Array calibration using CTC

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with the help of

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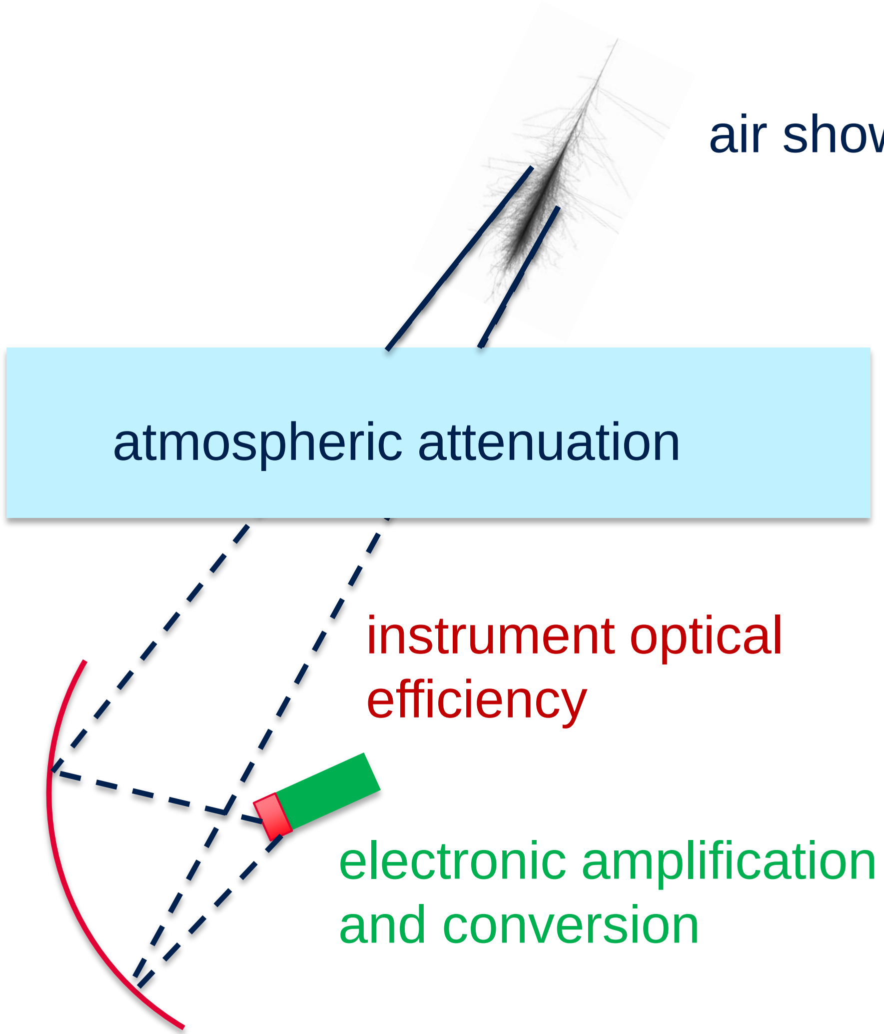
Cherenkov Transparency Coefficient



n_{ph}

$\downarrow \eta$

$n'_{ph} = n_{ph} \cdot \eta$

$\downarrow \mu$

$n_{pe} = n'_{ph} \cdot \mu = n_{ph} \cdot \eta \cdot \mu$

$\downarrow g$

$n'_{pe} = n_{pe} \cdot g = n_{ph} \cdot \eta \cdot \mu \cdot g$

Reminder: CTC for CTA

$$CTC = \frac{1}{N_{tel}} \sum_{i}^{N_{tel}} \frac{\left[\frac{1}{\mathcal{N}} \frac{1}{M}^{☹} R_i(\theta_{zen} = 0°)\right]^{\frac{1}{1.7}}}{\mu_i . g_i}$$

Problems applying the original scheme from H.E.S.S. to CTA:

- multiplicity factor *M*:
  - corrects for different telescope rates in runs with various numbers of active telescopes
  - does not account for different patterns of telescope layout
  - hard coded as one mean value taken over all possible layout scenarios
- not a solution for CTA: >> 4 telescopes, different telescope types, enormous number of possible subarray layouts
- different trigger thresholds

⟶ unrealistic look-up tables needed

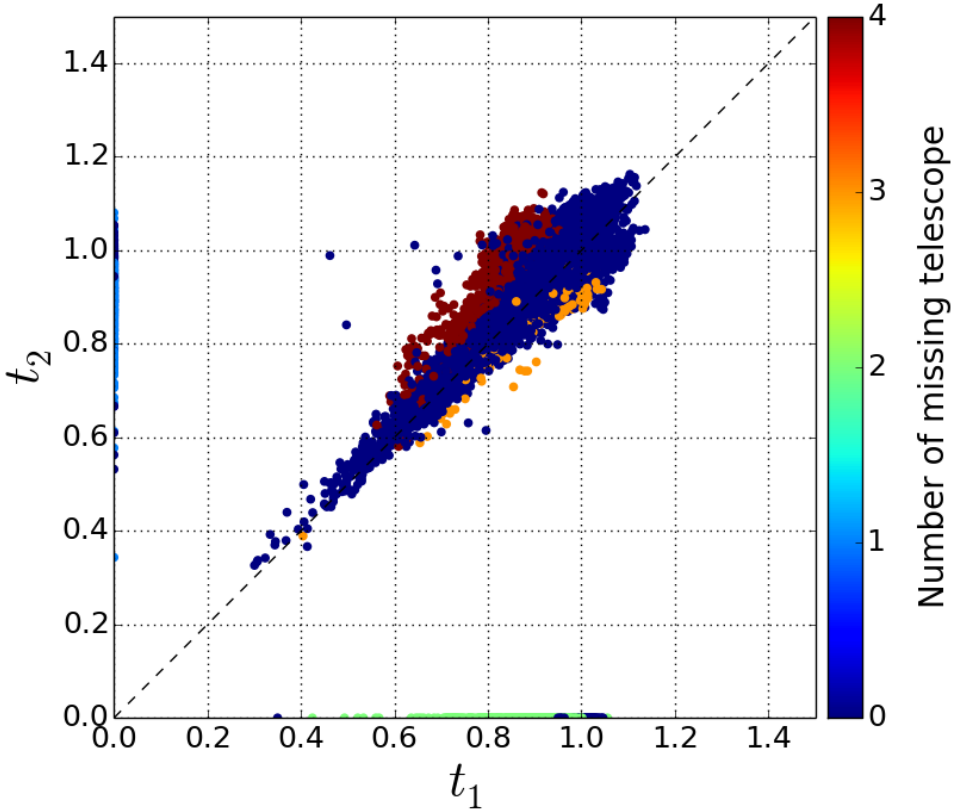
Array inter-calibration (telescopes of the same type)

Influence of telescope pattern

Lessons learned from H.E.S.S. data:

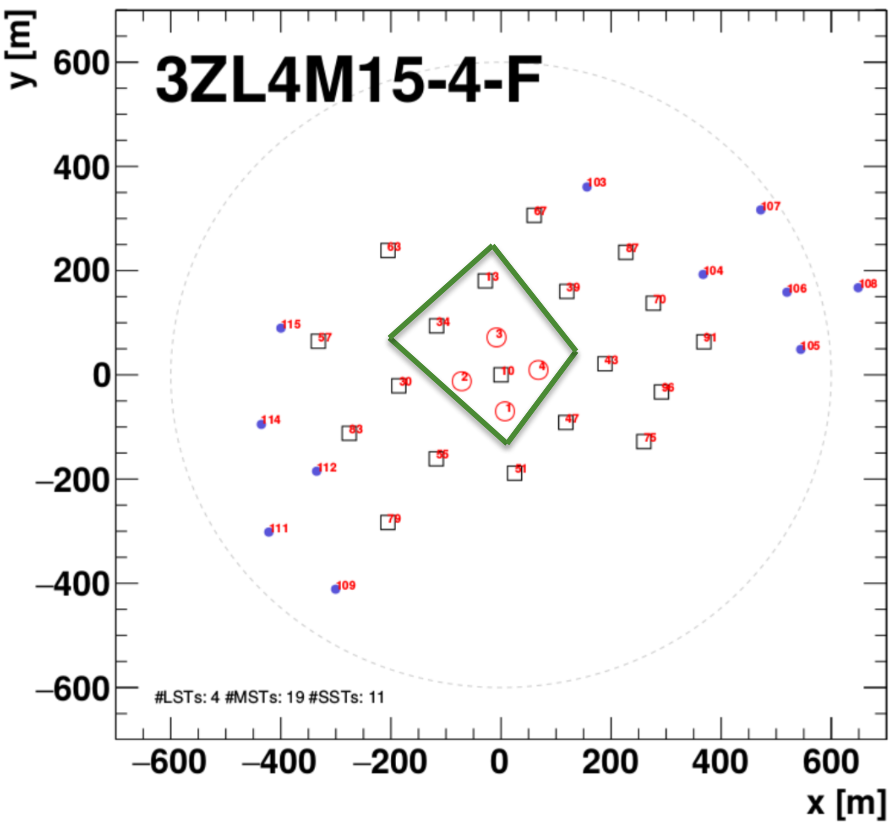
(many thanks to people at MPIK and H.E.S.S. coll. for providing me with data and advice)

- expect $t_i = t_j; i, j = 1 \ldots 4$ (at least for MC)
- not true even for MC:
  - not a hardware issue
- hidden feature: read-out rates depending on telescope positions
  - positions are not equivalent if the pattern of active telescopes is not regular

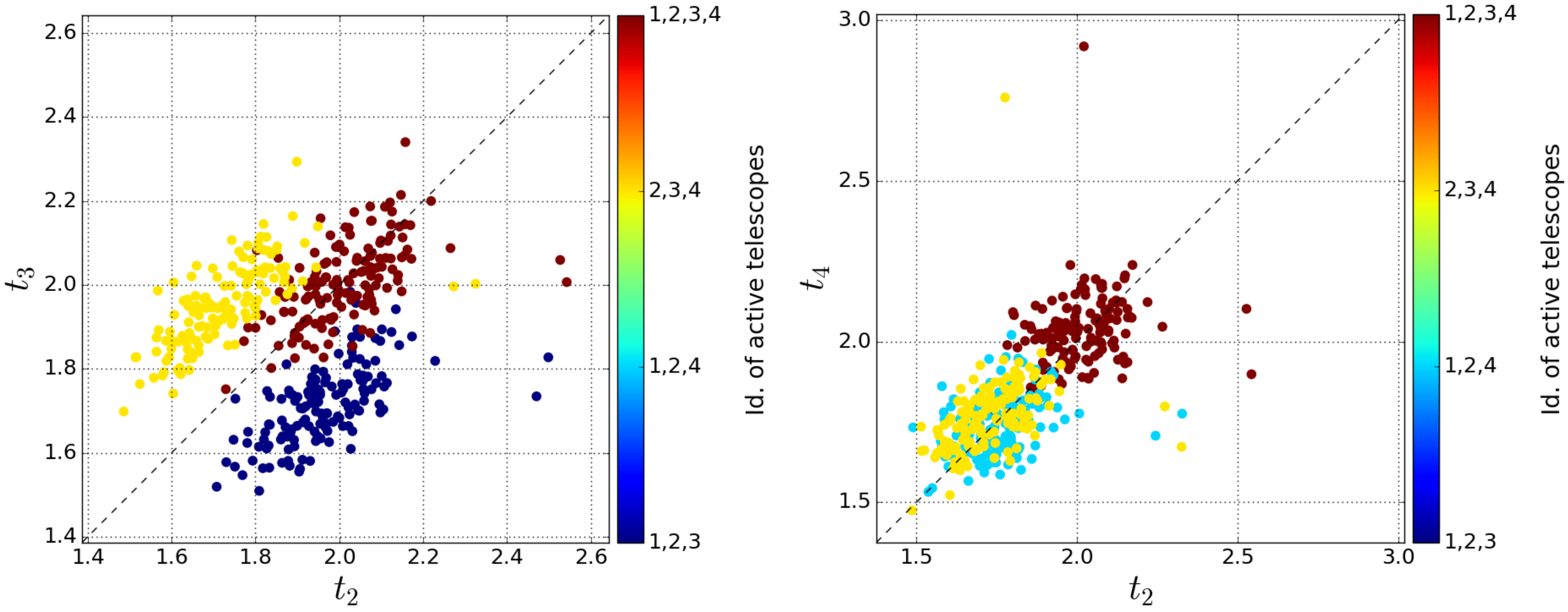


Array inter-calibration: Used MC dataset

- Prod 3, La Palma
- zenith angle 20°
- azimuth angle 180° (protons coming from north)
- $\mu, g = const$
- LST 1-4, MST 10,13,34
- max. 4 active telescopes at a time
  - start by reproducing the results for H.E.S.S.-I-like array, then continue with full CTA feasibility study



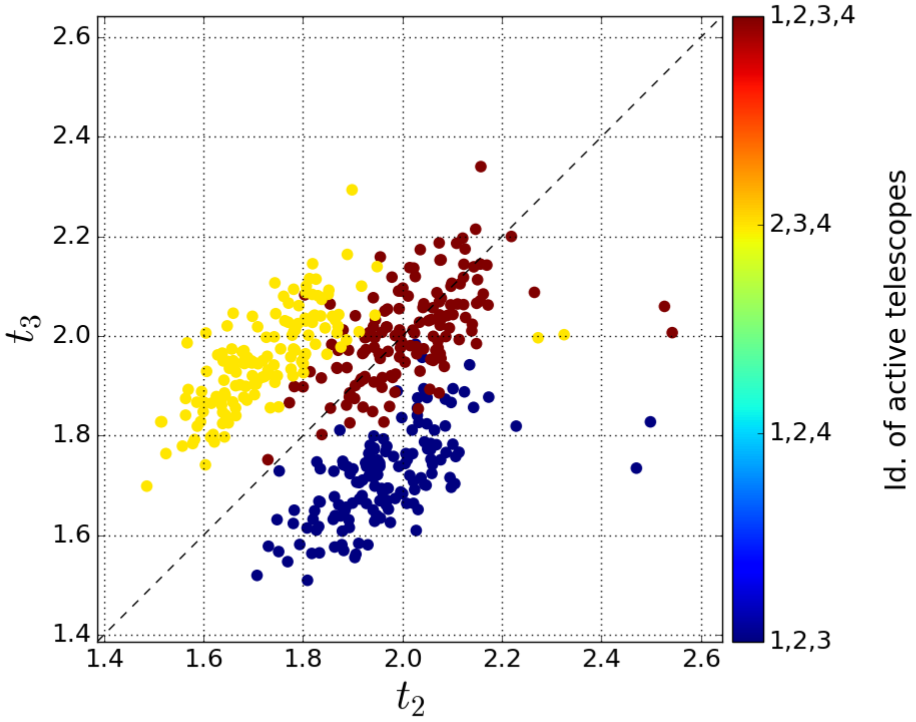
Influence of telescope pattern

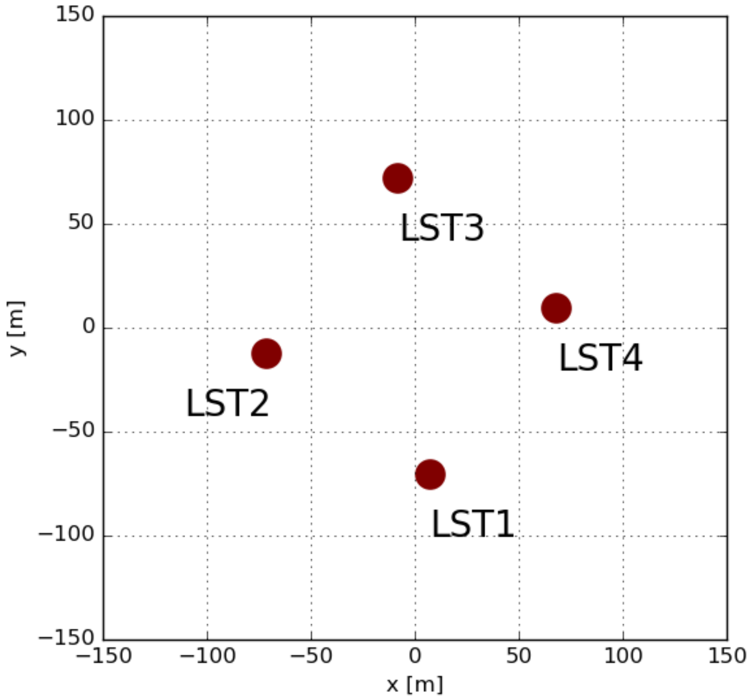


- 4 LSTs at La Palma are **approximately** the same as H.E.S.S.-I layout (different size, not actually a square)
- good for cross-check between H.E.S.S. and CTA

Influence of telescope pattern

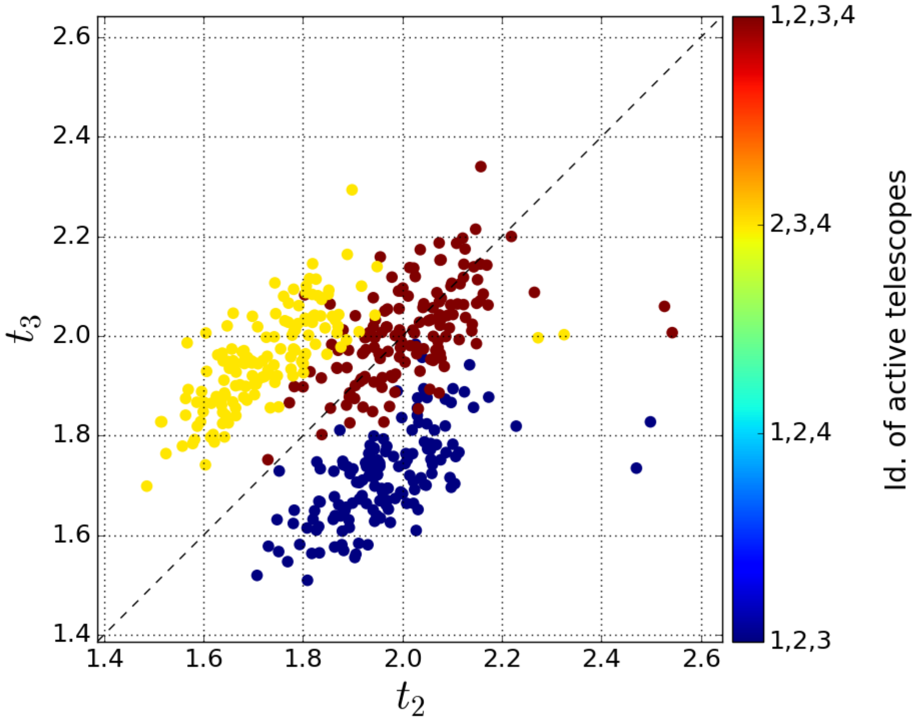
LST 2 & 3: non-equivalent positions

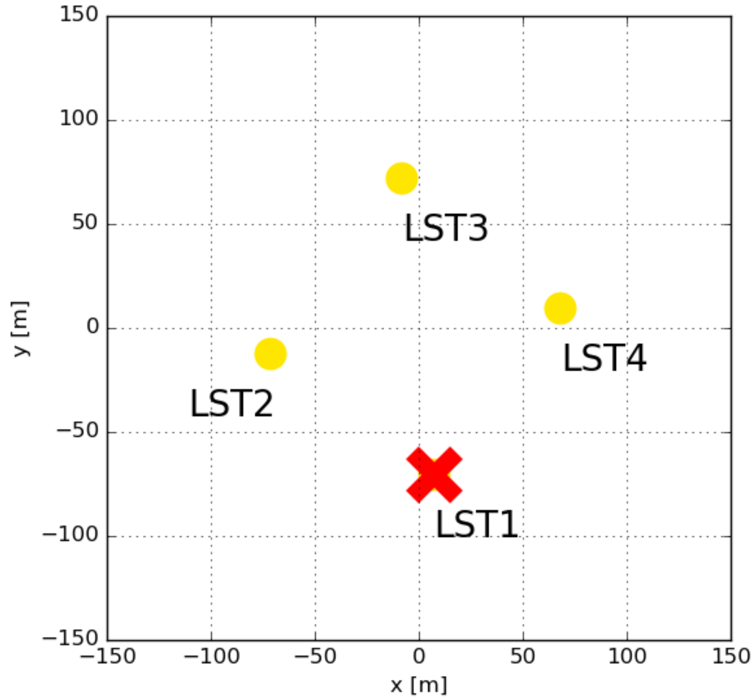




Influence of telescope pattern

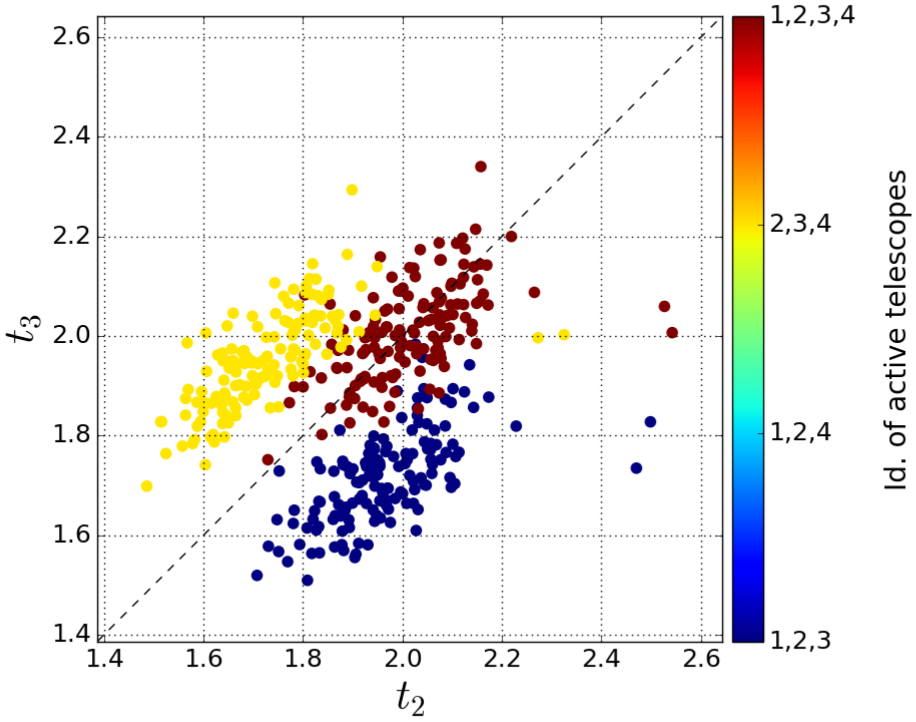
LST 2 & 3: non-equivalent positions

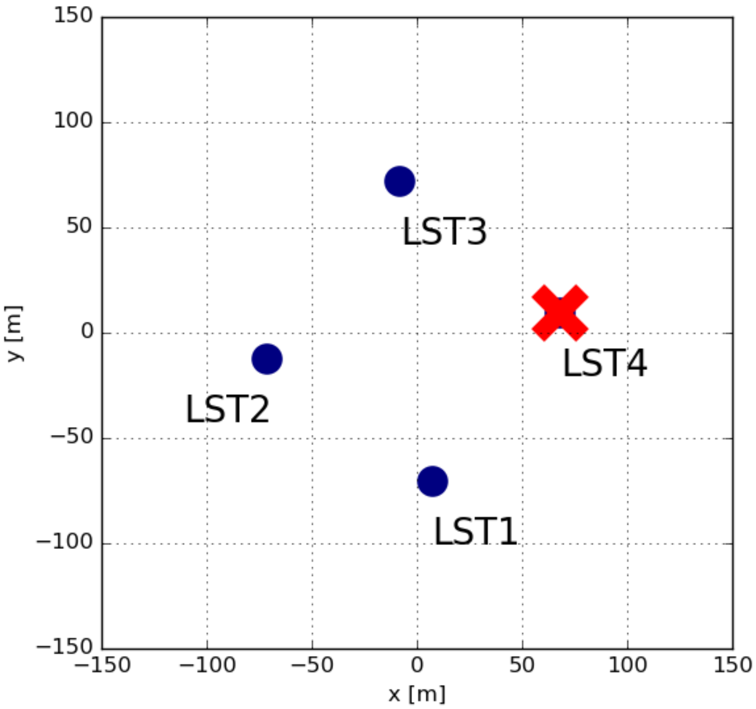




Influence of telescope pattern

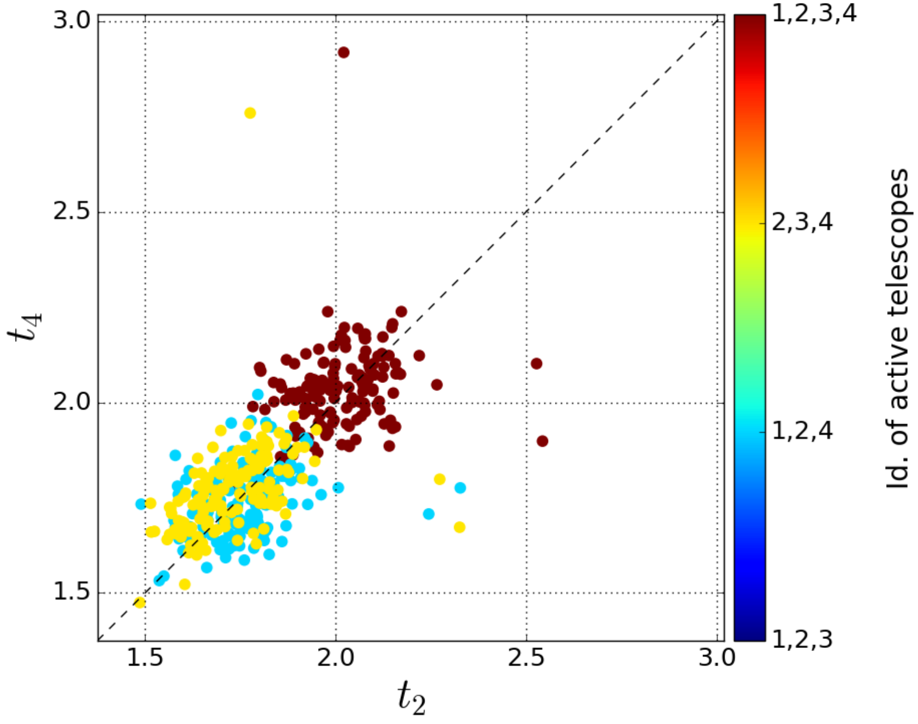
LST 2 & 3: non-equivalent positions

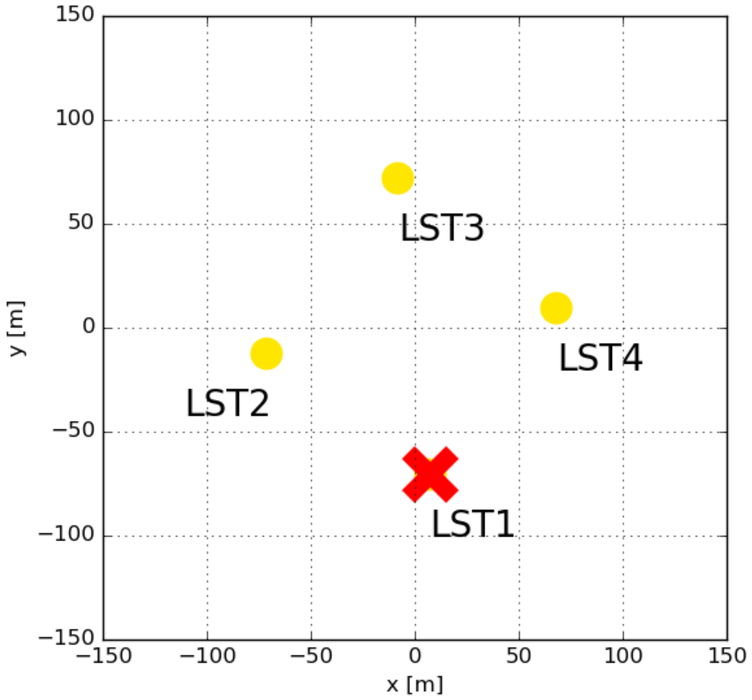




Influence of telescope pattern

LST 2 & 4: equivalent positions





Influence of telescope pattern

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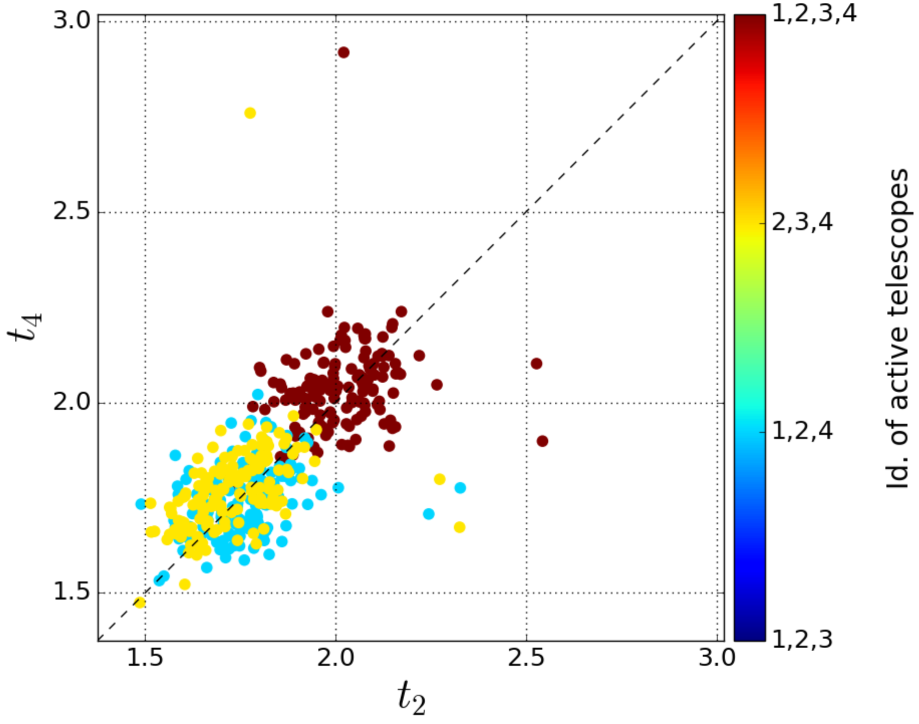
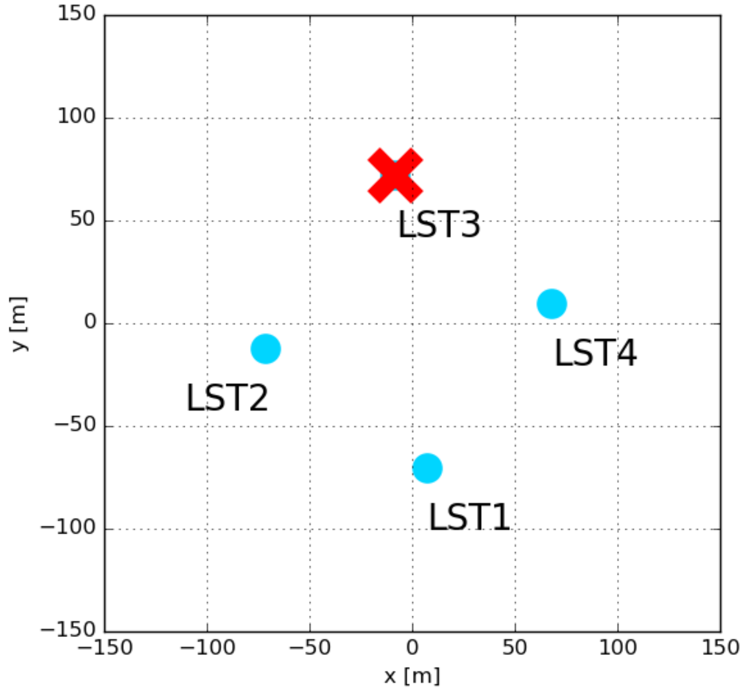




Array geometry factor

Example: LST 3 not working

$$D_1 = d_{12} + d_{14} = 2d_{12}$$

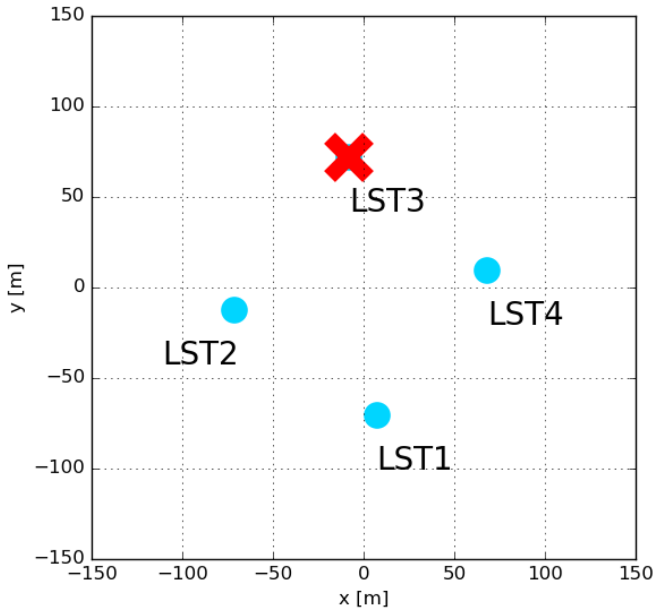
$$D_2 = d_{21} + d_{24} = \left(1 + \sqrt{2}\right)d_{12}$$

$$D_4 = d_{41} + d_{42} = D_2$$

$$f_i = \frac{D_i}{\min(D)}$$

$$f_1 = \frac{D_1}{D_1} = 1$$

$$f_2 = f_4 = \frac{D_2}{D_1} = \frac{1 + \sqrt{2}}{2}$$



$$R_i(corr.) = f_i . R_i$$

- caution: only illustration – $\left(1 + \sqrt{2}\right)$ valid for H.E.S.S., @ La Palma not exact square

Array geometry factor

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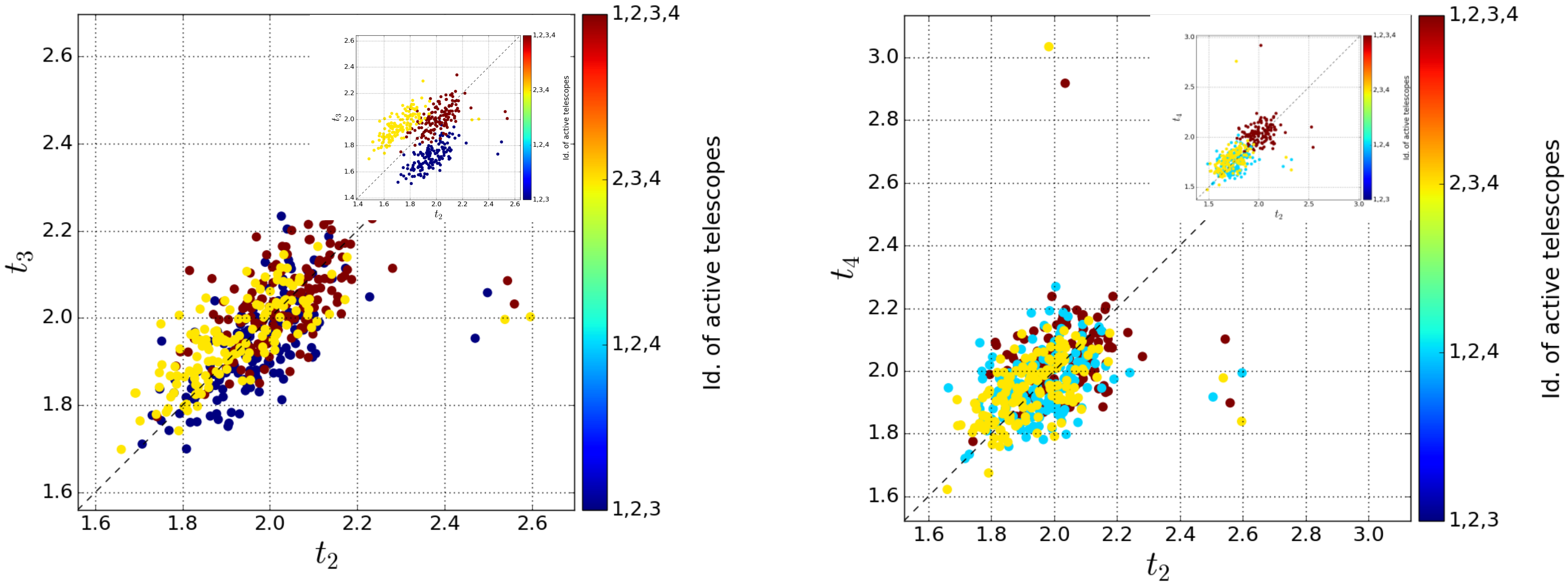
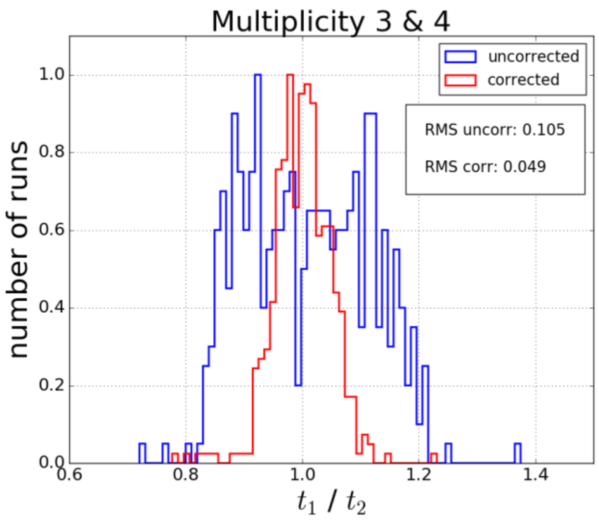
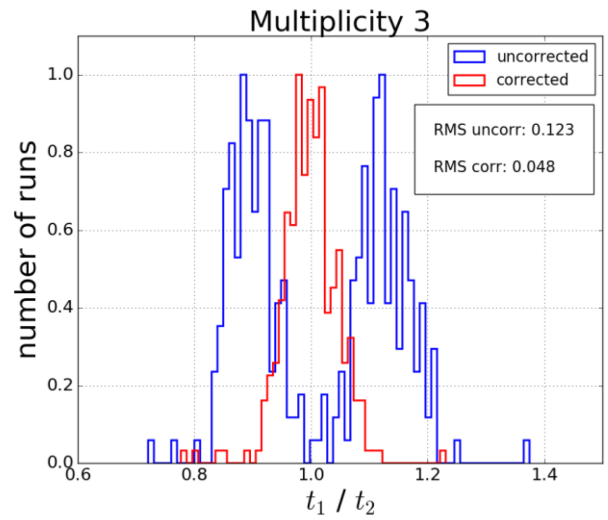


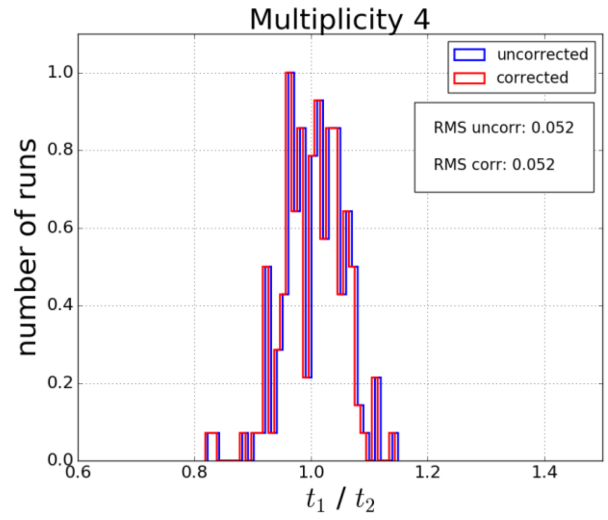
Array geometry factor





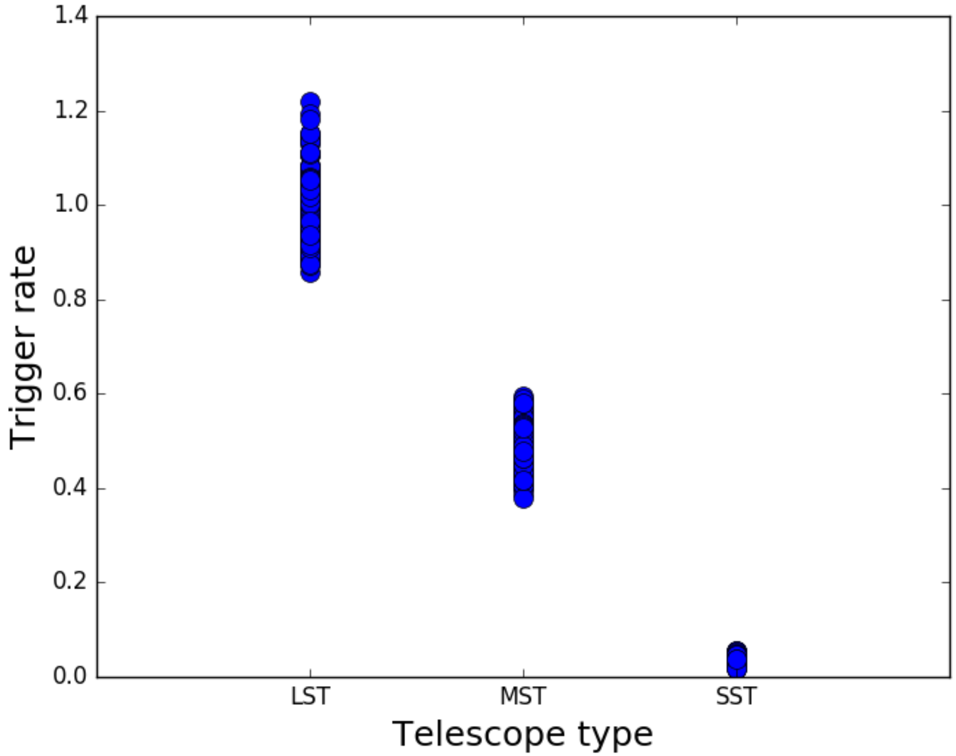
Example RMS for multiplicity 3

Tel. pair	Old	New
1, 2	0.12	0.05
2, 3	0.14	0.05
2, 4	0.06	0.06



Array cross-calibration (telescopes of different type)

Array cross-calibration



$$F(E) = N_0 \left(\frac{E}{E_0}\right)^{-2.7}$$

$$R(> E_{th}) = \int_{E_{th}}^{\infty} \mathrm{d}E\, F(E).\, A_{eff}(E)$$

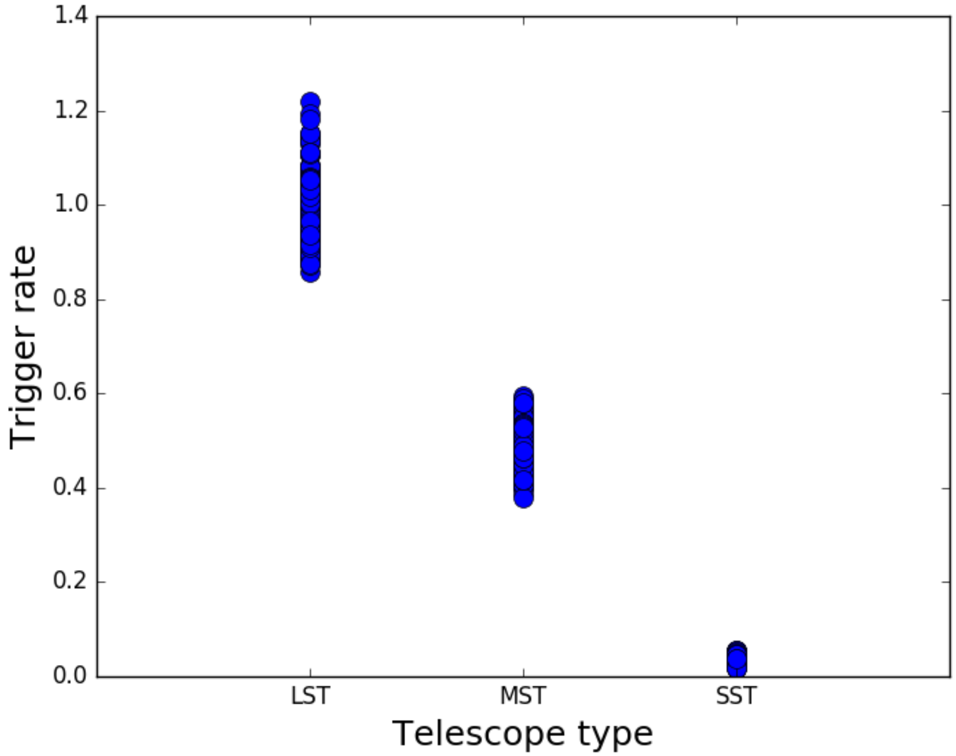
$$A_{eff}(E) = \int \mathrm{d}\Omega = \int_0^{\infty} \mathrm{d}r\, r.\, P_p(r, E)$$

$$P_p(r, E) = \frac{N_{trig}(r, E)}{N_{MC}(r, E)}$$

$$E_{th} \propto \frac{1}{\sqrt{A_{mir}}}$$

$$CTC \propto \frac{\left[\frac{1}{\mathcal{N}} \frac{1}{M}^{☹} R_i(\theta_{zen} = 0°)\right]^{\frac{1}{1.7}}}{\mu_i.\, g_i} \rightarrow \frac{\left[\frac{1}{\mathcal{N}} f(\text{tel.pat.})^{☺}.\, g(A_{mir}) R_i(\theta_{zen} = 0°)\right]^{\frac{1}{1.7}}}{\mu_i.\, g_i}$$

Array cross-calibration

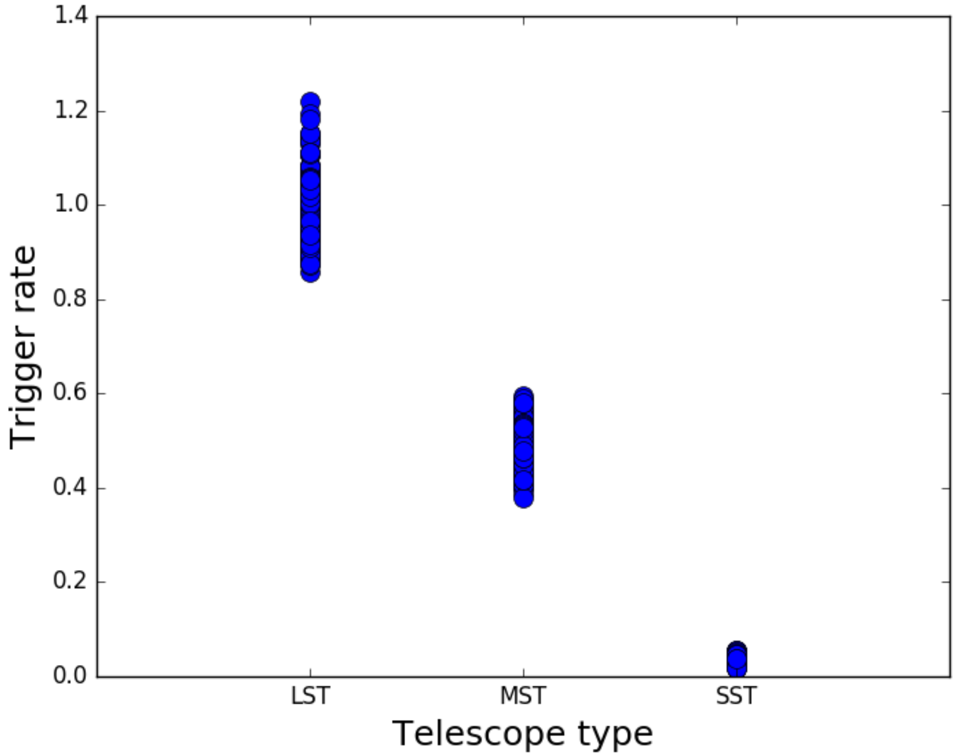


$$E_{th} \not\approx \frac{1}{\sqrt{A_{mir}}}$$

Tel. type	Mean trigger rate	Mirror [m^2]
LST	1.00	386
MST	0.49	103
SST	0.03	12

$$CTC \propto \frac{\left[\frac{1}{\mathcal{N}}\frac{1}{M}^{☹} R_i(\theta_{zen}=0°)\right]^{\frac{1}{1.7}}}{\mu_i . g_i} \rightarrow \frac{\left[\frac{1}{\mathcal{N}} f(\text{tel.pat.})^{☺} . g(A_{mir}) R_i(\theta_{zen}=0°)\right]^{\frac{1}{1.7}}}{\mu_i . g_i}$$

Array cross-calibration



$$E_{th} \propto \frac{1}{\sqrt{A_{mir}}} . ??$$

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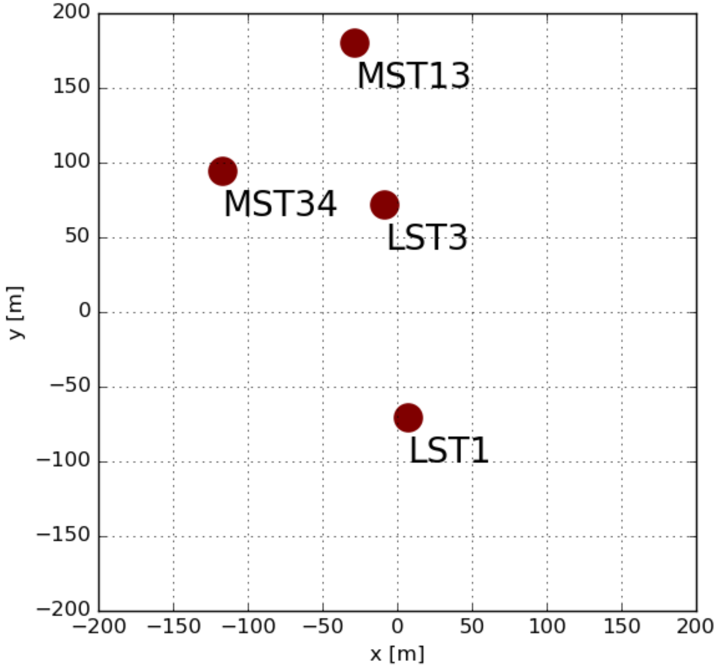
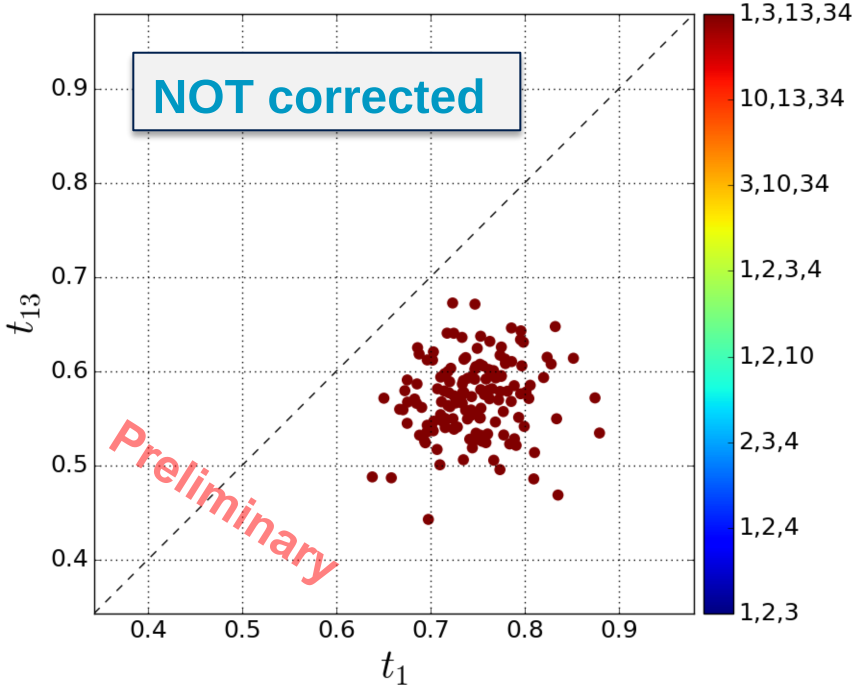
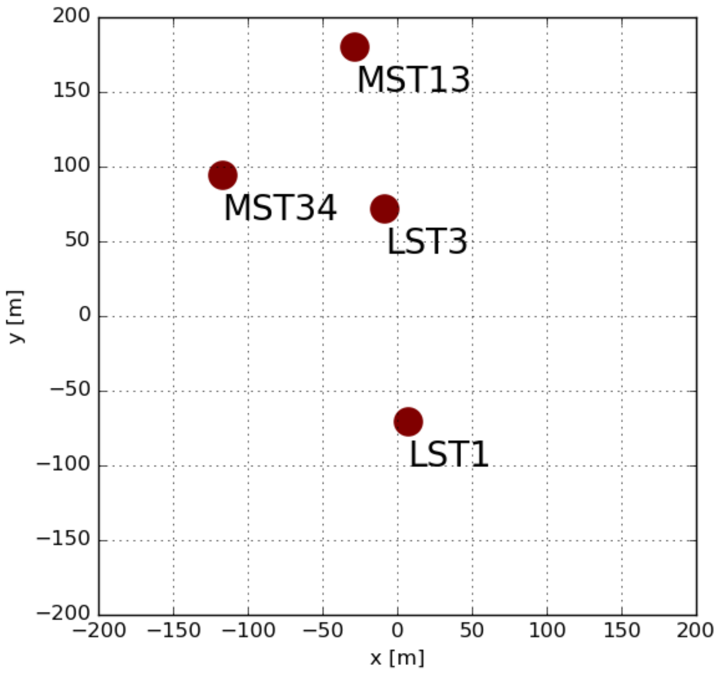
Array cross-calibration

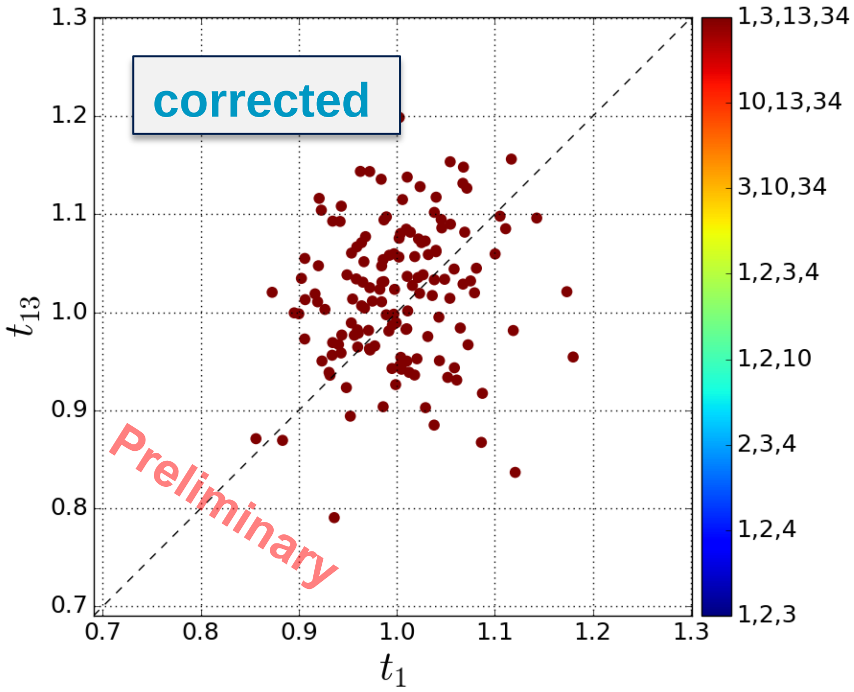




CTC correlation for LST 1, MST 13

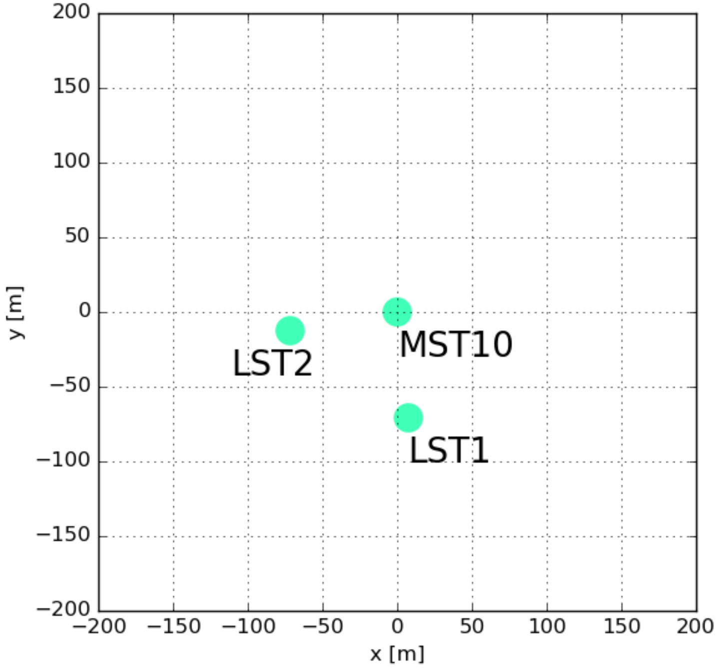
Array cross-calibration

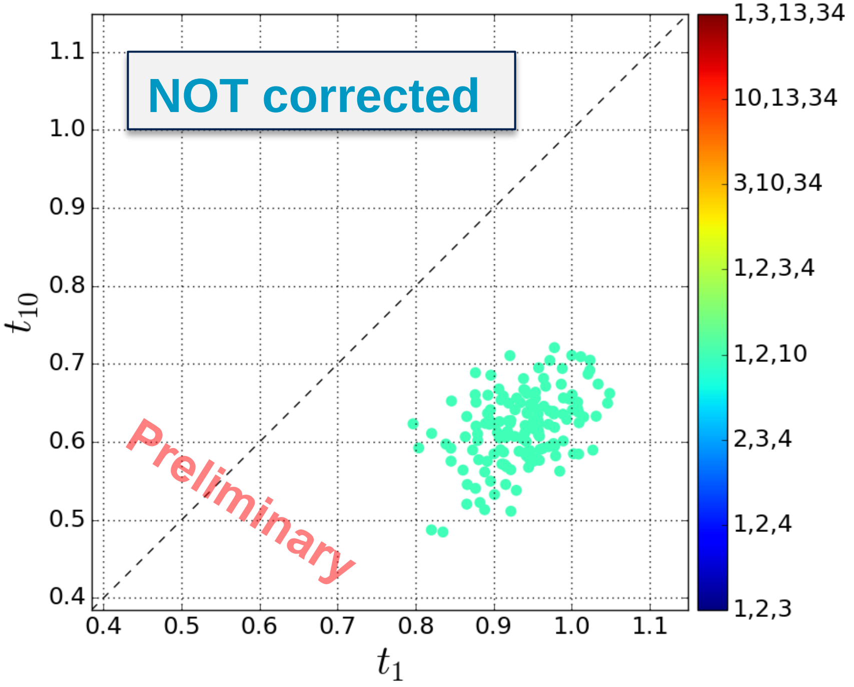




CTC correlation for LST 1, MST 13

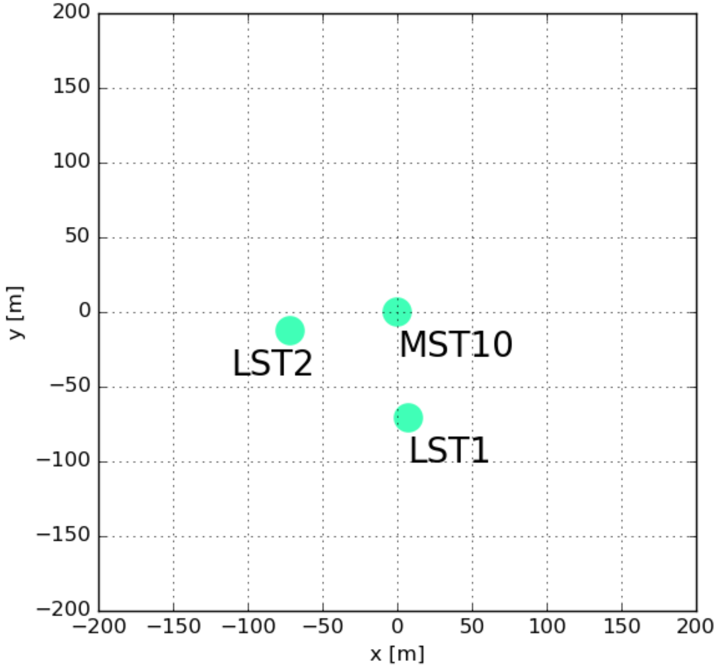
Array cross-calibration

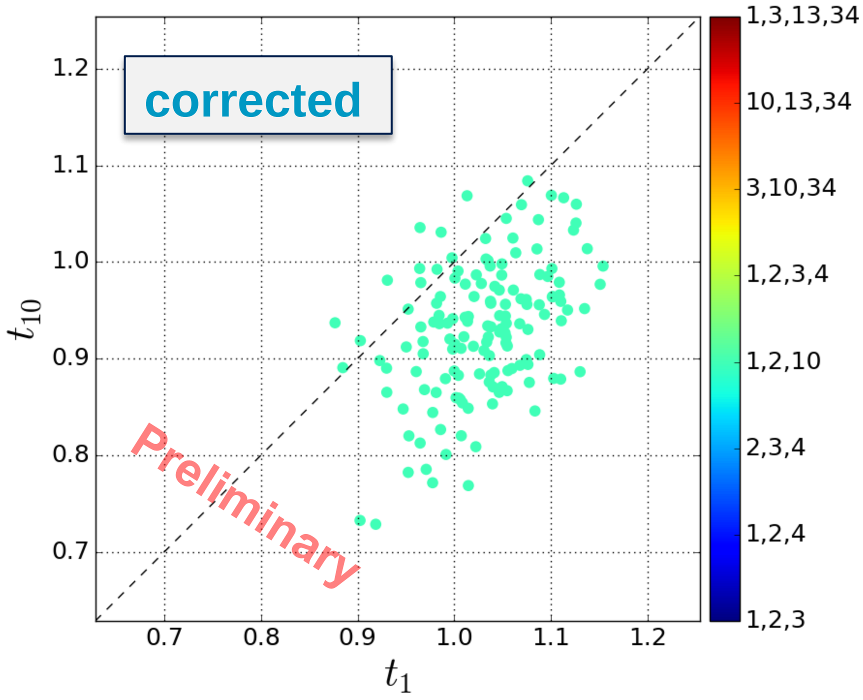




CTC correlation for LST 1, MST 10

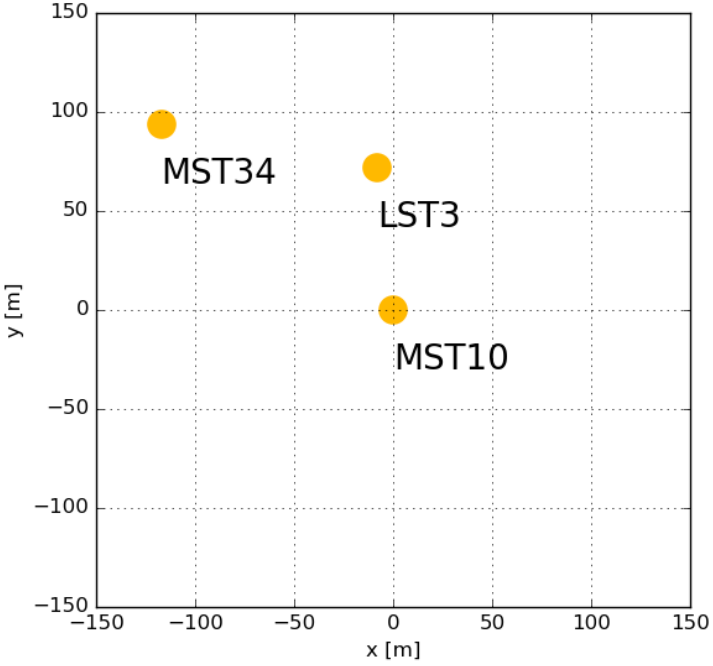
Array cross-calibration

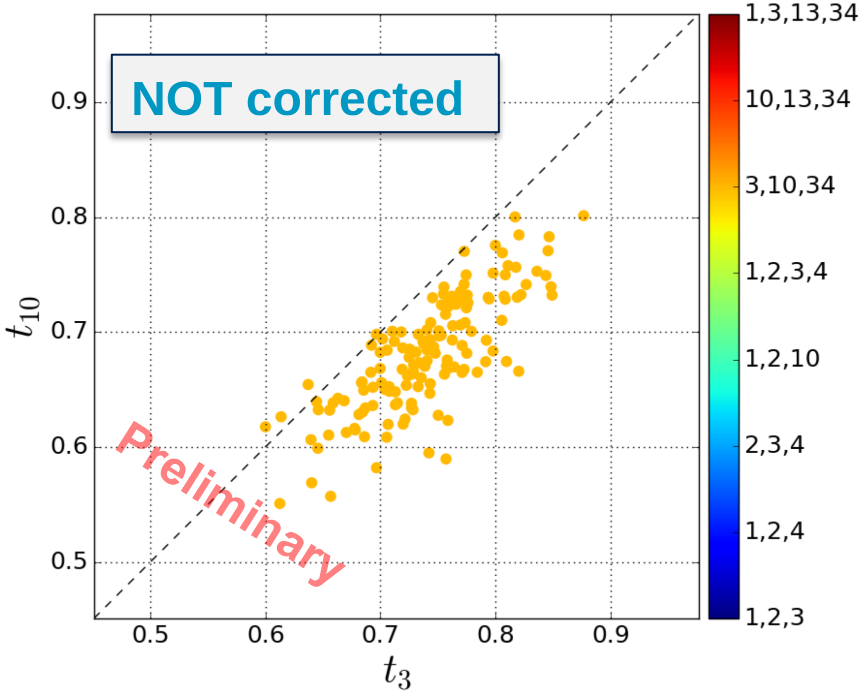




CTC correlation for LST 1, MST 10

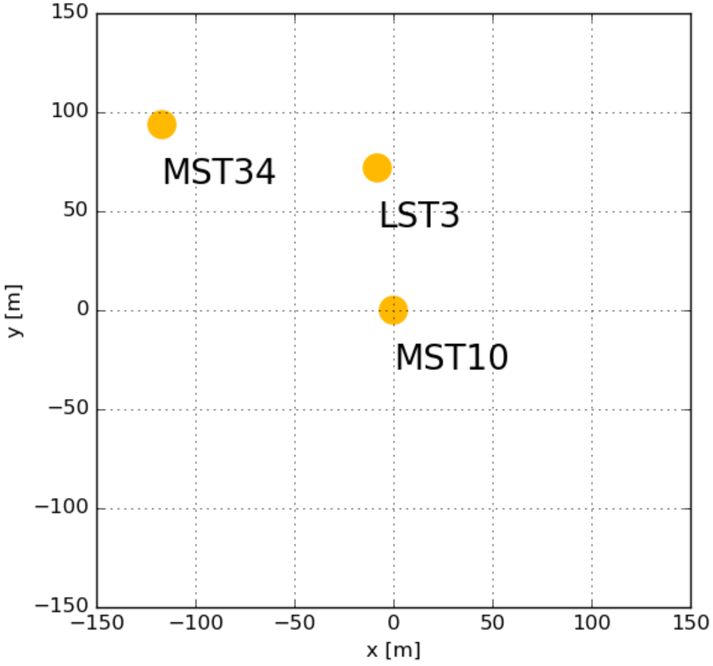
Array cross-calibration

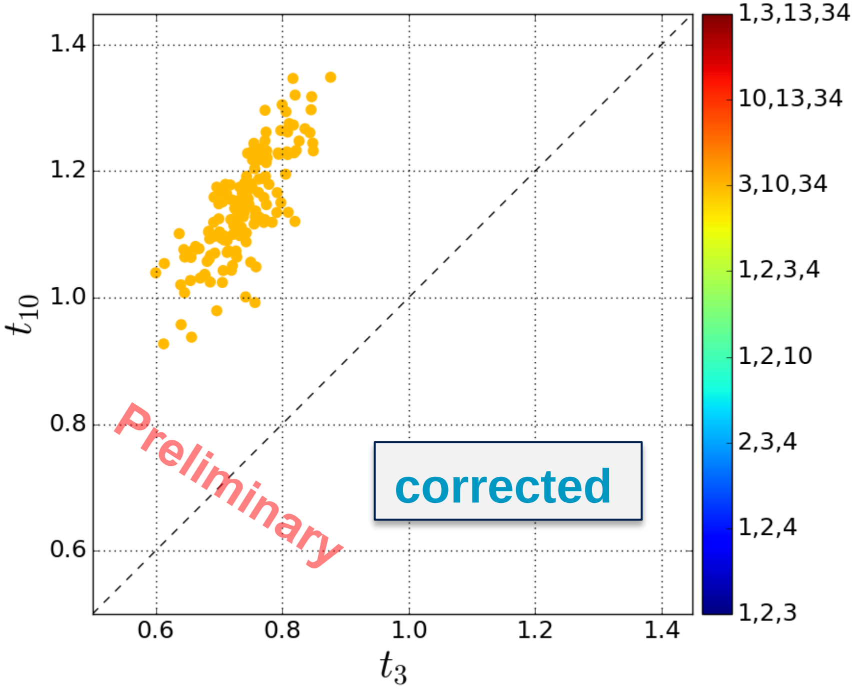




CTC correlation for LST 3, MST 10

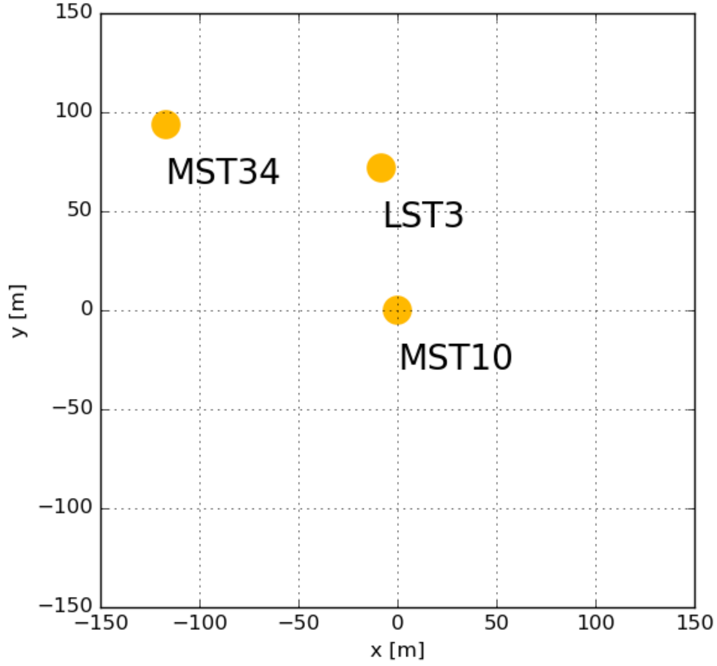
Array cross-calibration

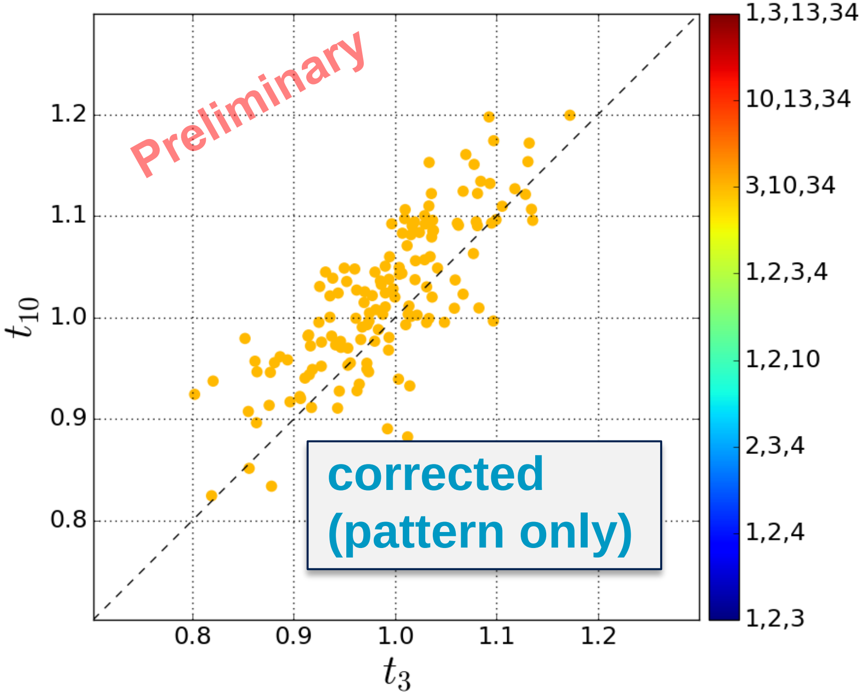




CTC correlation for LST 3, MST 10

Array cross-calibration





CTC correlation for LST 3, MST 10

Next steps

- variations in muon efficiency and gain
- different trigger conditions throughout the observation?
- H.E.S.S. MC findings:
  - read-out rates larger in specific directions
  - possible correlation with geomagnetic field

$\longrightarrow$ must examine:

- different azimuth/zenith angle combinations
- different B-field strengths: La Palma vs Paranal

Summary

Inter-calibration:

- exchanged hard-coded M for $f(\mathrm{tel.pat.})$ which is easily derived
  - inter-telescope CTC ok?
  - probably yes, at least for small numbers of telescopes with comparable separations
  - need to analyze larger dataset to verify

- RMS of per-telescope CTCs reduced from ~12-14% to ~6%

Summary

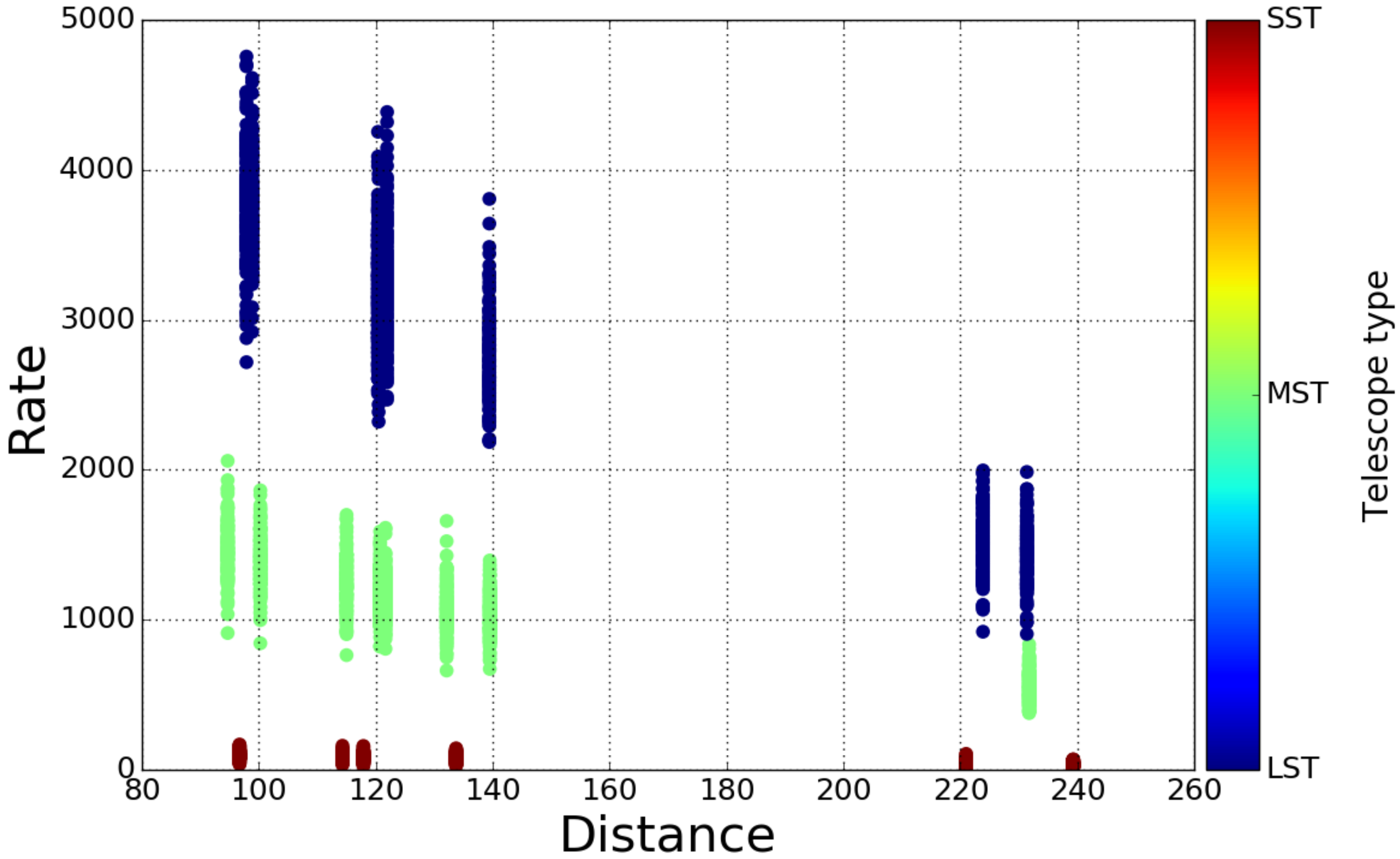
Cross-calibration:

- ad hoc correction for dish size only partially successful
  - cannot treat the dish size irrespective of the telescope position
  - generalization necessary for effective cross-calibration

Overall:

- investigate other possible systematics
- new MC simulations crucial for further feasibility study – but it is the only “investment” needed for this method
  - zenith / azimuth angle
  - hardware conditions

Back-up


5000
4000
3000
2000
1000
0
Rate
80
100
120
140
160
180
200
220
240
260
Distance
SST
MST
LST
Telescope type