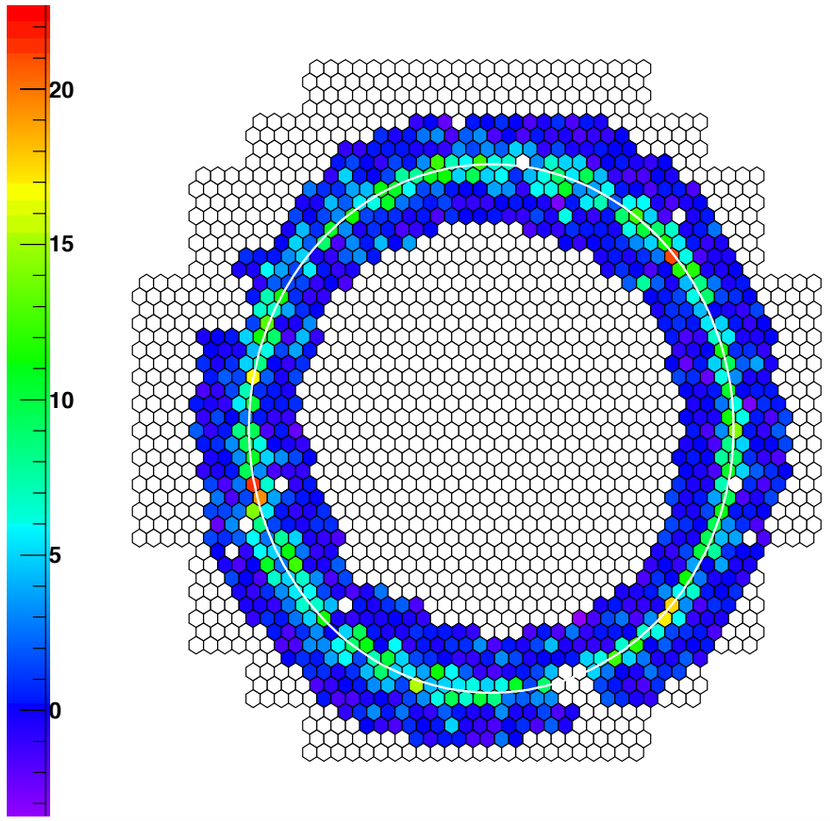
Flexible Muon Reconstruction Algorithms

or "Things to consider for implementing CTA muon calibration"



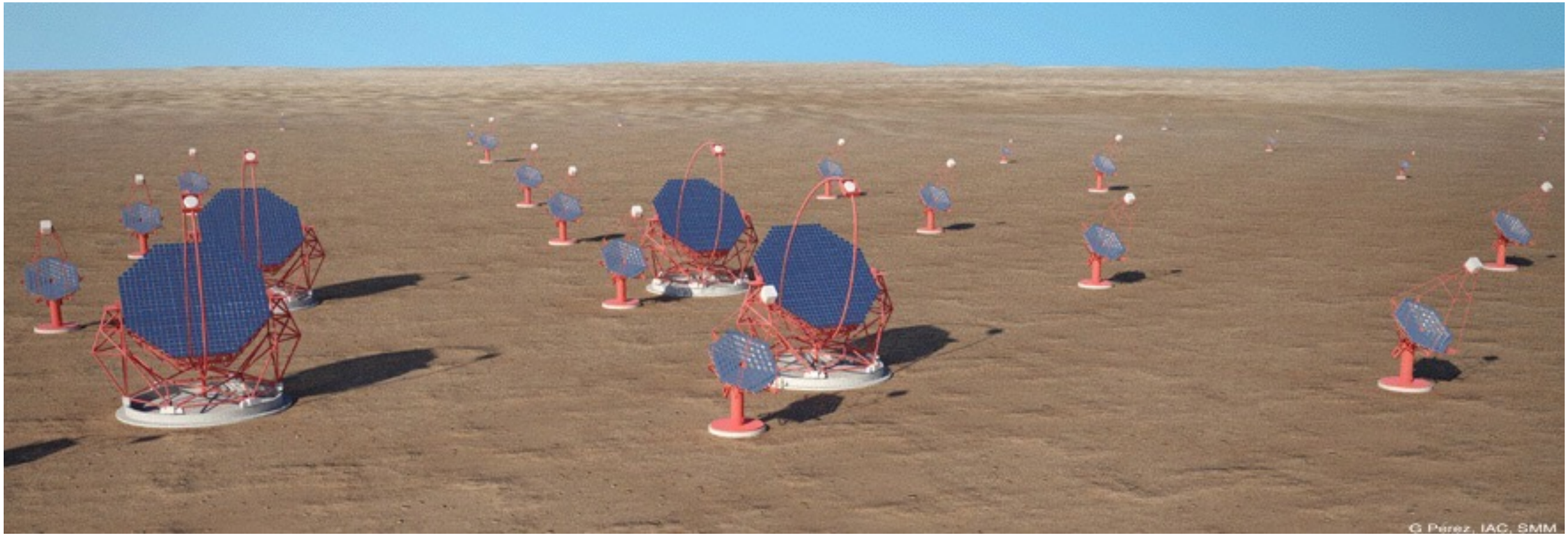
CCF Meeting, Barcelona 27/10/15

A. Mitchell

See also Muon Feasibility Document on Sharepoint

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

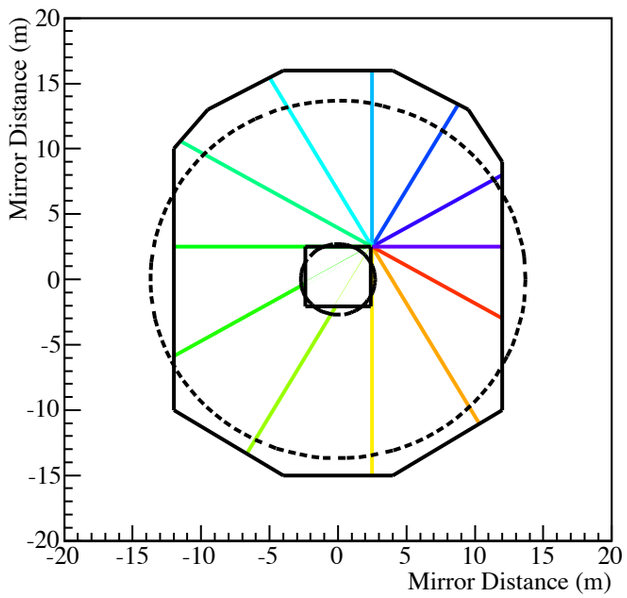
- H.E.S.S. II is the only currently operational multi-sized IACT array

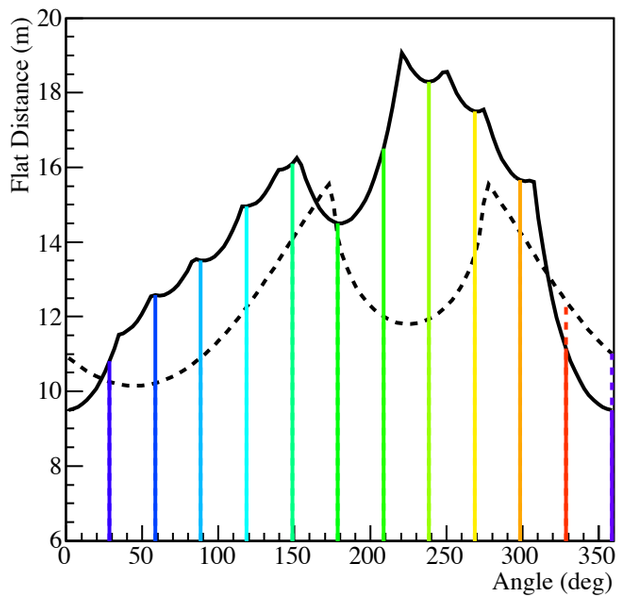
- Needed to rework the muon calibration code to adapt for applicability to both telescope types

- Mirror interpolation vs circle approximation

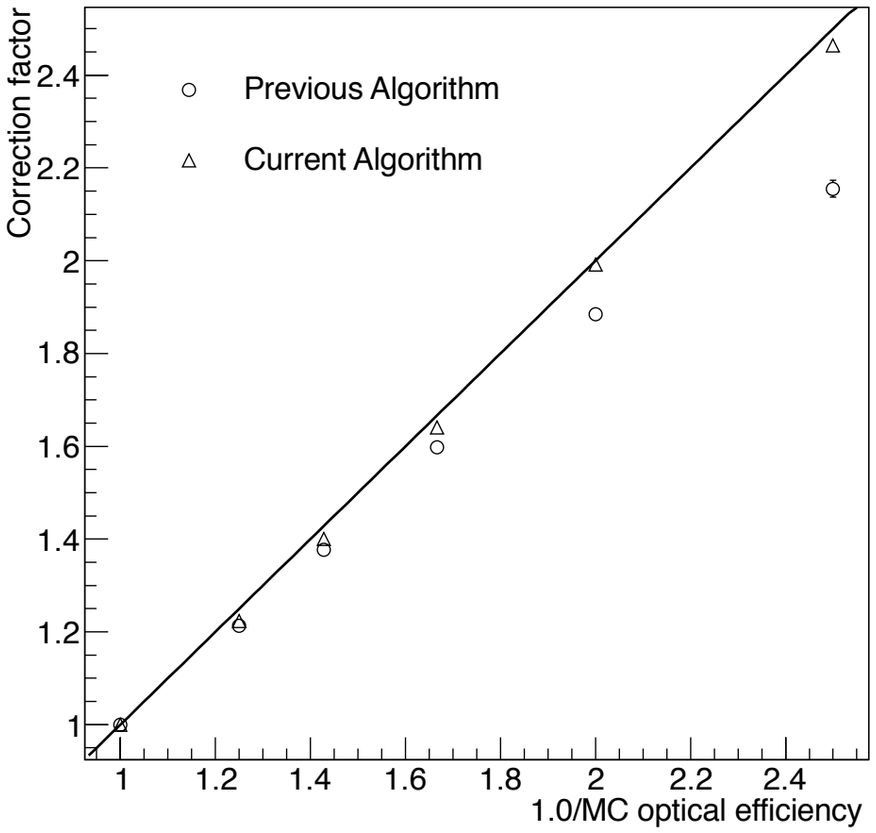
- Change from chi-squared fit to 2D pixel-wise log likelihood

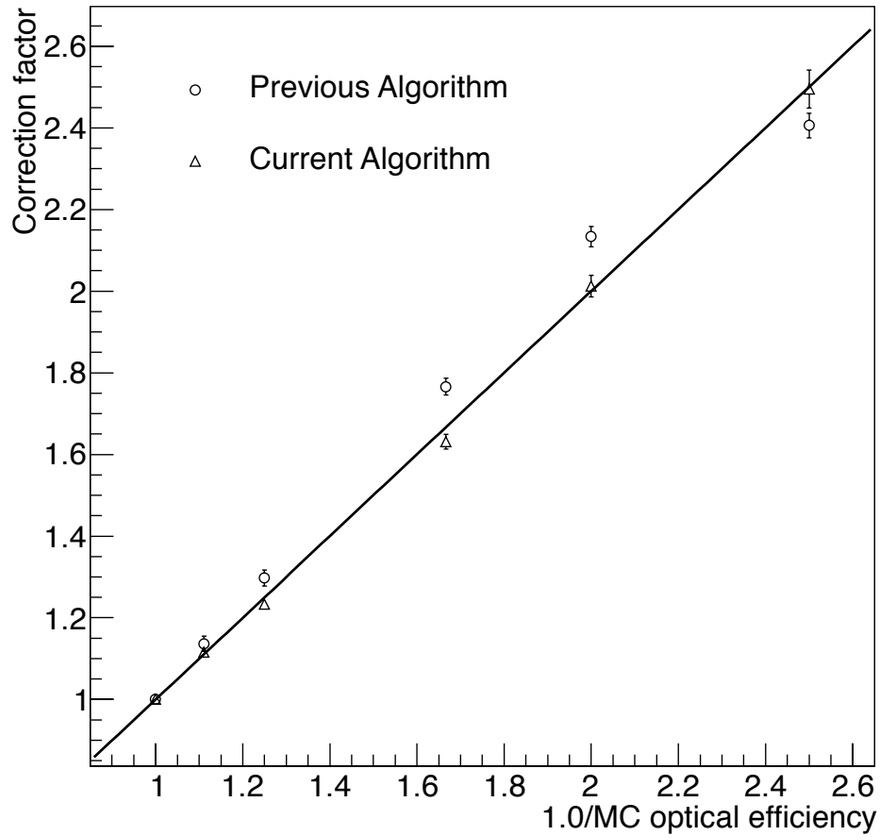
- Same code now used for all HESS telescopes; telescope configuration passed as input





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)

Other Muon Calibration Approaches

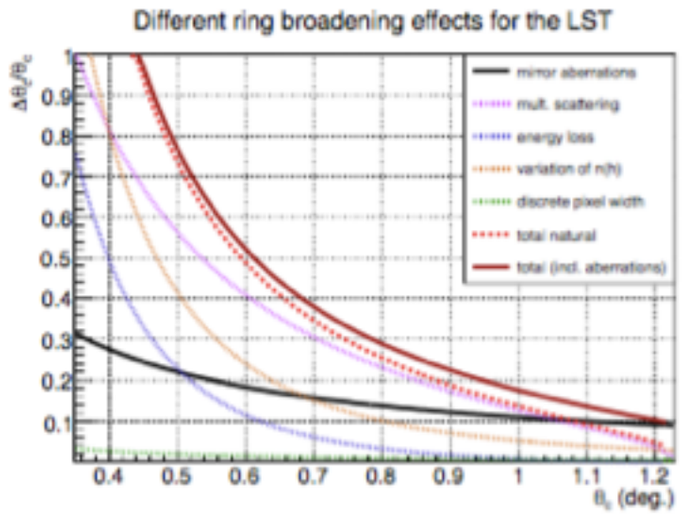
- **Identification**:
  - Veritas originally used analytical circle fit (Humensky, ICRC 2005)
  - Later with a Hough transform (Tyler, ICRC 2013)
  - FACT use both TMVA and a Hough transform (ICRC 2015)
  - MAGIC used analytical circle fit, and Gaussian fit of projected signal onto radial distance (Goebel, ICRC 2005)
  - CTA - (identify from trigger pattern?)

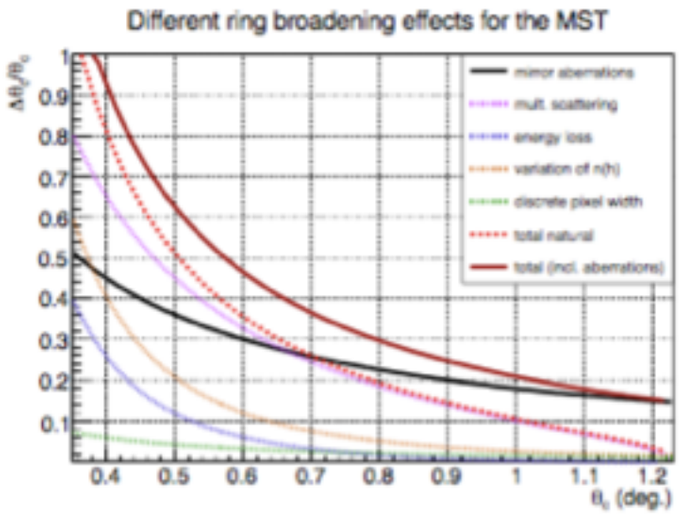
- Existing algorithms are well summarised in the **Muon Feasibility Document** —> main algorithm from HESS
  - need to enhance for timing/psf/flat-fielding

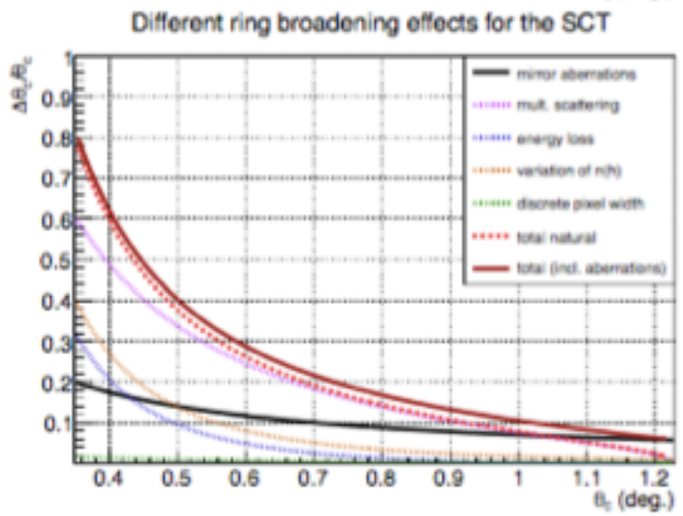
- Cross-check algorithm?
  - flexible/adaptable
  - robust/stable
  - Transparent for future modifications (no “mystery numbers”)

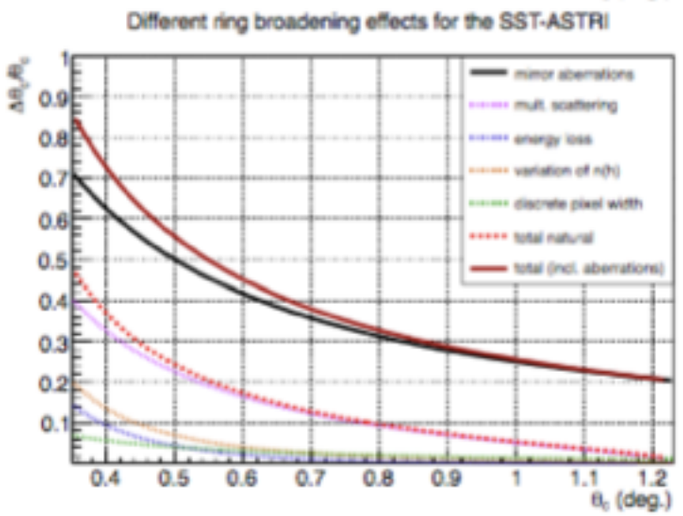
Dominant Effects

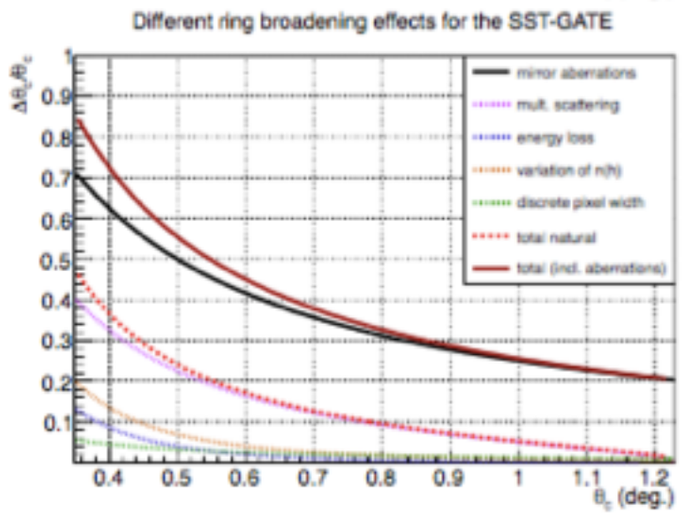
- FACT - Muons for timing calibration (early peak)
- SiPMs do not degrade as quickly as standard PMTs
- Different mirror coatings degrade at different rates
- MAGIC mirror facet actuators - psf dominates ring broadening; HESS multiple scattering dominates
- Dominant effect varies according to telescope; can affect how muons are used for calibration
- Atmosphere:
  - atmo. —> μ ?
  - μ —> atmo. ?

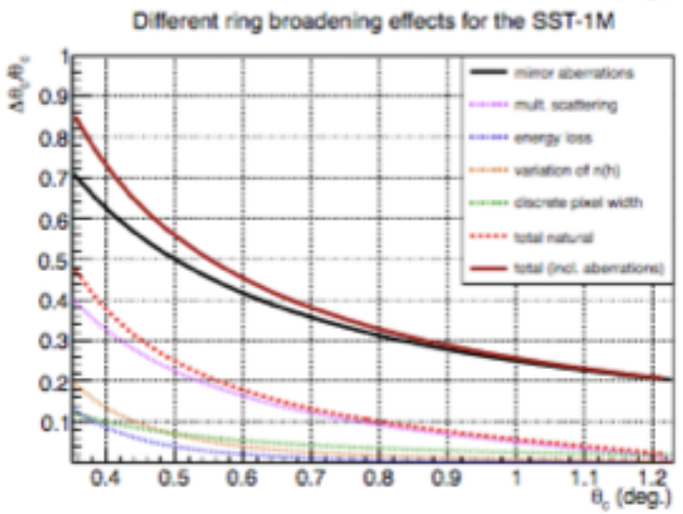








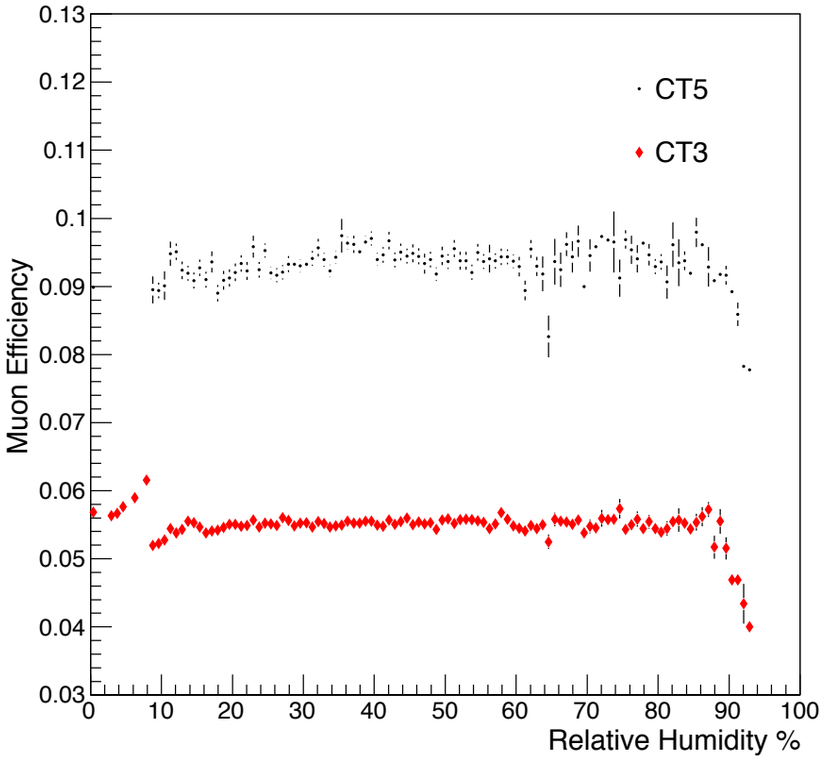


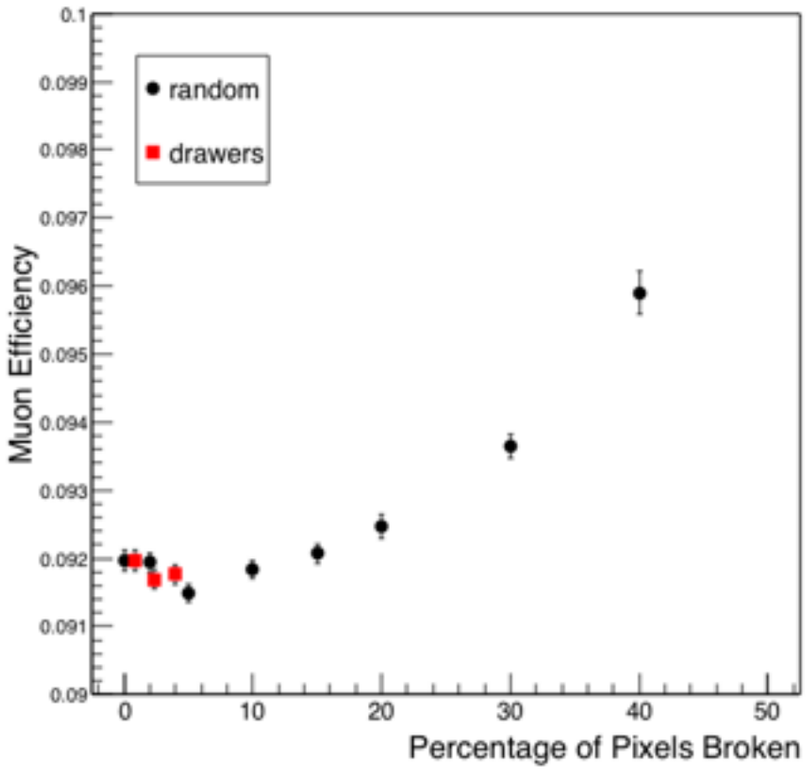


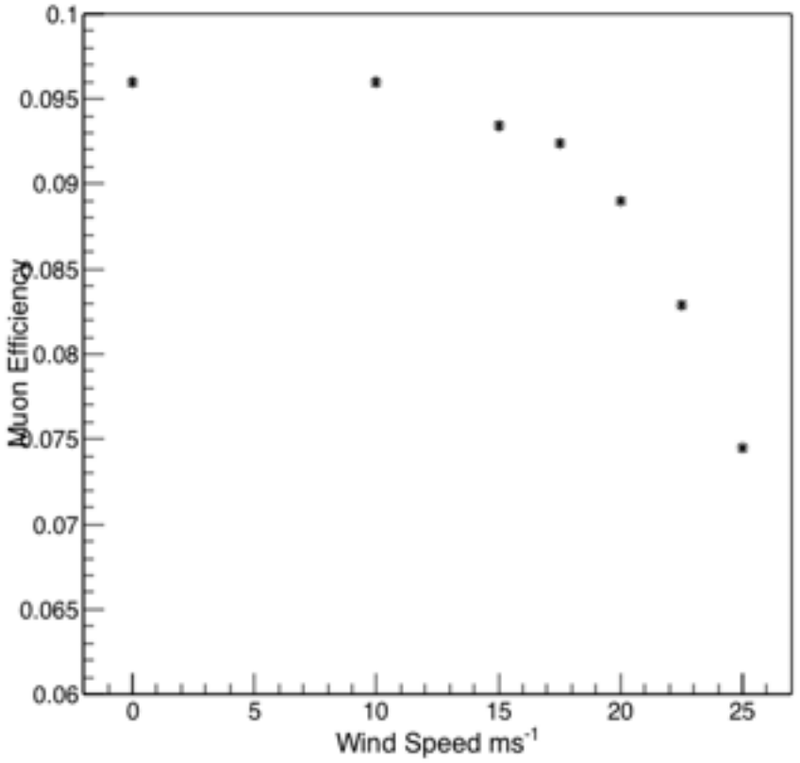
Cut parameters for muon selection

Cut Parameter	HESS I	HESS II	MAGIC	VERITAS	CTA
N Pixels	✓	✓		✓	?
N Broken Pixels	✓	✓			?
N Edge Pixels	✓	✓			?
<NN> pix	✓	✓			?
Radius	✓	✓	✓	(✓)	?
Outer Radius	✓	✓			?
Ring Width	✓	✓	✓		?
Impact Parameter	✓	✓			?
I fractional rms	✓	✗			?
frac. killed pixels	✓	✗			?
χ^2 circle fit	✓	✗			?
χ^2 intensity fit	✓	✗			?
Inclination	✓	✗	(✓)	(✓)	?
Ring completeness	✗	✗	✓		?
Image cleaning	✓	✓	✓		?
Image size (pe)	✗	✗		✓	?
Hillas width	✗	✗		✓	?
RMS time spread	✗	✗		✓	?
Δ ring parameters	✗	✗		✓	?
“Hough parameters”	✗	✗		✓	?

Other factors affecting muon calibration



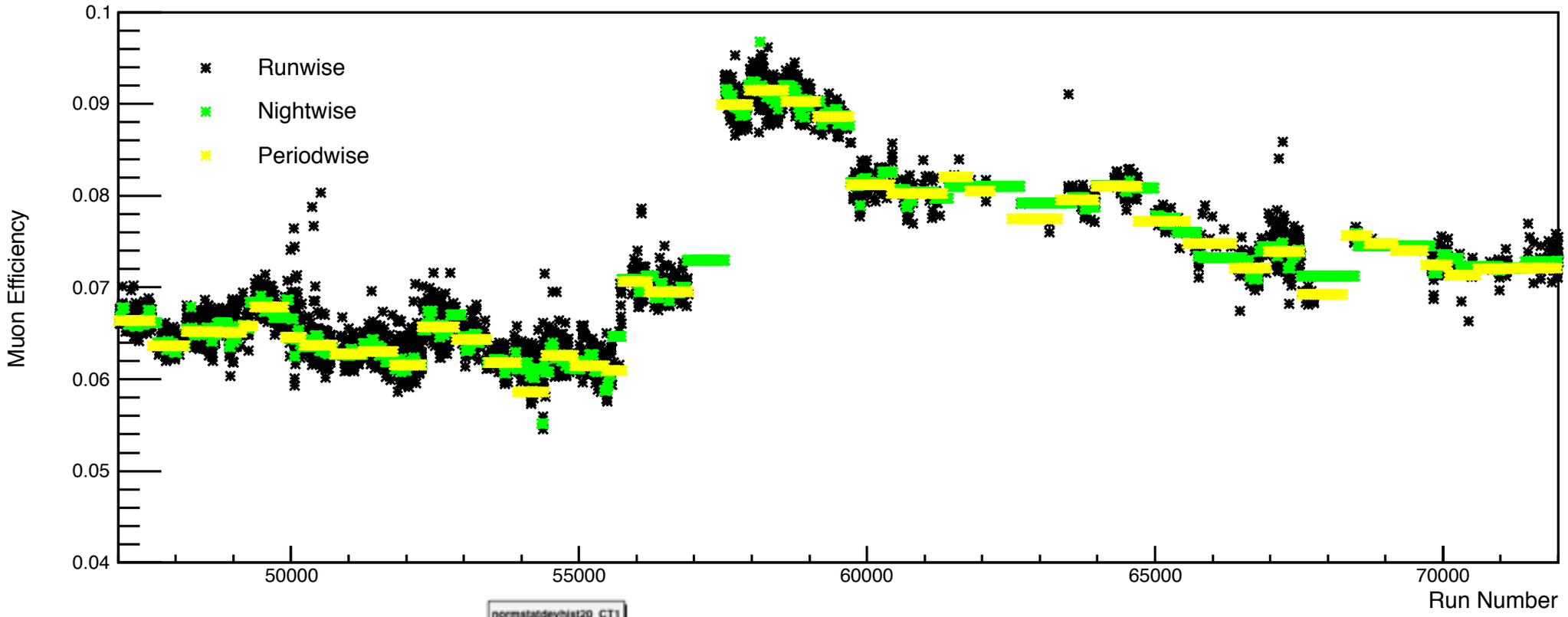


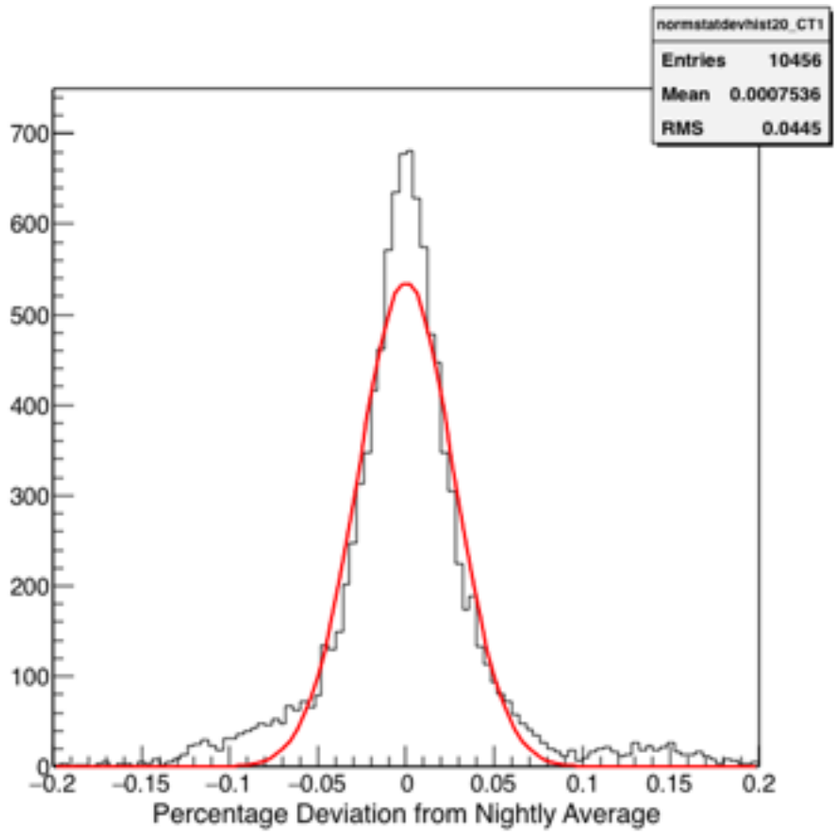


- Quality cuts based on environment and hardware:
  - Reject data with large number of broken pixels
  - Reject data with high humidity/extreme environment

- Cherenkov angle depends on atmosphere & altitude

Variation over time





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

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 $\rho \sin\phi < R'$

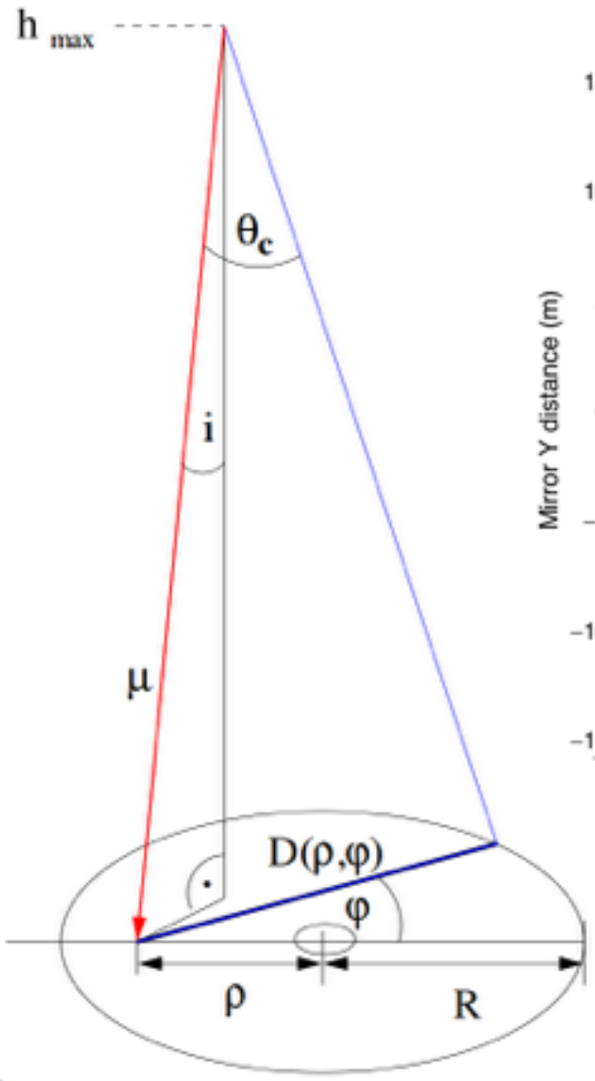
   (a) $\rho > R'$

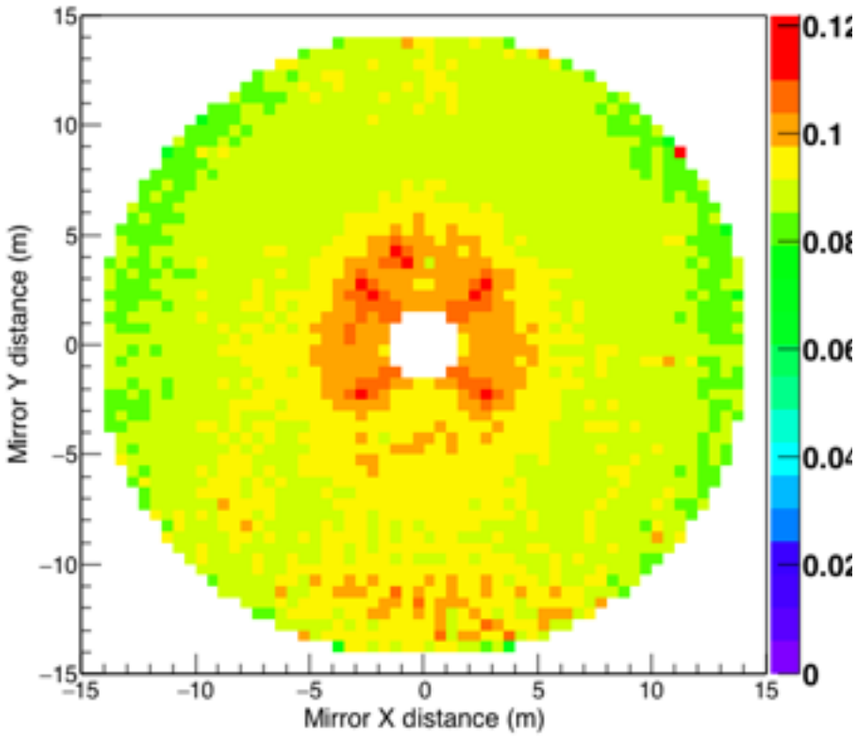
   $C = D - D'$ (3.,2.)

   (b) $\rho < R'$

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

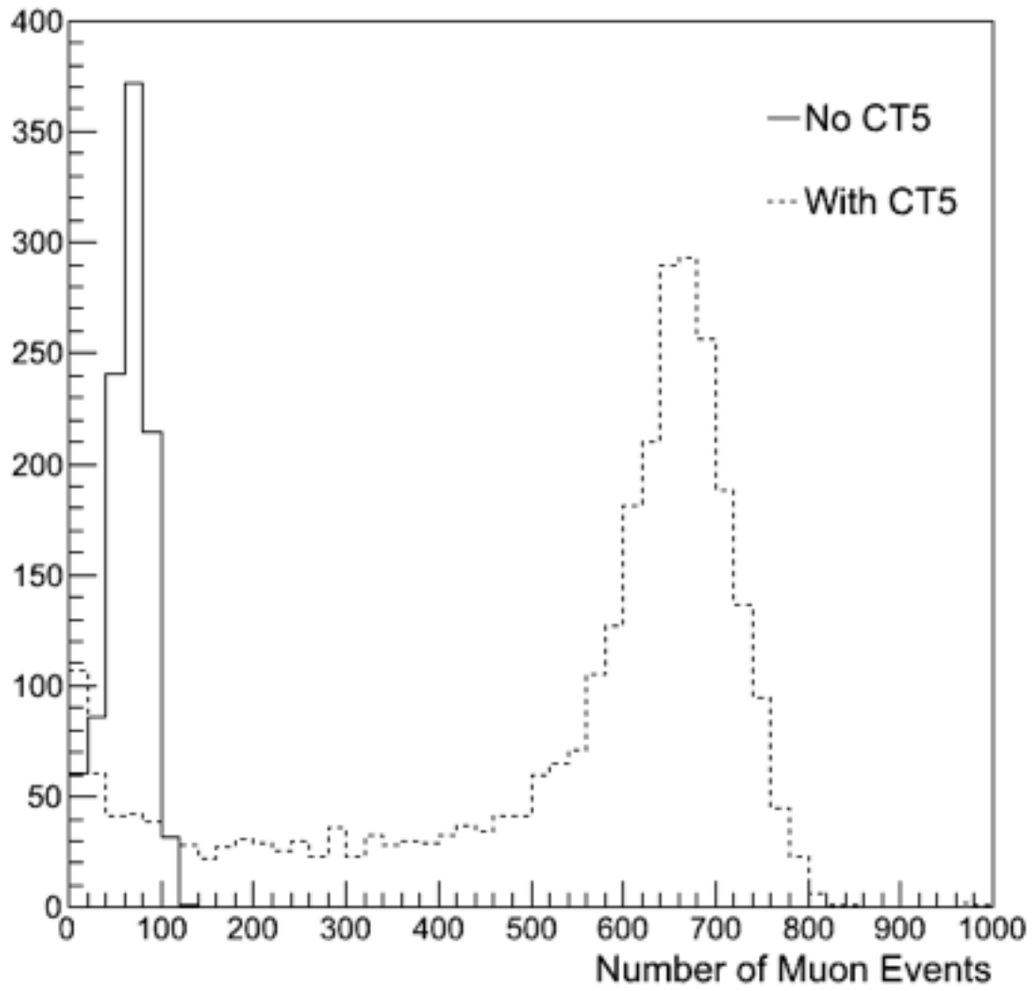
$$D'(\rho,\phi) = R'\left[\sqrt{1-\left(\frac{\rho}{R'}\right)^2 \sin^2\phi} + \frac{\rho}{R'}\cos\phi\right]$$





- 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?

Number of muons



Number of muons detected depends on telescopes taking data
—> depends on array location
Mono muon trigger for MSTs?

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**
- 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 use a scale factor/size ratio to scale the **PMT quantum efficiency**
  - **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)*
  - *How is it foreseen to be applied in the reconstruction? (OVERLAP)*

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Thank you for your attention

Any Questions?

cta
cherenkov telescope array