Cross-calibration using Cosmic Ray air showers

CCF Meeting, Barcelona 22/06/16

A. Mitchell, R. D. Parsons

Cross Calibration of Optical Efficiencies

A. M. W. Mitchell, R. D. Parsons, W. Hofmann and K. Bernlöhr; "*Cross Calibration of Telescope Optical Throughput Efficiencies using Reconstructed Shower Energies for the Cherenkov Telescope Array,*"

Astroparticle Physics 75, 1-7 (2016)

http://arxiv.org/abs/1510.06526

Calibrate telescope optical efficiencies by comparing how two telescopes view the same shower

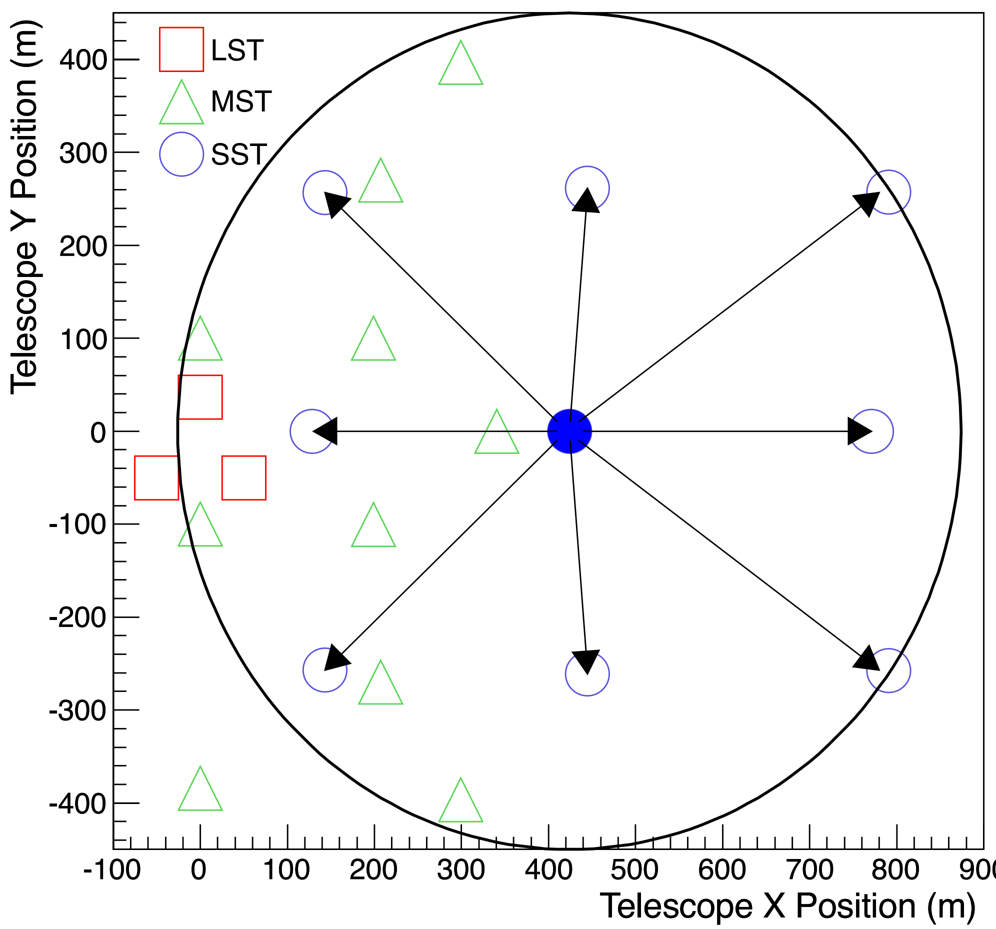
On average, the telescopes should agree

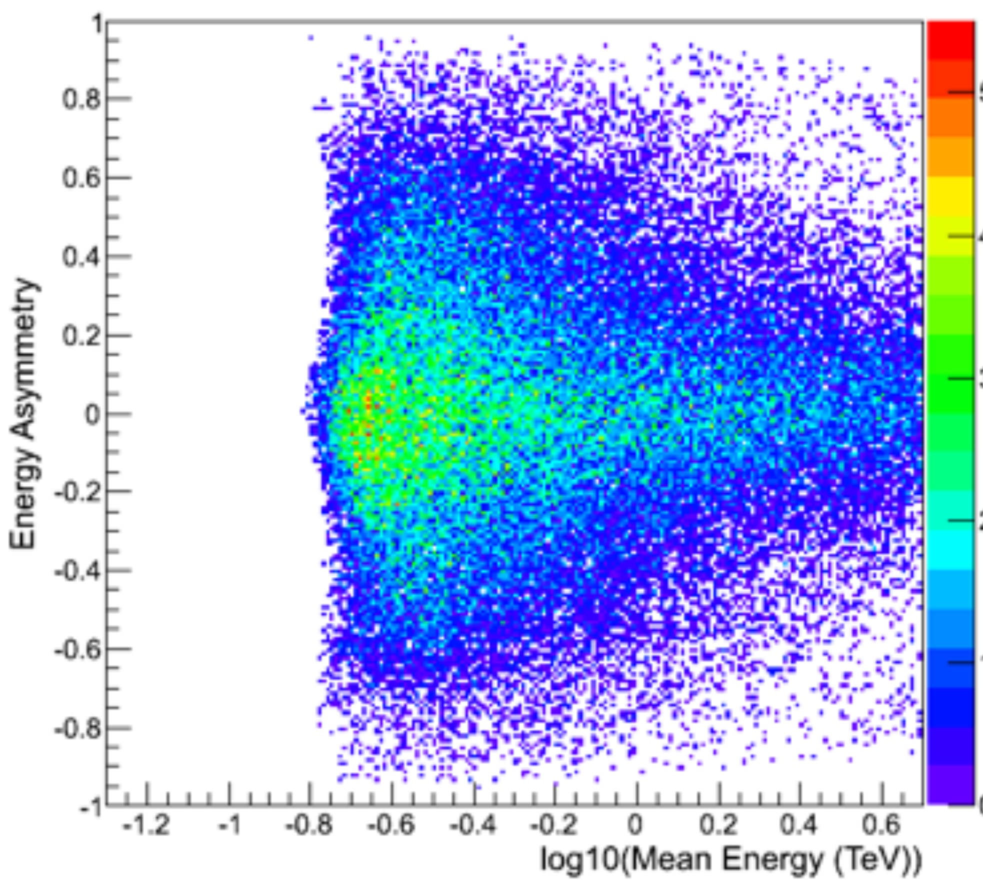
Interpret systematic differences as due to different optical efficiencies

Relative calibration, complementary to muon calibration

Reminder: Intercalibration Principle

- Principle of pairwise comparisons between telescopes
- Number of pairs grows with N telescopes as $\sim N^2$
- Many pairwise comparisons enable calibration of the entire array
- Symmetry asymmetry distribution - mean is used for calibration





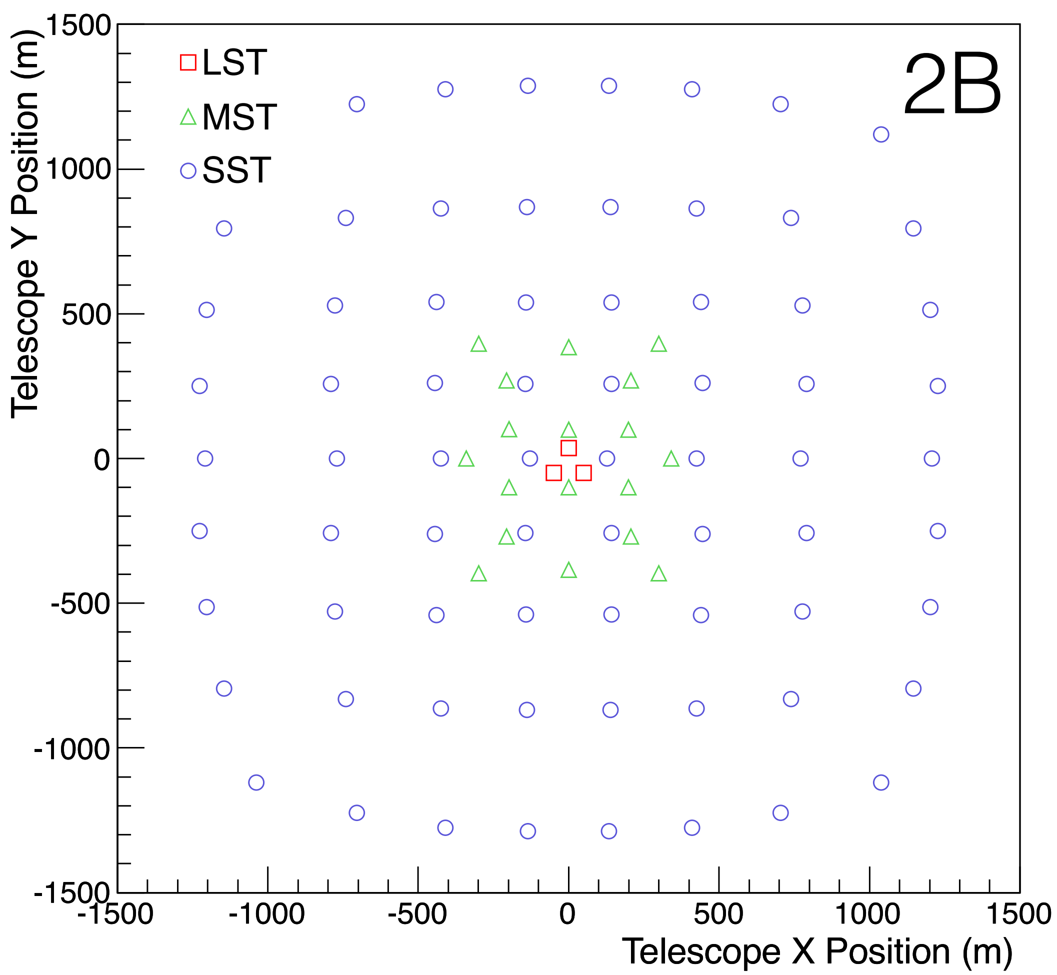
Reminder: Intercalibration

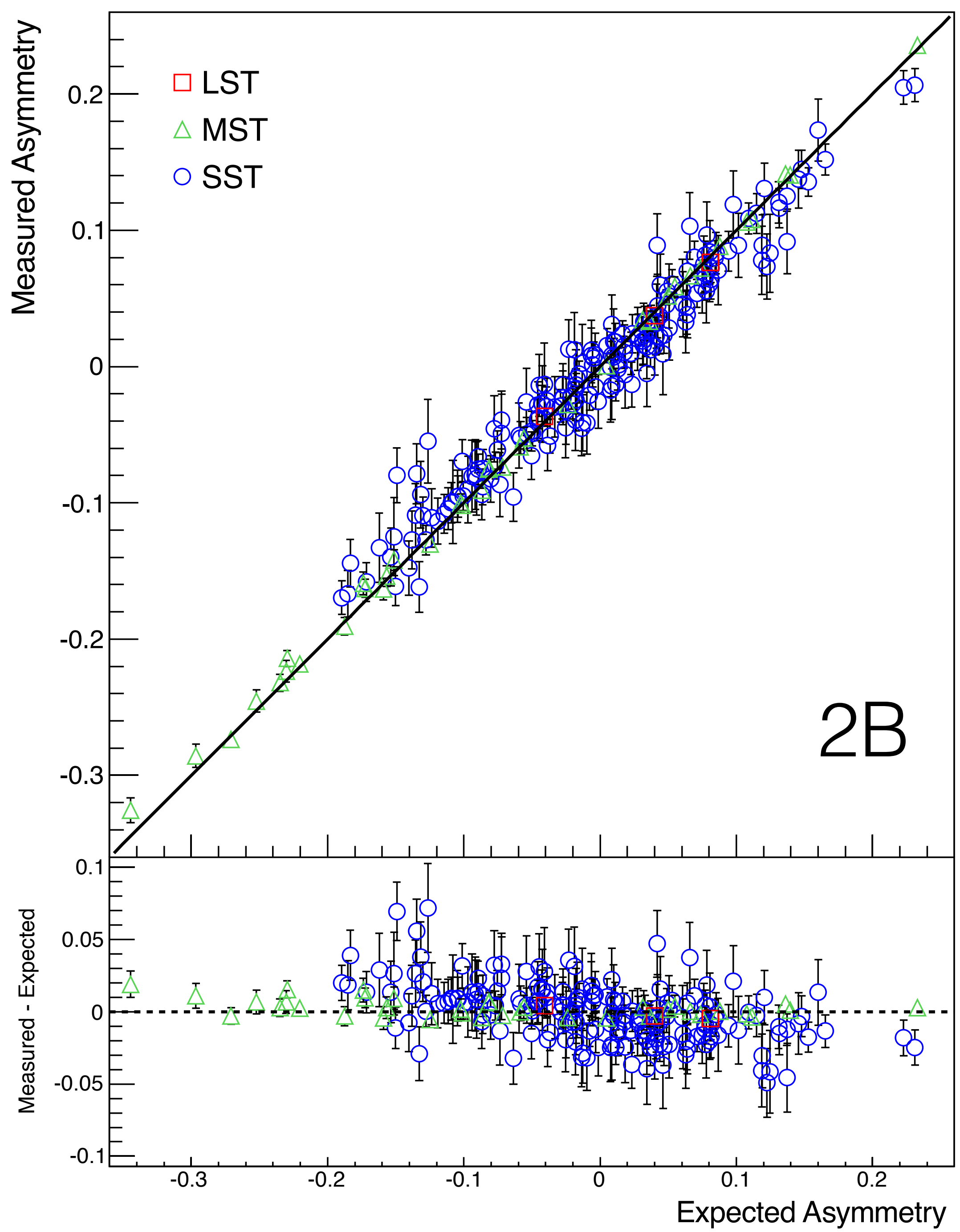
- Comparison via an asymmetry parameter in reconstructed energy (rather than image size) as a probe of optical efficiency

$$a_x = \frac{x_i - x_j}{x_i + x_j}$$

- On MC, measured energy asymmetries agree with input random optical efficiencies

- Tested two layouts, 2A and 2B (shown, 4m dual-mirror SSTs)





Reminder: Intercalibration

- A chi-square minimisation for each telescope subsystem was performed to recover the individual telescope coefficients.

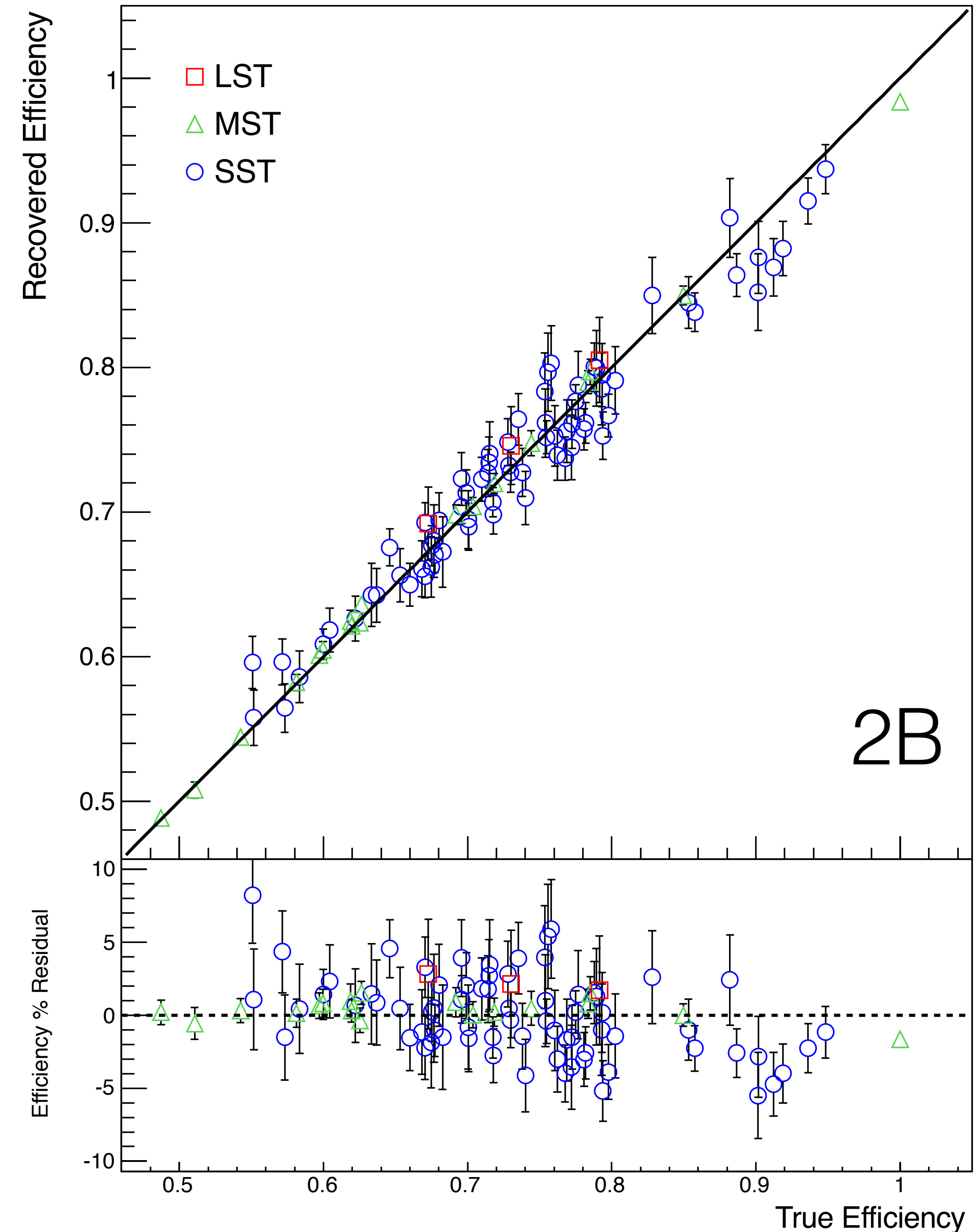
$$\chi^2 = \sum_{i=1,j>i}^{N} \frac{\left(a_{ij} - \frac{c_i - c_j}{c_i + c_j}\right)^2}{\sigma_{ij}^2}$$

- Different telescope subsystems were normalised

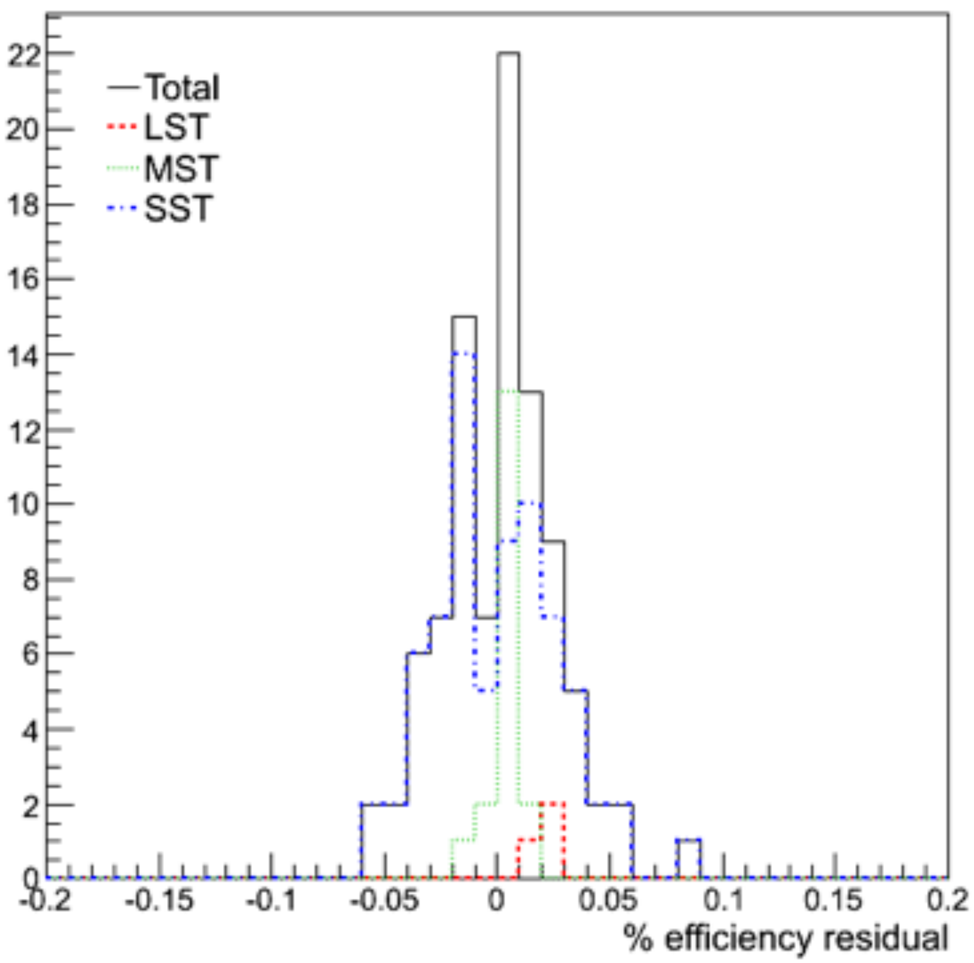
- Good agreement between recovered efficiencies and input values

- Results after MC <=> 13 hours on a source with 10% Crab flux:

Array Component	2A	2B
LSTs	0.2%	0.5%
MSTs	0.9%	0.7%
SSTs	1.2%	2.8%
Full array	1.7%	2.5%



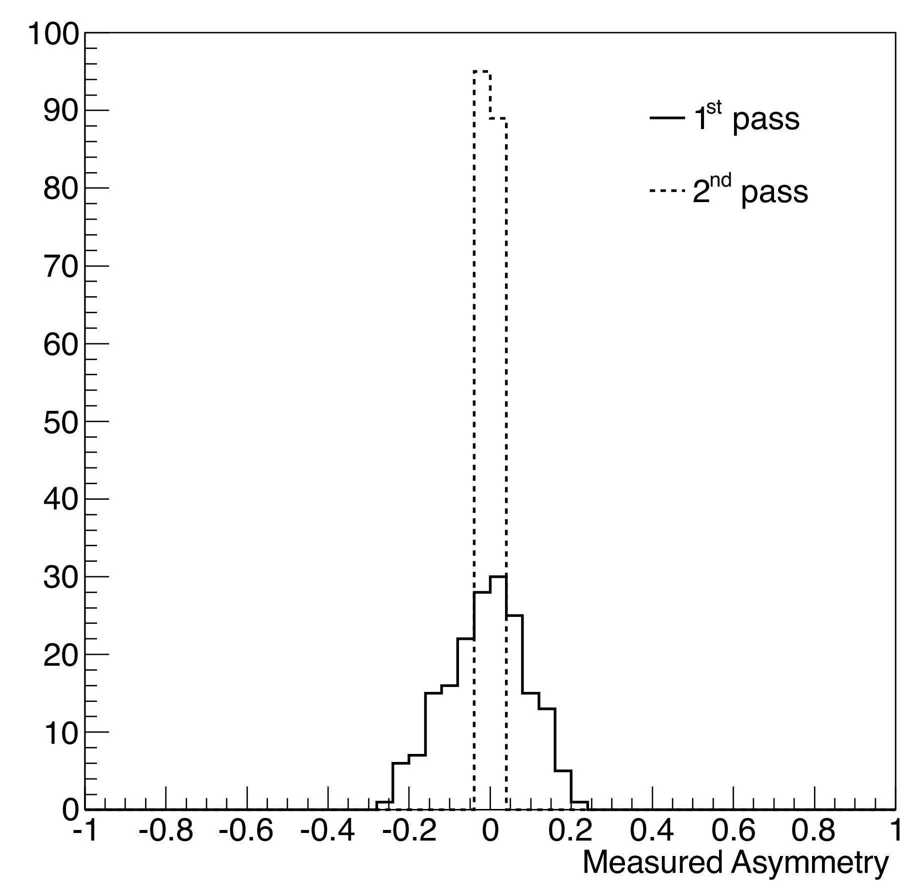
Reminder: Intercalibration Principle



Some residual offset between subsystems

- In practice, expect to use an iterative approach, correcting energy estimates as $E_t \longrightarrow E_t \times (\varepsilon_{avg}/\varepsilon_t)$

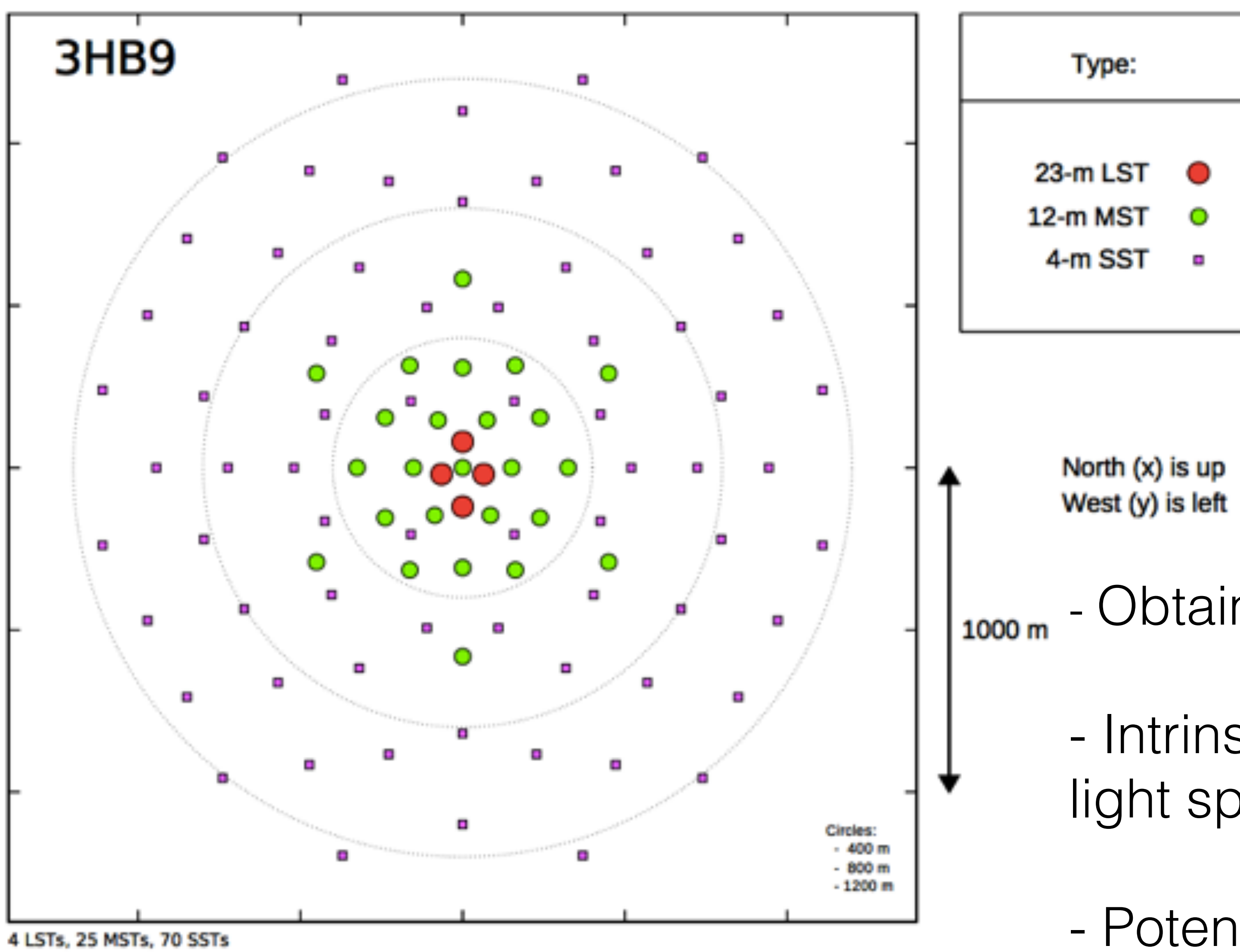
- Shows clear improvement in spread of asymmetries



Reminder: Intercalibration Principle

- Note: restriction on distance between telescopes; out to ~350m needed for SSTs

- Should not be a problem for 3HB9 (chosen layout, circles are 400m apart)



- Obtained from data (no extra equipment)

- Intrinsically uses the correct Cherenkov light spectrum (muons are shifted)

- Potentially available nightwise

- Good precision demonstrated

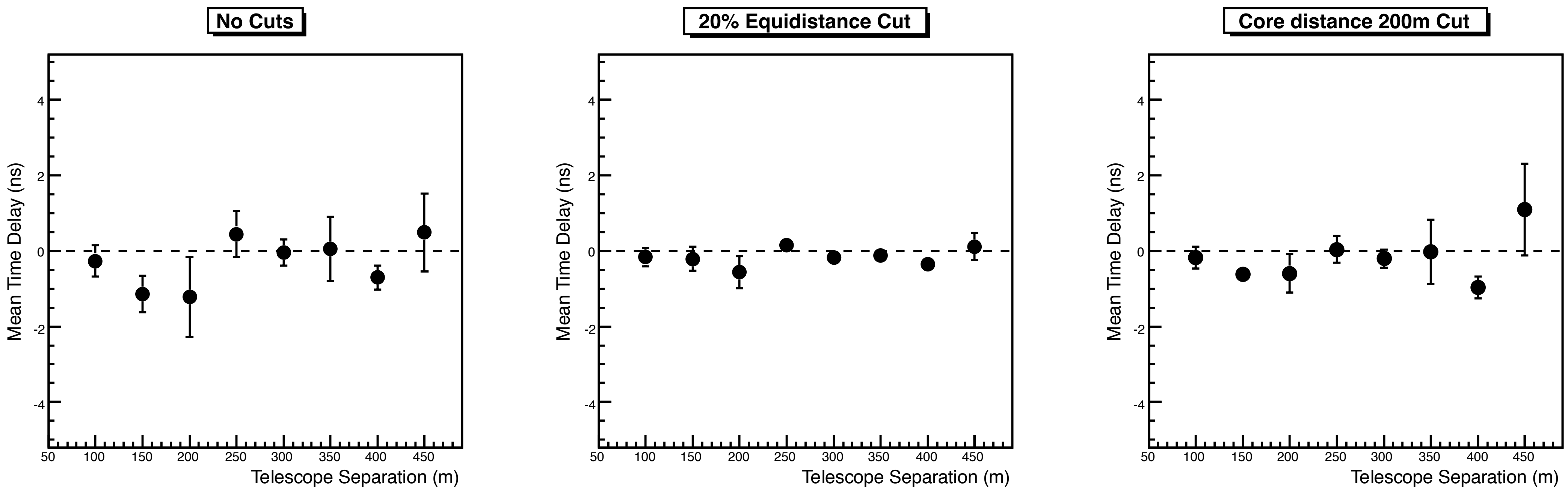
Cross Calibration - Extension to Timing

For optical efficiency calibration, the same principle can be used with the image size for telescopes of the same type

Principle can be extended to timing calibration (suggestion from M. Punch)

- Make comparisons between telescope pairs
- Average over the time delays for a given telescope separation distance
- Test for telescopes of the same type and for different types

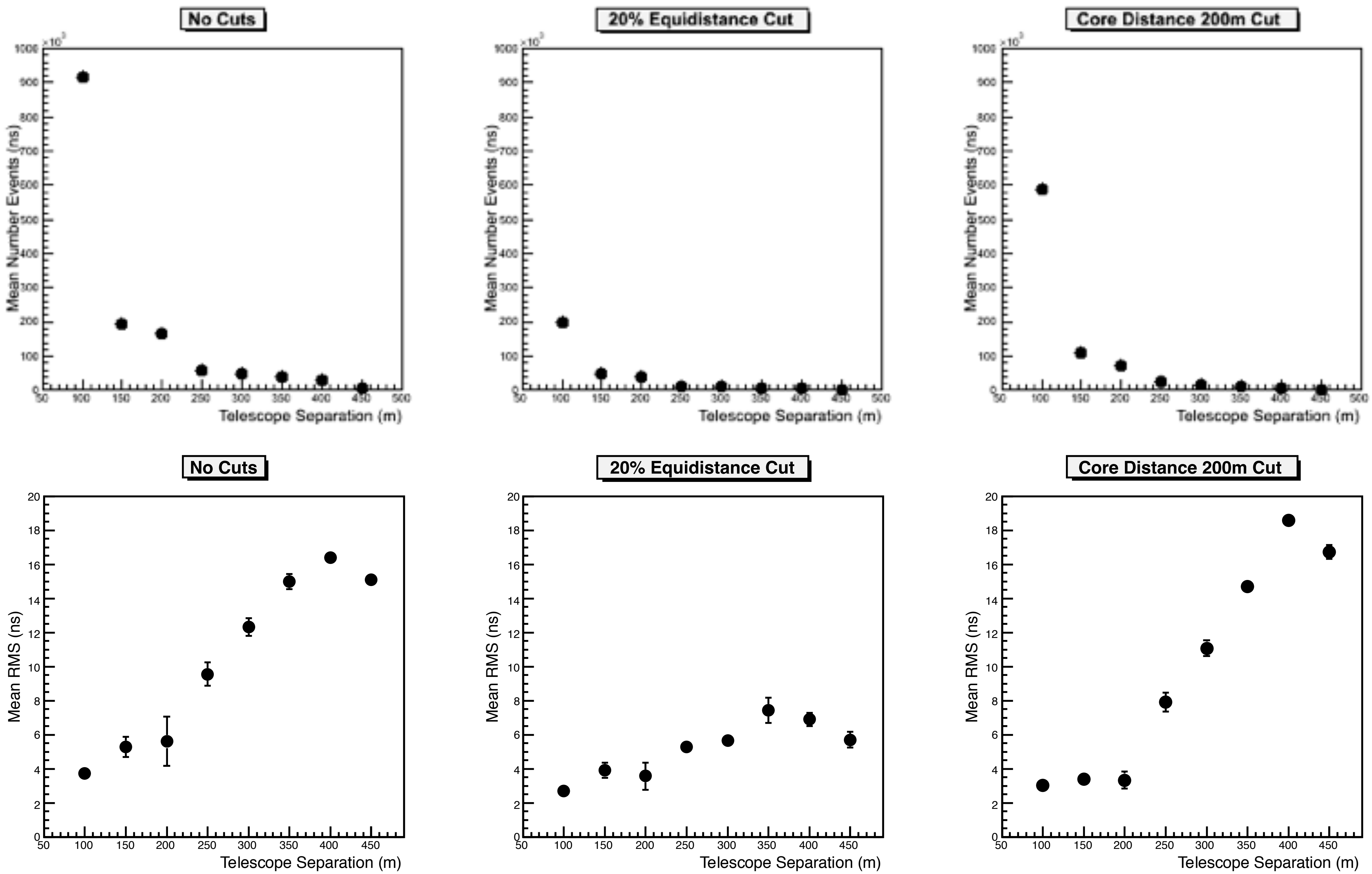
Same type comparisons



Difference in central trigger time,
Averaged per telescope separation
Calibrate to within 10ns, 2ns with cuts (meets requirements)

γ- MC only

Number of events and RMS spread



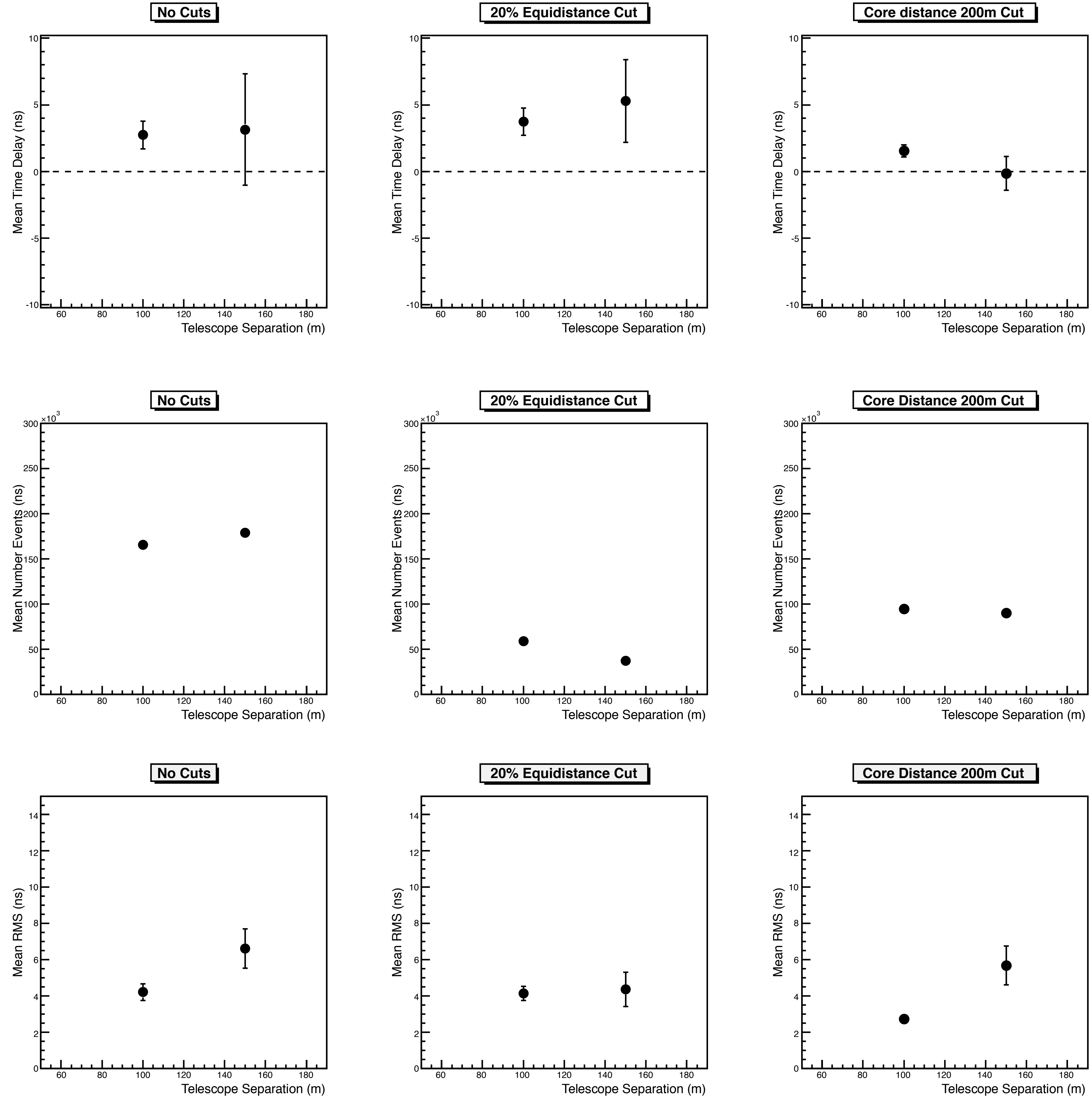
Same type comparisons

Equidistance cut reduces rms

(cuts on image size and shape - no significant effect)

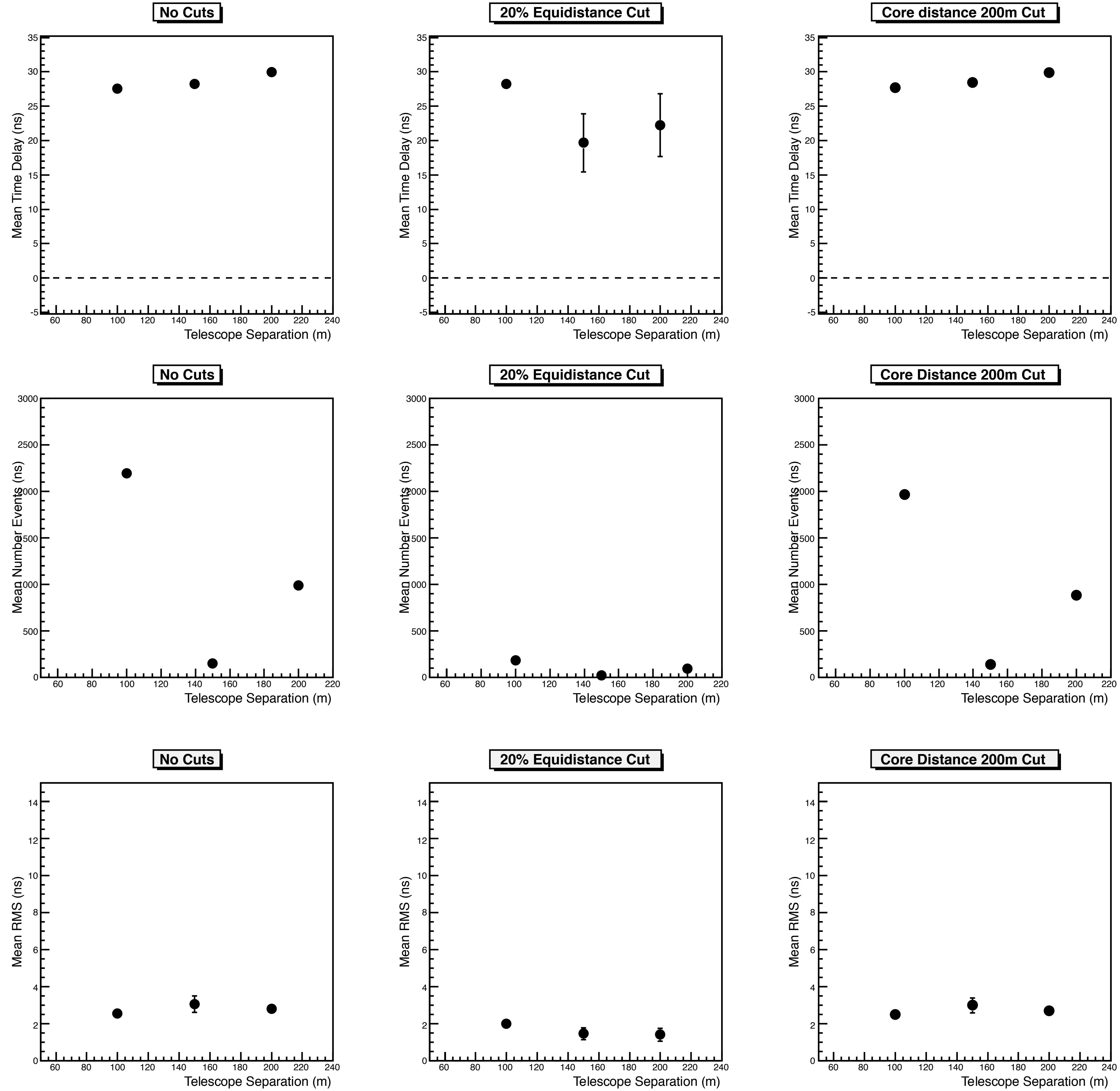
LST - MST

- Systematic offset of ~3ns
- Reduced by core distance cut



MST - SST

- SC-SSTs
- Systematic offset ~30ns
- core distance cut did not remove many events



Causes of Systematic Offset & Further Work

- Possibly due to the height difference between telescopes:
This was investigated, and found not to be the cause

- Most likely explanation: due to differences in the way the trigger is defined; (analogue sum, digital sum, or majority trigger)

- Both LST & MST use analogue sum: 3 ns difference likely due to the longer time required for the MSTs to collect sufficient light to surpass the trigger threshold

- Application: cannot compete with White Rabbit - but, to use picosecond accuracy we need to understand nanosecond discrepancies

-Suggest to use during commissioning

Future Work

- Implement Cross Calibration in the CTA pipeline
- Develop timing cross calibration method and explore possibilities for implementation

- Rough outline for optical efficiency calibration in CTA:
  1. initial calibration, image cleaning and identification
  2. Muon calibration on muon events
  3. If results are different to current telescope efficiencies, change these
  4. (Can also perform cross calibration with image size)
  5. Simulate run with these optical efficiency values
  6. Energy cross calibration done each night -> identify systematic offsets between telescopes or subsystems
  7. Large discrepancies —> re-simulate run. Otherwise —> adjust stored values as appropriate

- See also my thesis (available after the summer…)

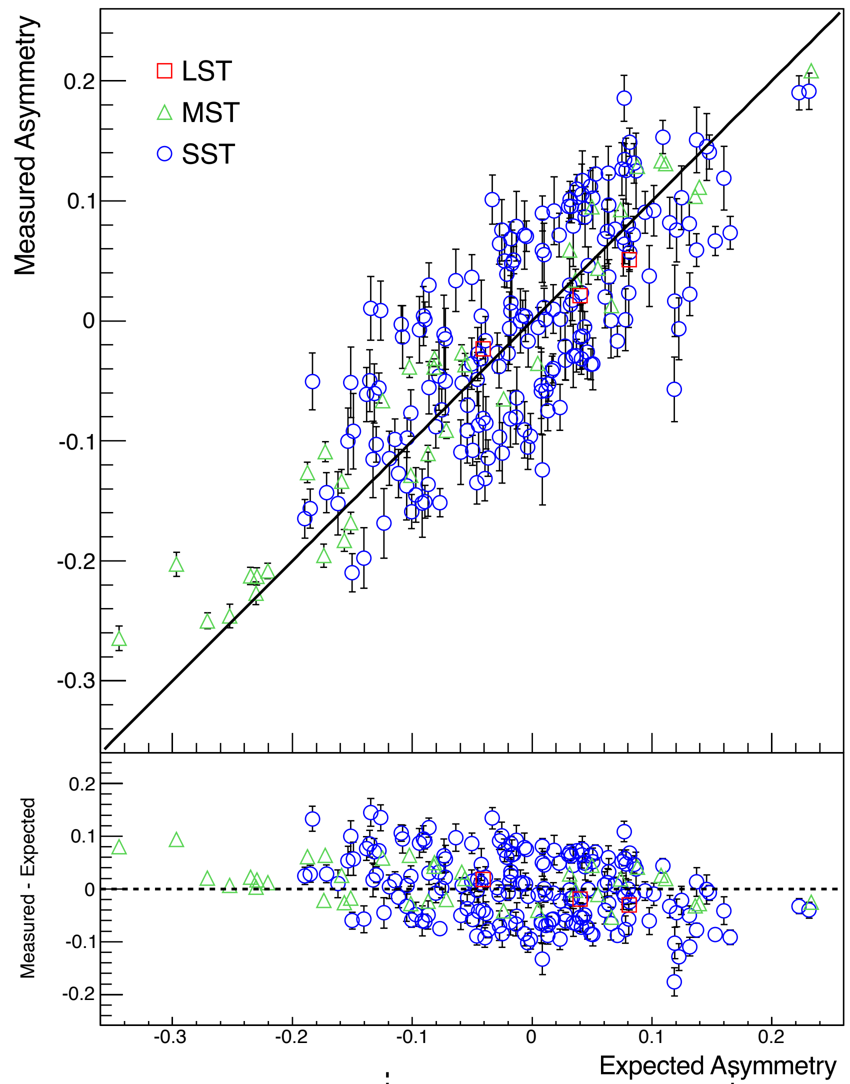
Thank you for your attention

Any Questions?

Max-Planck-Institut für Kernphysik

Cross Calibration on hadronic background

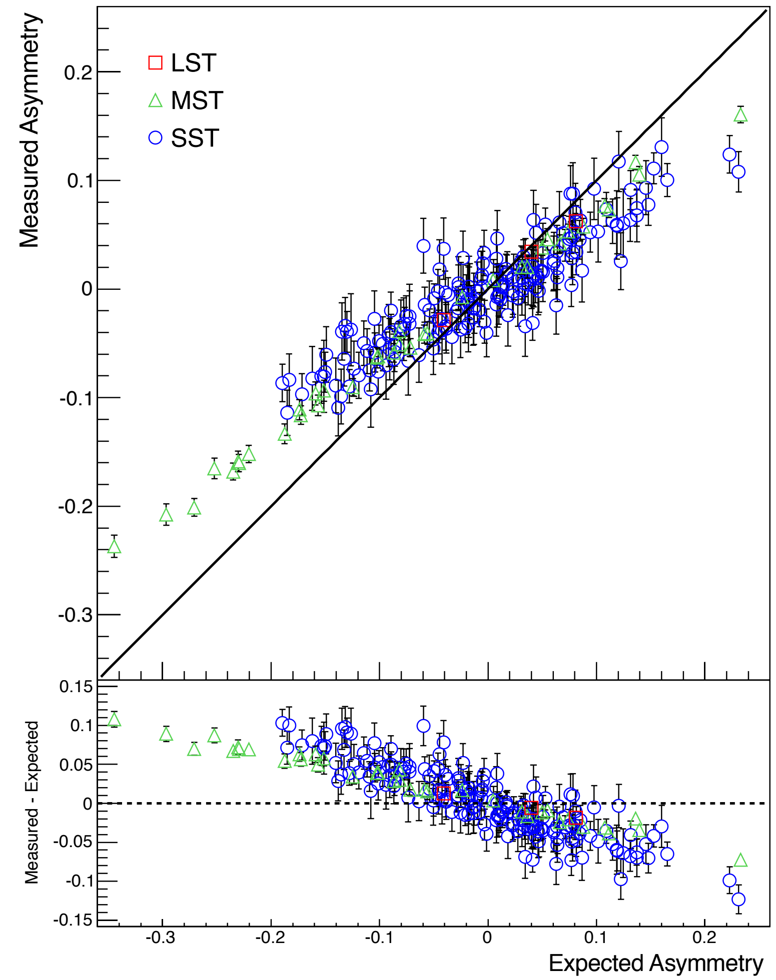
- Protons
- good correlation in asymmetries
- low statistics; ~O(10^{-3}%) survive cuts
- large scatter for smallest telescopes
- Results after MC <=> 23s livetime



Array Component	2A	2B
LSTs	1.3%	2.7%
MSTs	11.3%	12.8%
SSTs	25.0%	30.2%
Full Array	21.3%	27.9%

Dealing with biased energy reconstruction

- Deliberately biased energy reconstruction with core distance
- Bias factor (200/d) applied
- subsystem scaling factors difficult (not applied)



Array Component	2A	2B
LSTs	0.9%	1.6%
MSTs	3.9%	5.7%
SSTs	5.0%	6.4%
Full Array	4.7%	7.3%

Energy Asymmetry

- Energy Asymmetry histogram between two telescopes of different sizes
- need to remove the biased region via a fit.