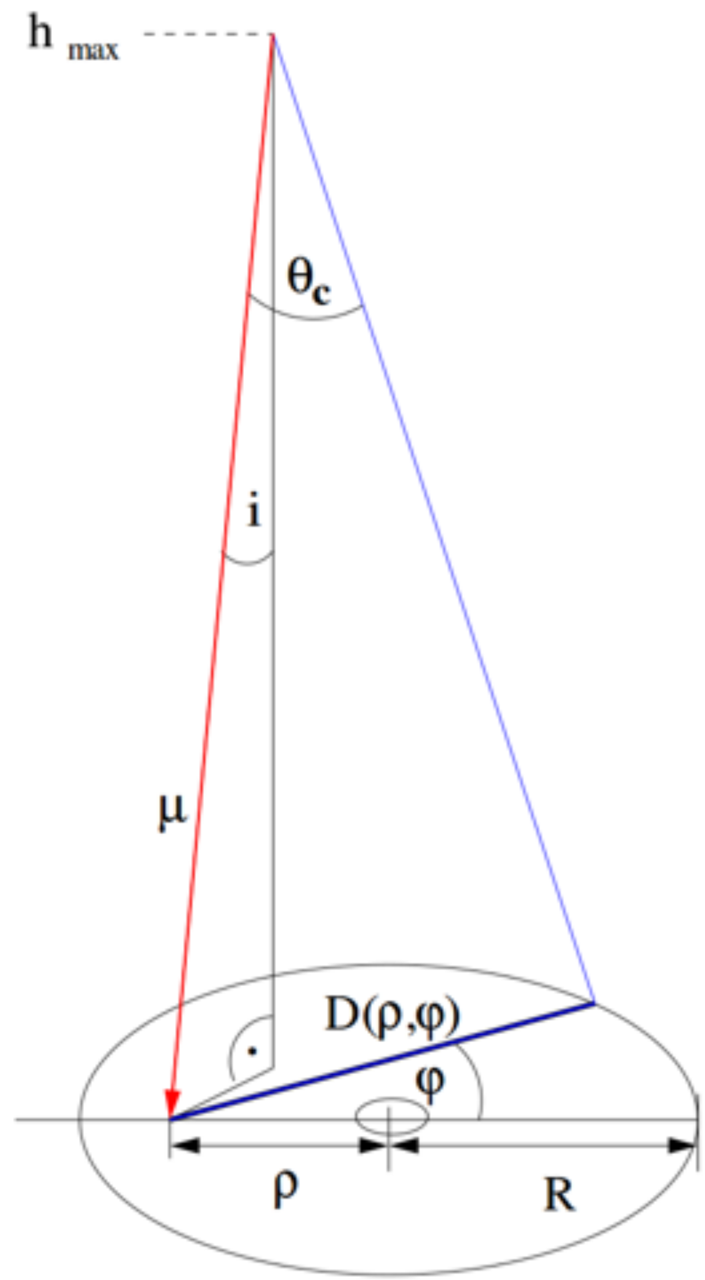
   (a) $\rho > R'$

   $C = D - D'$ (3.,2.)

   (b) $\rho < R'$

   $C = D - D'$ (3.,4.)

$$D'(\rho,\phi) = R'\left[\sqrt{1-\left(\frac{\rho}{R'}\right)^2 \sin^2\phi} + \frac{\rho}{R'}\cos\phi\right]$$



- How to treat secondary mirror?
- Same as hole in centre of HESS mirrors? Or like shadowing?
- Efficiency of mirrors separately, or telescope as a whole?

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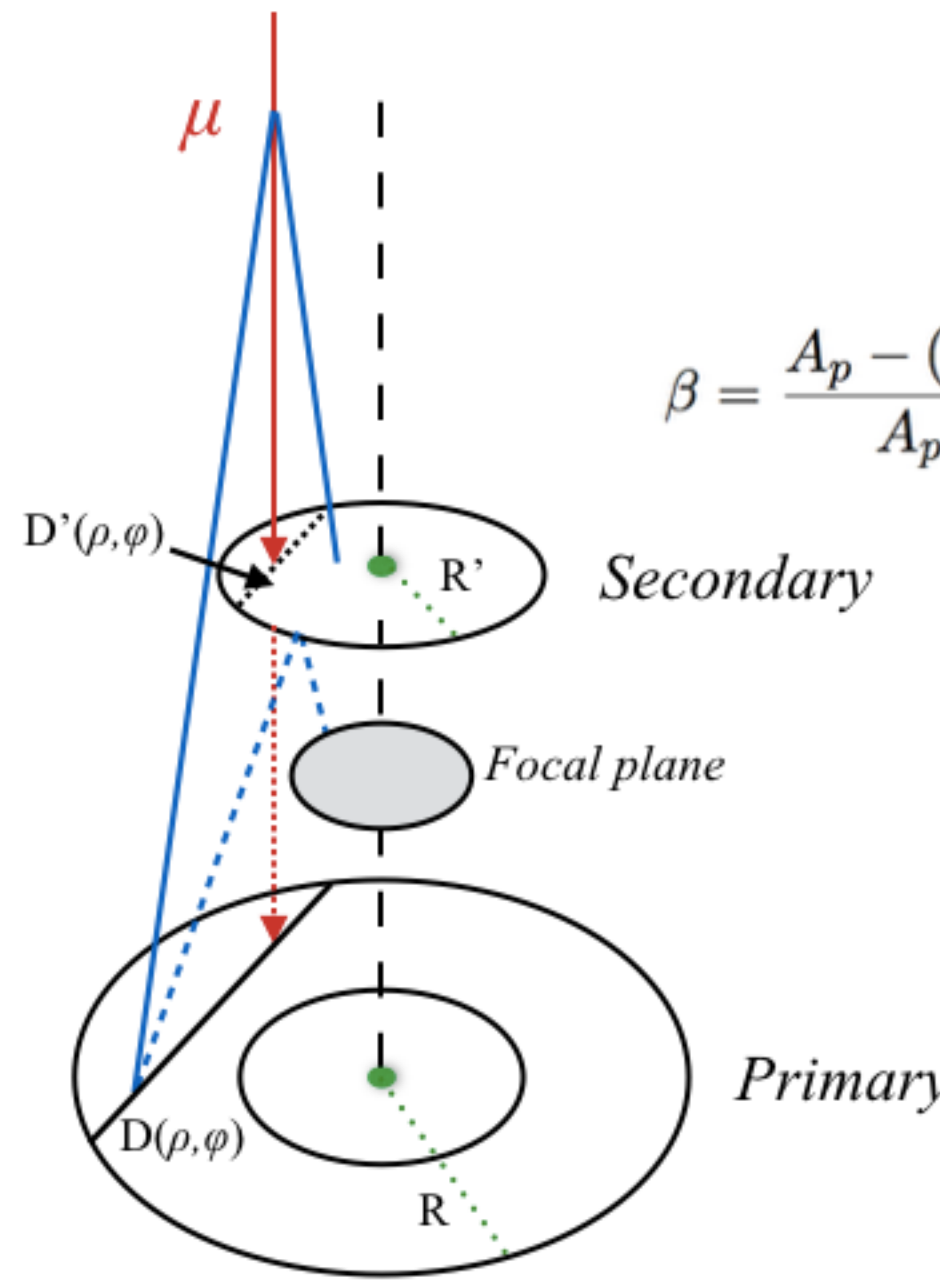

$$\beta = \frac{A_p - (A_s - A_{sh})}{A_p - A_{ph}}$$

- How to treat secondary mirror?
- Same as hole in centre of HESS mirrors? Or like shadowing?
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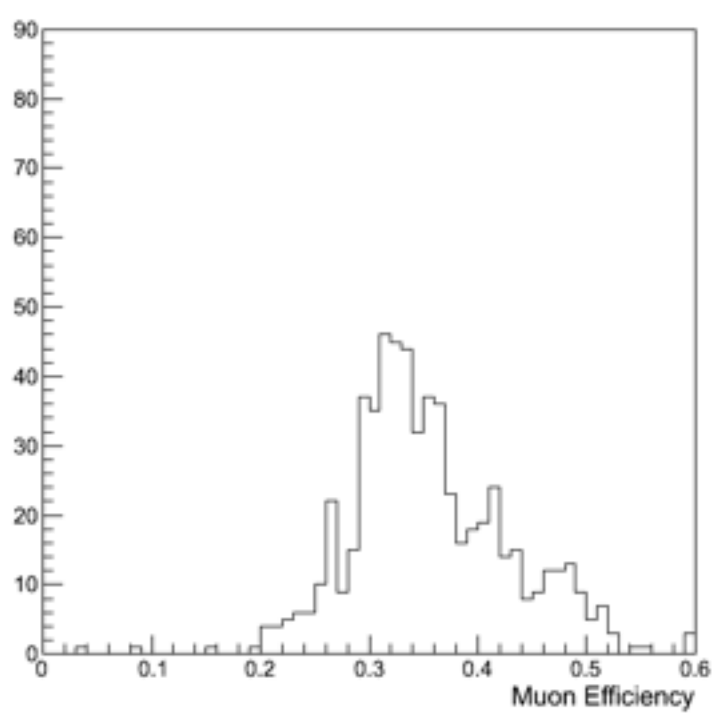
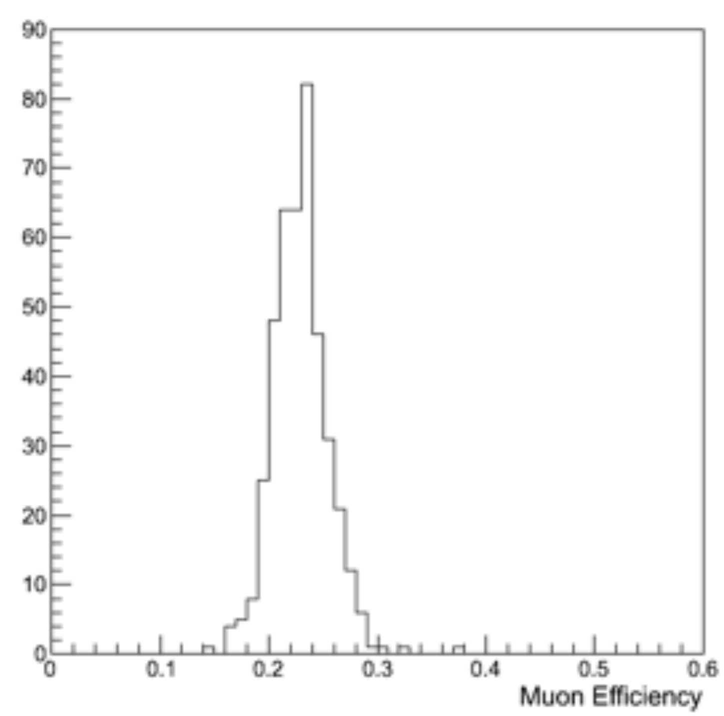
Dual-Mirror telescopes

- Find poor distribution when treating the secondary mirror as a hole/loss of light (left)
- Improved by adding contributions to the chord across both mirrors (right)
- However, need to scale to account for the overall shadowing

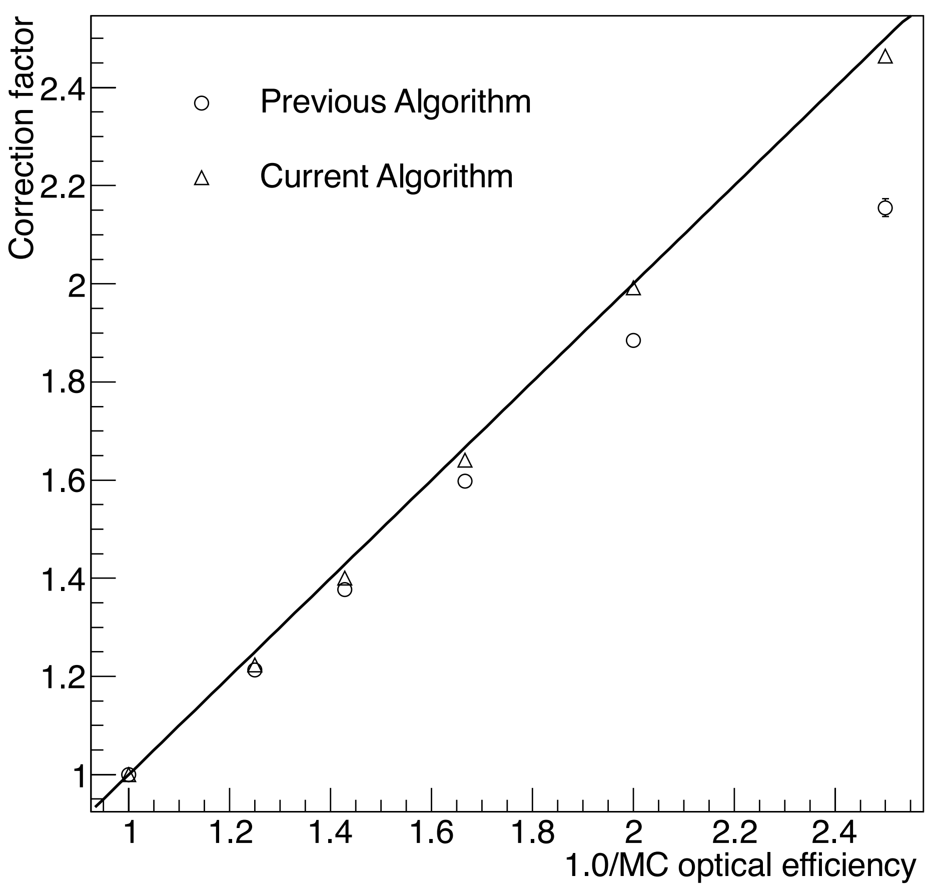
$$\beta = \frac{A_p - (A_s - A_{sh})}{A_p - A_{ph}}$$

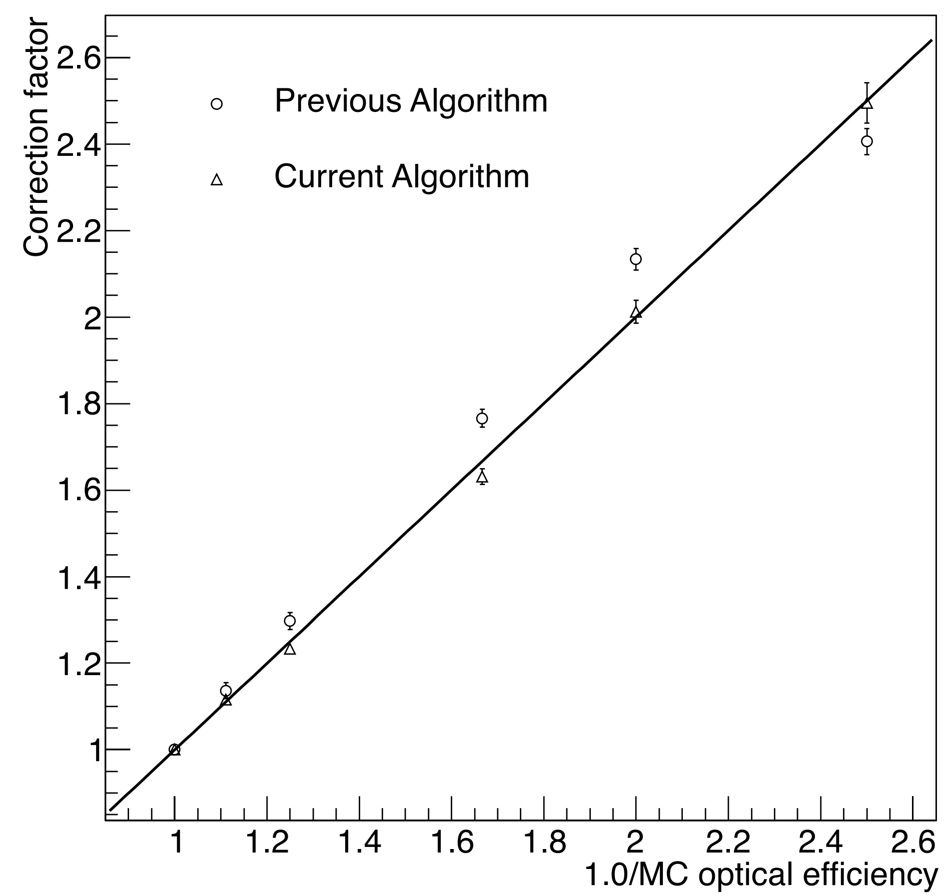
- N.B. —> Seems to work; not the final word!





H.E.S.S. II μ Performance

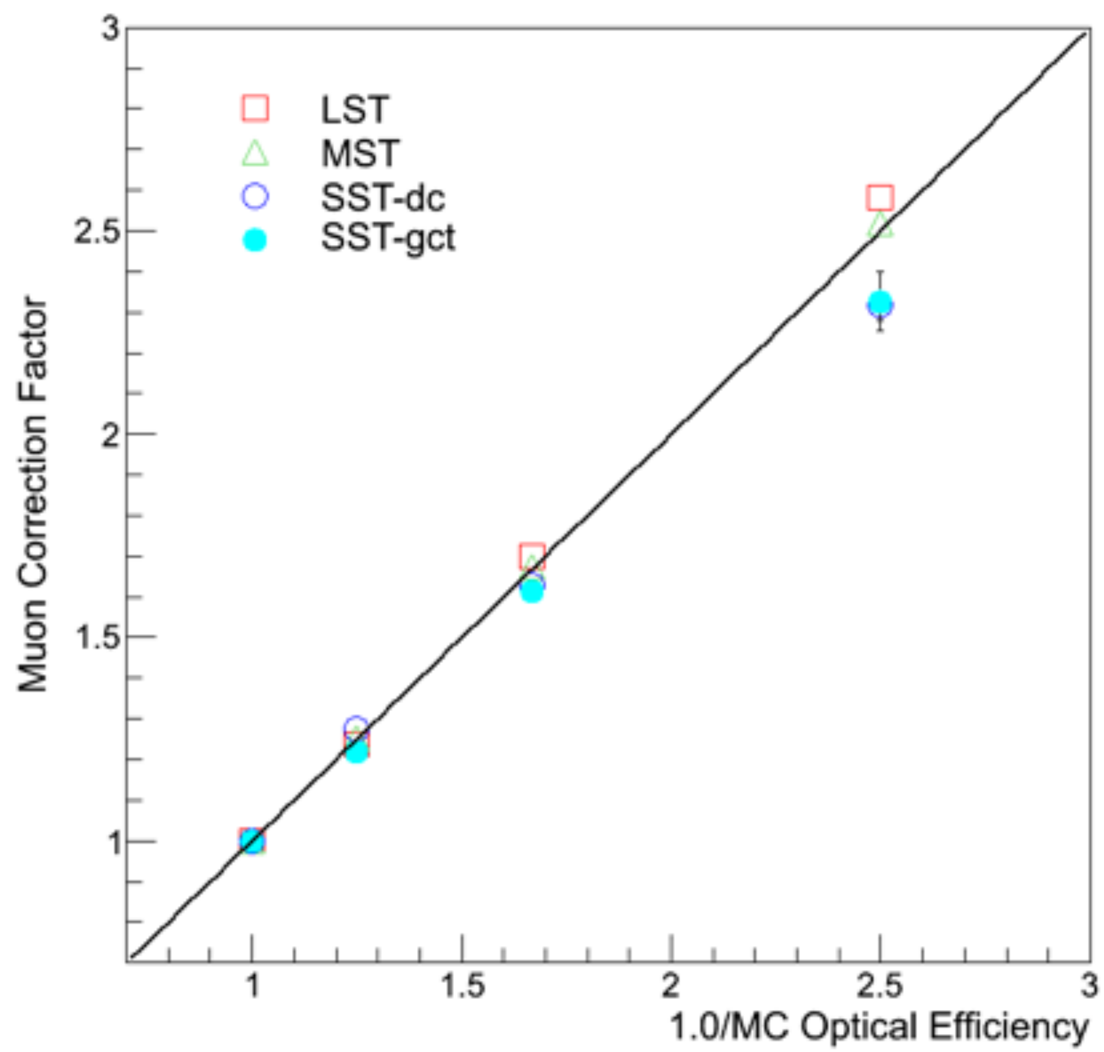




- Linearity of correction factor with degradation is improved over previous algorithm
- Shown on MC (linearity always assumed in application to data)

$$c = \varepsilon_\mu(\text{degraded MC})/\varepsilon_\mu(\text{nominal MC})$$

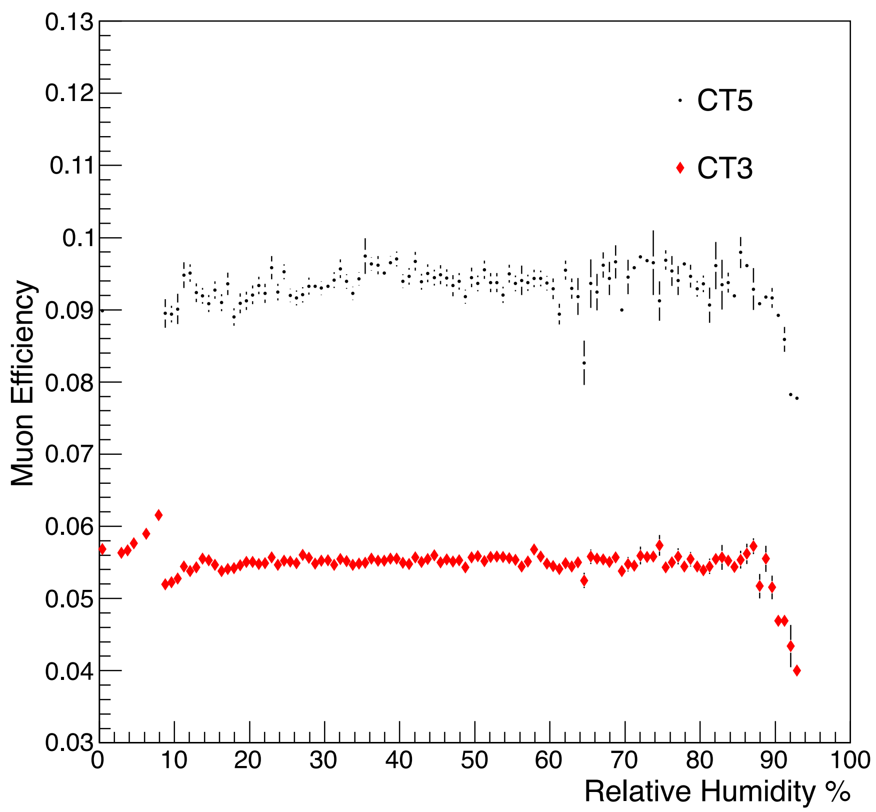
CTA μ Performance

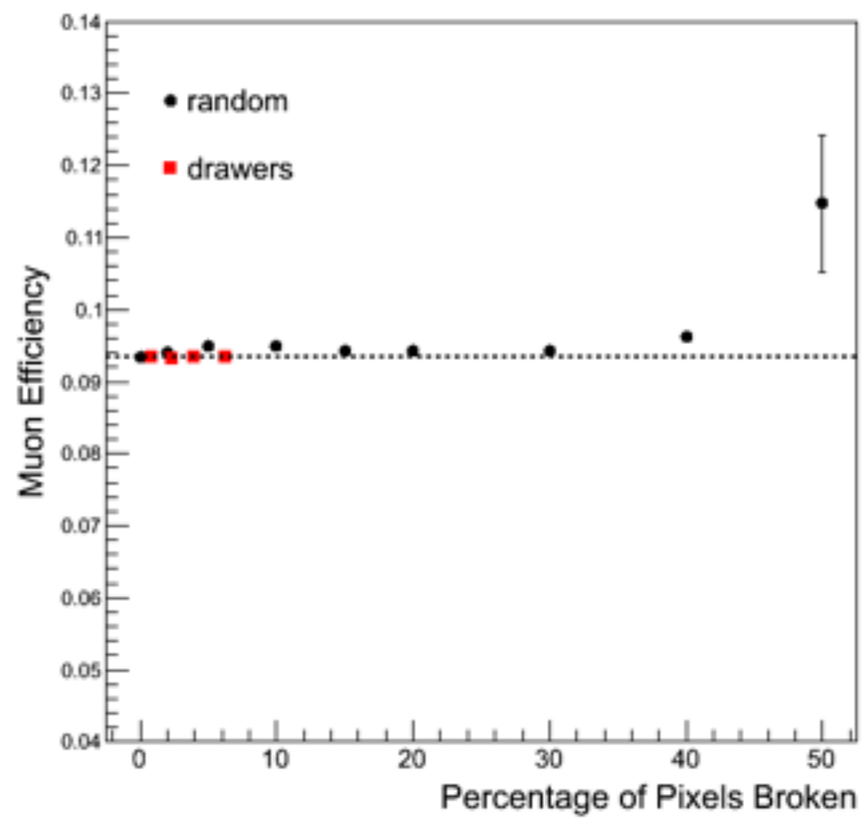


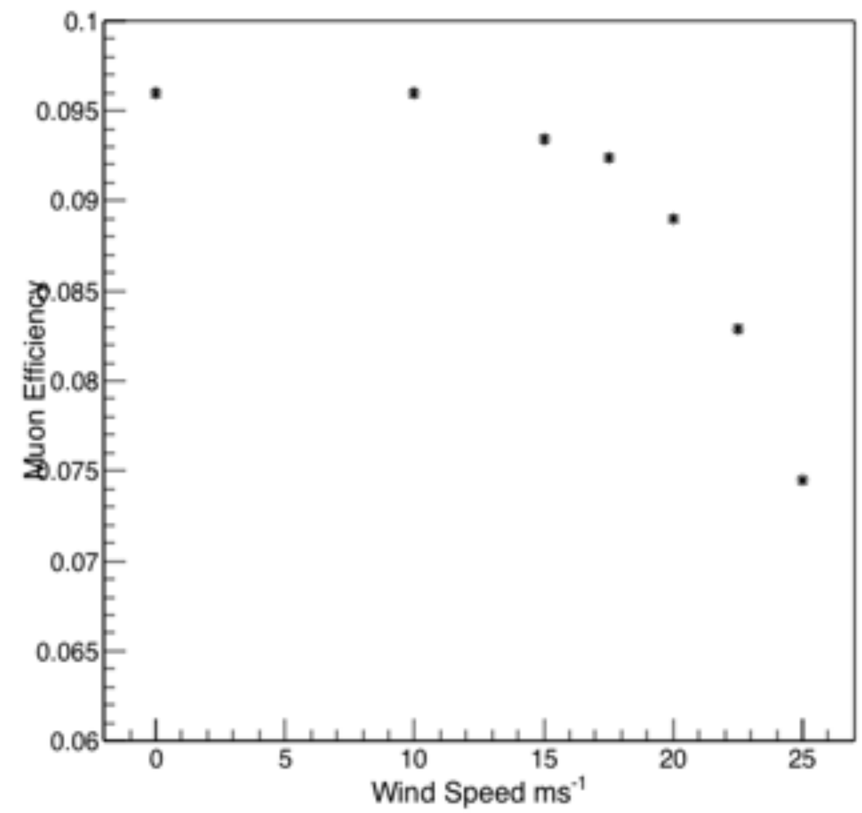
- Correction factor mostly linear with optical efficiency degradation
- Treatment of secondary mirror needs more thought
- Cut optimisation still needed

$$c = \varepsilon_{\mu}(\text{degraded MC})/\varepsilon_{\mu}(\text{nominal MC})$$

Other factors affecting muon calibration



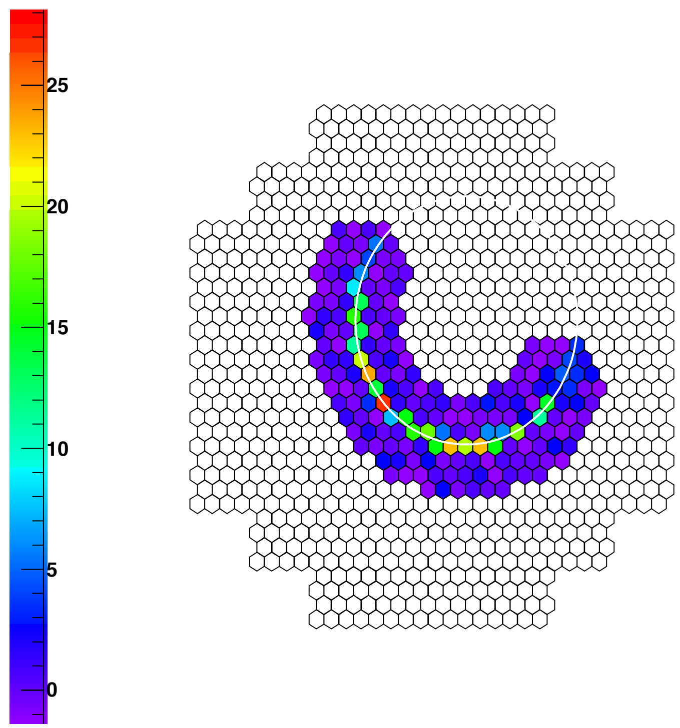


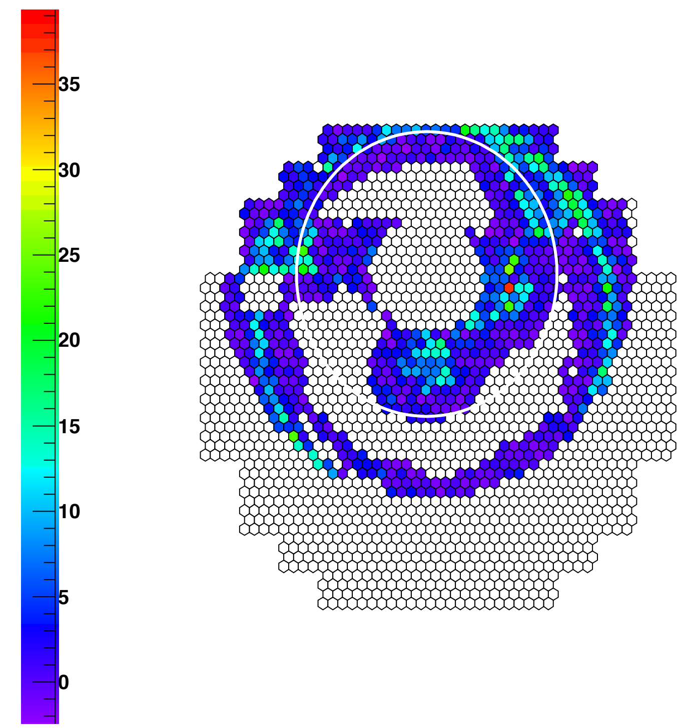


HESS

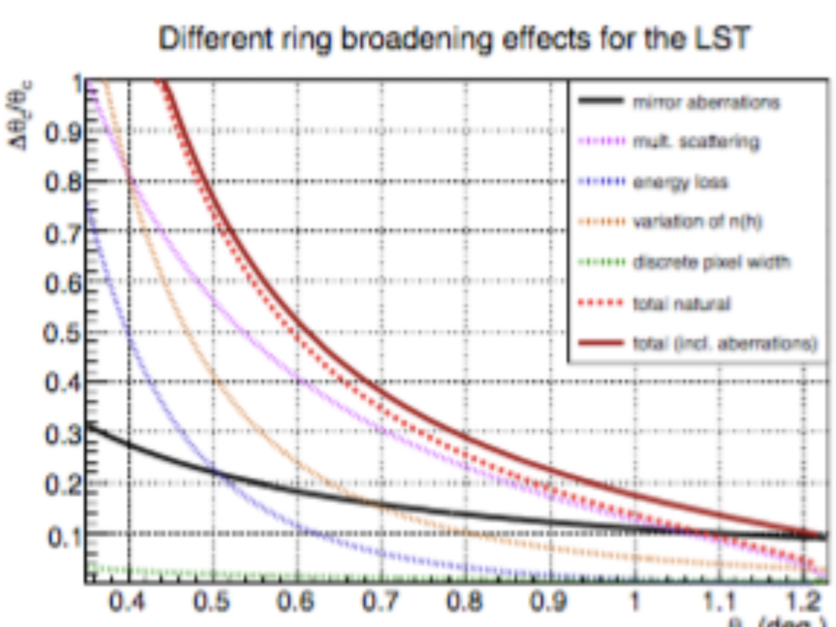
- Quality cuts based on environment and hardware:
  - Reject data with large number of broken pixels
  - Reject data with high humidity
  - (Wind speed <=> aerosol content in simulations)
- Cherenkov angle depends on atmosphere & altitude

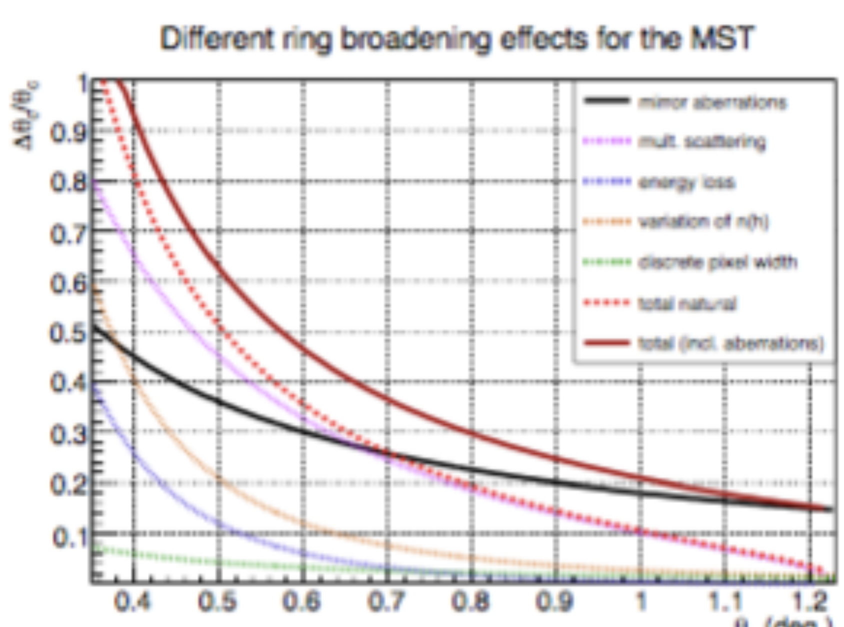
Other factors affecting muon calibration



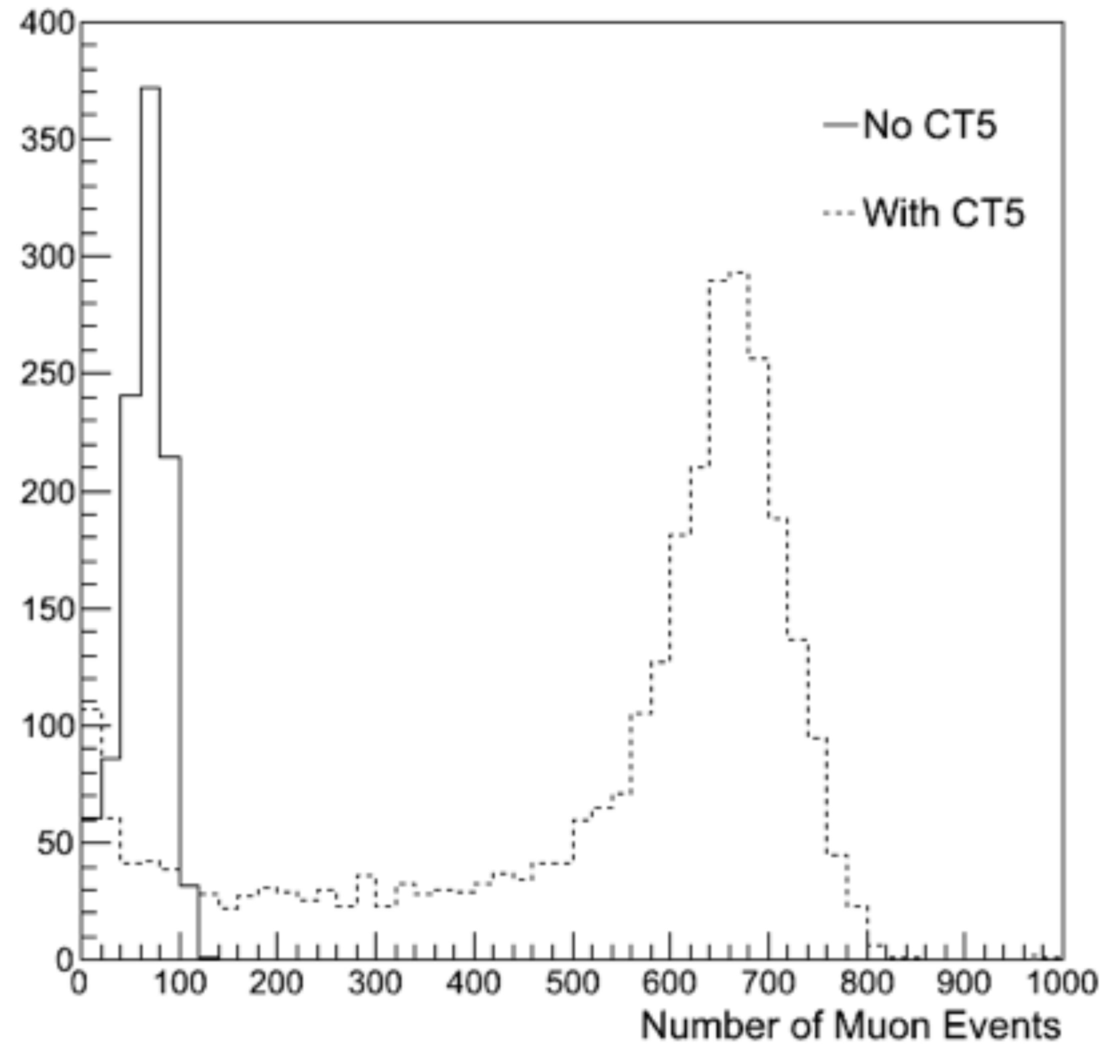


- Partial Muon Rings
- Background from hadronic shower
- Ring Broadening effects…





Number of muons



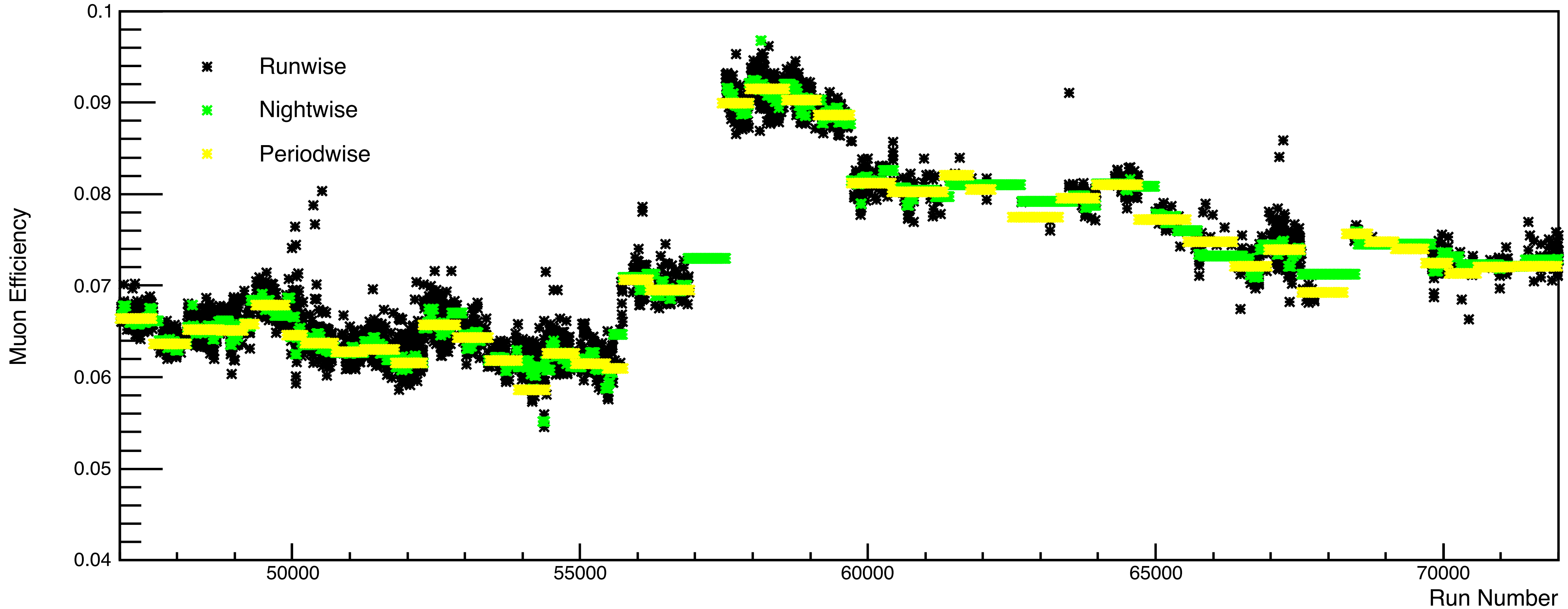
Number of muons detected depends on telescopes taking data

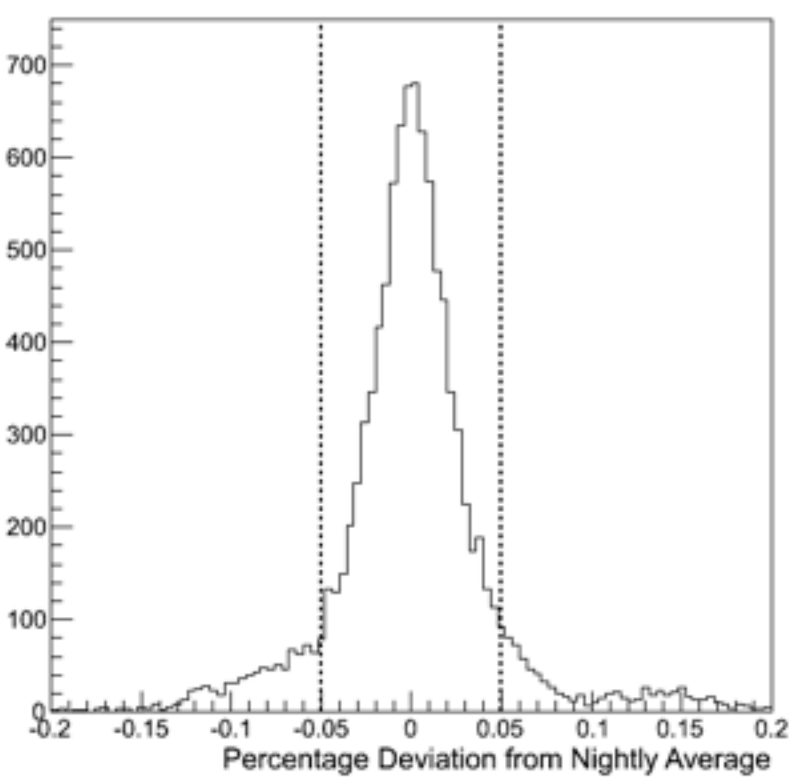
—> depends on array location

Mono muon trigger for MSTs?

Variation over time

HESS





- Should the muon calibration be implemented per “run”, per night, or per month?
- All three currently available in HESS

How to apply muon calibration to data?

- In HESS: currently, take ratio of muon efficiency to a reference value from Monte Carlo - gives a correction factor
- Correction is applied directly to **reconstructed energy** estimates rather than **image size**
- Alternatively; interpolate between lookup tables rather than applying a correction
- Also affects the **effective area** of the array

- Two schools of thought within HESS:
  - Reproduce Monte Carlo when efficiencies deviate significantly (~10%) from current set
  - Continue with same Monte Carlo, adjusting by correction factor

- Other approaches?
  - MAGIC use a conversion efficiency ratio as a correction to the **MC ADC counts - photons conversion factor**
  - MAGIC also measure the **PSF** from the width of the Gaussian fit
  - VERITAS - no corrections directly applied (?)
  - **Run-wise simulations**: no correction (factor =1.0) - monitoring only?

- **Which to adopt?** (at array level and at telescope/camera level)

“Shopping list” for input needed :

- <u>Need to know from telescope/camera specifics</u>:
  - Material of PMs/PMTs & mirrors —> which dominate degradation? ✓
  - Mirror and camera configuration (optics…) ✓
  - PSF - which effects dominate broadening? ✓
  - Can muon candidates be identified at trigger level? If so, how? (✓)

- <u>Need to know wrt CTA pipeline/Monte Carlo</u>:
  - Format of data arriving/framework of reconstruction
  - How often to simulate/reproduce MC? (per run? Muon input?)
  - *Over what time period should efficiency be averaged?*
  - *How is it foreseen to be applied in the reconstruction?*

- <u>Need to know from CCF:</u>
  - Which parameters to obtain? (timing, efficiency, psf…) ✓
  - Input from muons to atmospheric calibration or vice versa?
  - *Over what time period should efficiency be averaged? (OVERLAP)*
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Thank you for your attention

Any Questions?