# Alan Watson: GCOS Discussion for Session on Surface Detectors

## General Remarks

- At least one site, there should be a large area with closely spaced-detectors ('infilled')

- The dynamic range of the detectors is very important

- Area of Detectors: larger the better but perhaps limited by road width

Linsley (in 1977) achieved 0.5 to 5 x $10^5$ $m^{-2}$ on the compressed VR array

- We really know **NOTHING** about what goes on close to the core (< 500 m) of a shower of 10 EeV.  Surely this is a place to test forward-physics

- Also we must try to see shower-to-shower differences in LDF – important measurement related to mass measurement

- Choice of geometry of layout is important

**CGOS 13 July 2022: Discussion on Surface Detector Arrays**

# Use of the Signal at an Optimal Distance from the Shower Core as Surrogate for Shower Size

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**Hillas (1969)** **analysed 50 events,** ***recorded using the Haverah Park array of the time – a star-shaped geometry*** **– using power-law lateral-distribution functions, differing by 0.6 (consistent with observations)**

**For the early Haverah Park geometry,**

**Hillas found that the fluctuation in the signal at 500 m was less than 12%**

**For $E_{100}$ , with the same values of the power law, differences were typically around 1.7**

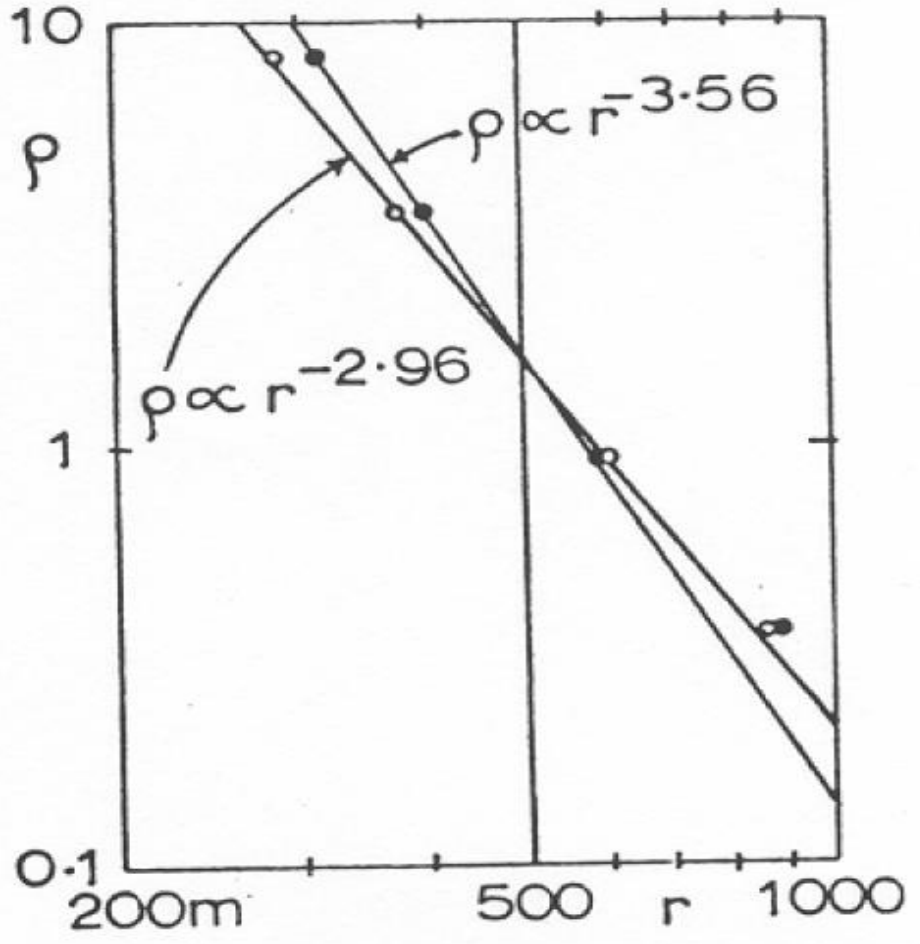



Fig. 2: Effect of change of assumed structure function in analysis of a shower.

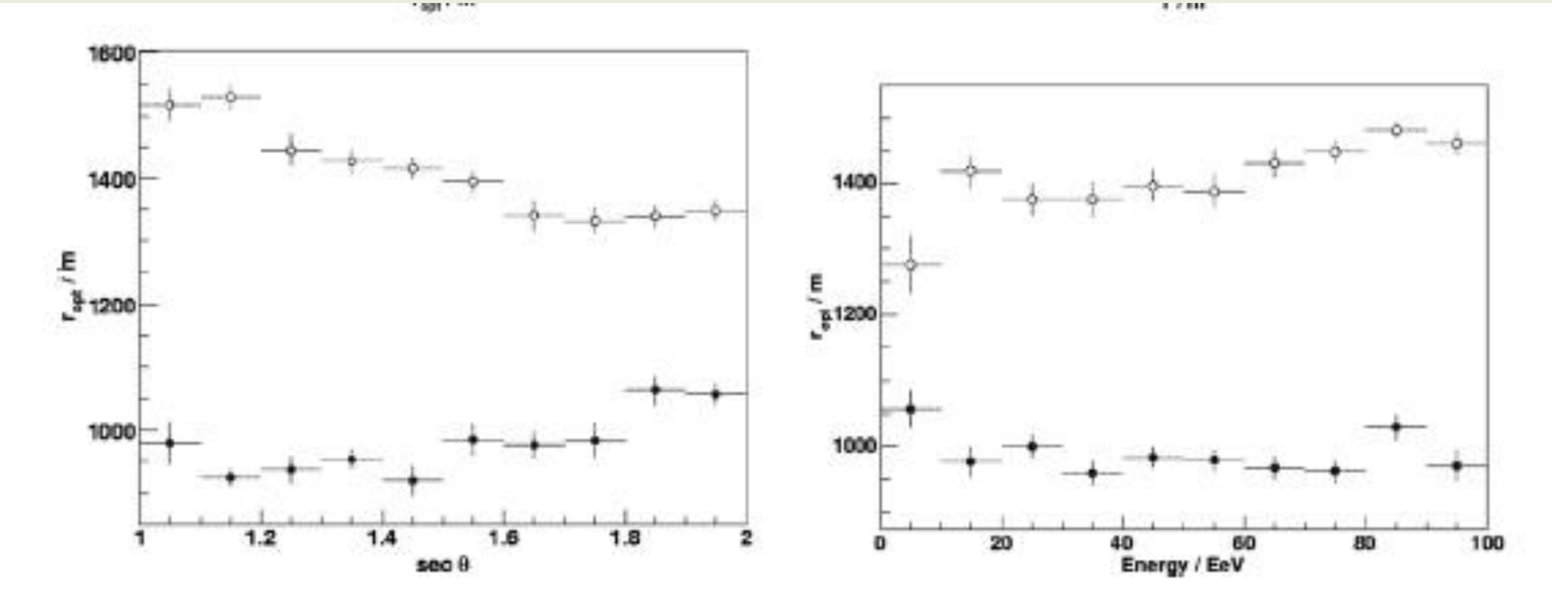
Hillas 1971

# Detailed study for Auger Observatory (Newton, Knapp and Watson et al 2007)

| LDF | $r_{opt}$/m, mean | $r_{opt}$/m, RMS | $\Delta S(1000) = \frac{S(1000)_{LDF}}{S(1000)_{NKG}}$ |
|---|---|---|---|
| Power law | 960 | 110 | $1.045 \pm 0.001$ |
| 'Haverah Park' | 940 | 100 | $0.986 \pm 0.001$ |
| 'NKG' type | 970 | 110 | 1.00 |

**Difference between optimum values for various ldfs (940 – 970 m) typically shows a spread in S(r) smaller than that at 1000 m of ~2%. So using 100m rather than smaller value not very important**

**Very little dependence on zenith angle or energy**



## Dependence of $r_{opt}$ on detector spacing?

- **For triangular geometry: ~2/3 of spacing is appropriate choice for $r_{opt}$**
- **Used (and checked) for 750 m array of Auger Observatory**
- **Used (but not checked) by TA for square array**
- **No obvious relation for HP geometry used in Hillas's seminal work**

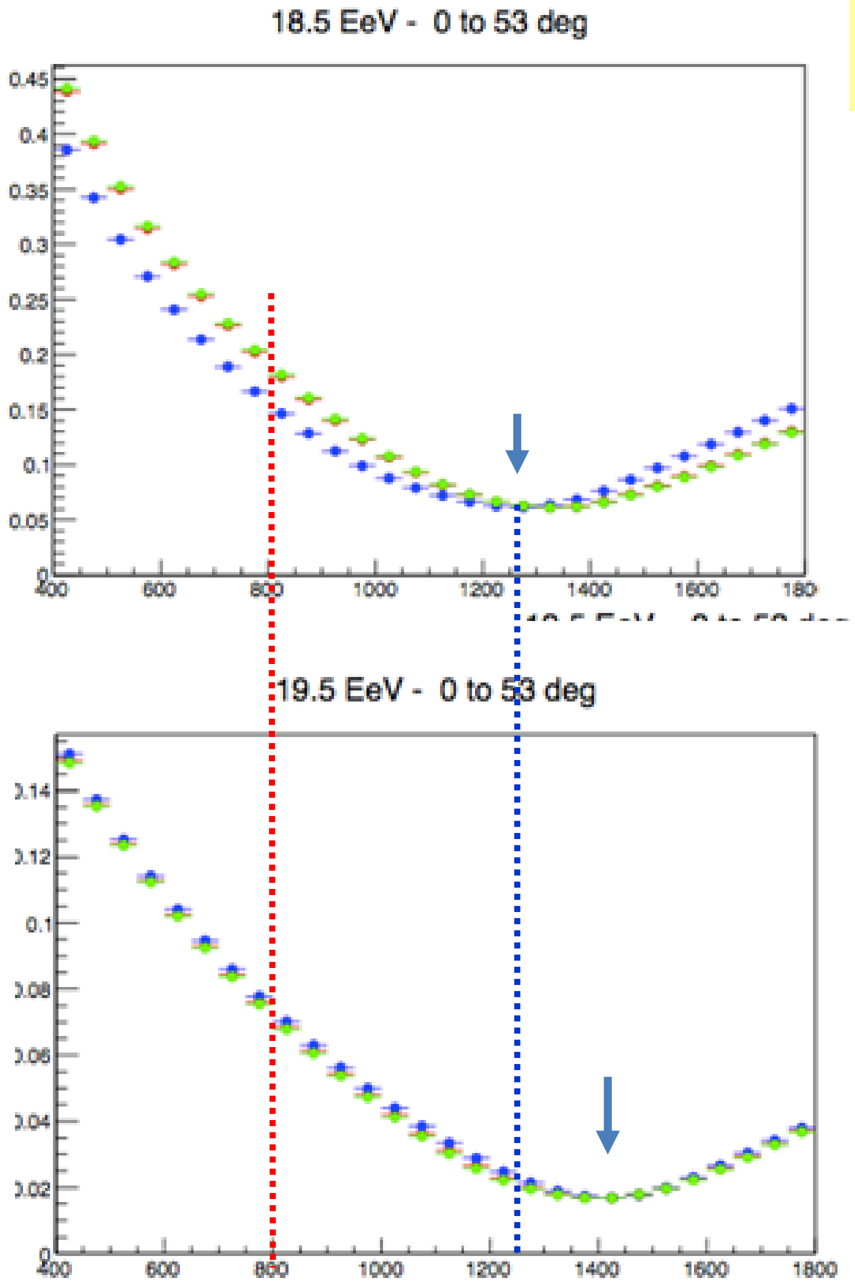
**Does the layout of the detectors have an influence on the $r_{opt}$ to be used?**

**Auger: Triangular grid 1500 m**
**Telescope Array: Square grid 1200 m**

**Simulations using TA array with Water-Cherenkov detectors – for two energies and range of angles**

σ/S

σ/S




**Green – no saturated stations**

**Blue – saturated stations**

**Red – all**

**σ/S is larger at 800 m than at $r_{opt}$**

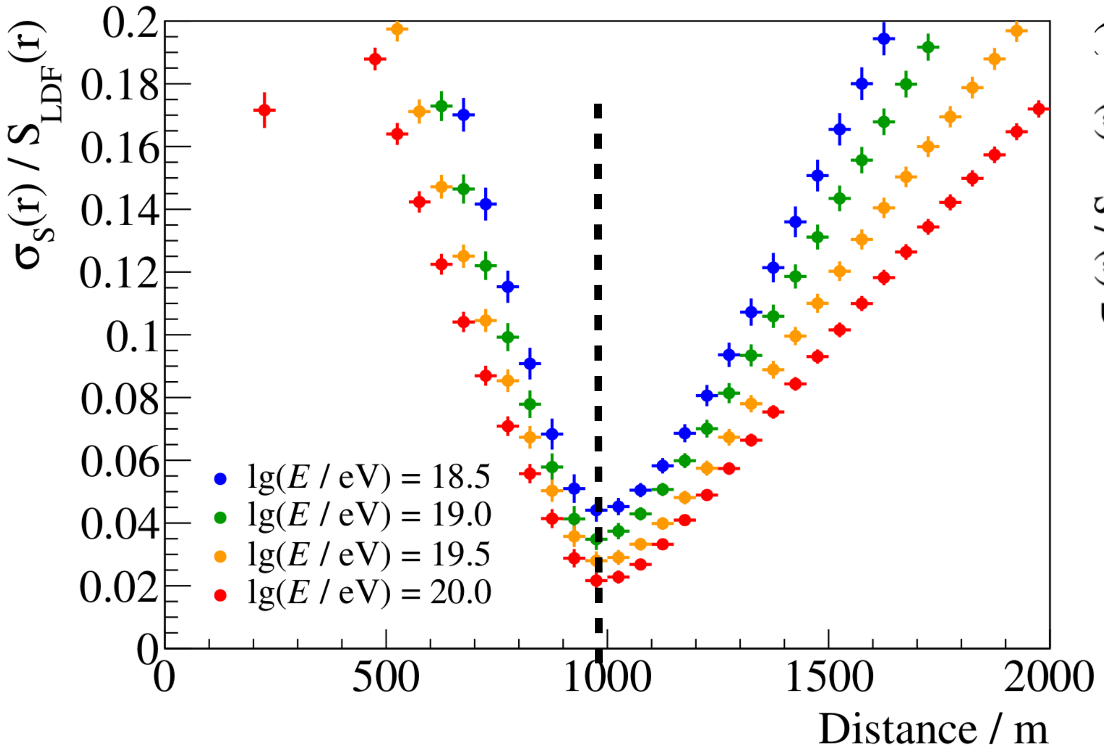
**log E = 18.5: 7% vs ~20%   19.5: 2% vs ~7%**

# Comparison of results for Triangular and Square grids

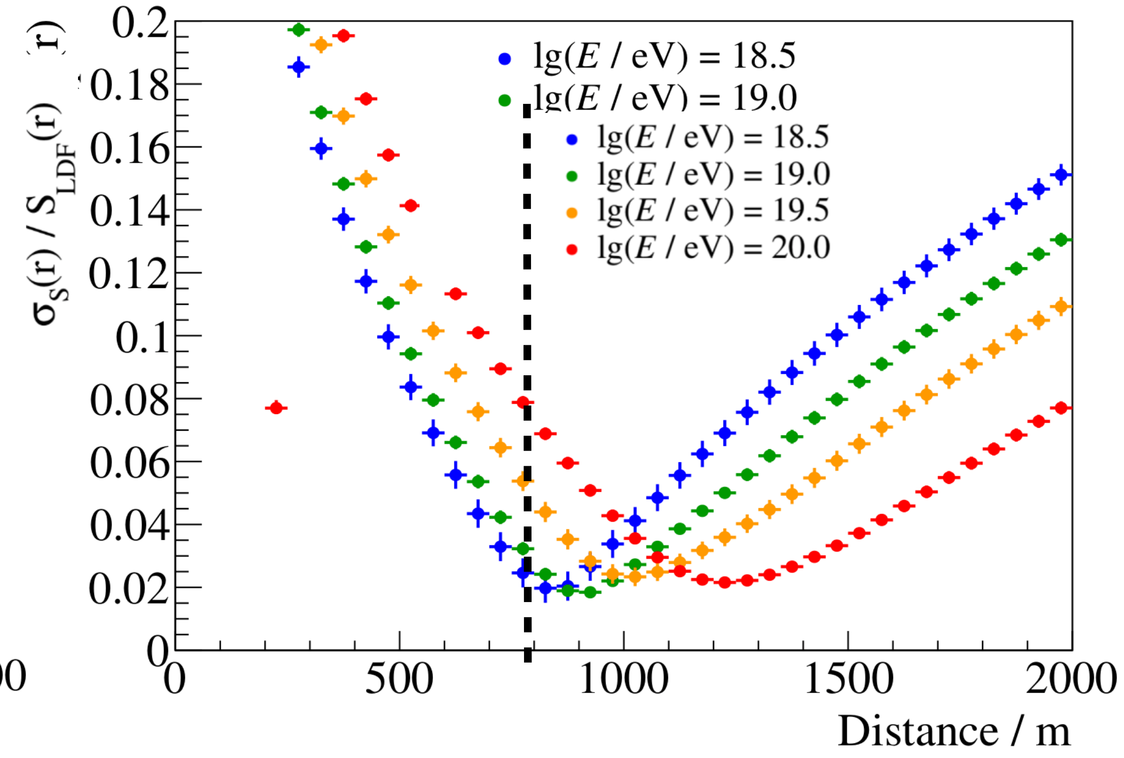
QGSJet-II.04
Proton

$\theta = 0^\circ$

**WCD - Triangular grid – 1500 m**
**Auger-NKG LDF**




**SSD - Square grid – 1200 m**
**AGASA LDF**



# Fluctuations of S($r_{opt}$)

**Fluctuations in S(1000) are biased because of underlying differences in β, the LDF parameter.**
**Biases stronger for scintillators**

$\theta = 0^\circ$

QGSJet-II.04
Proton

**WCD - Triangular grid – 1500 m**
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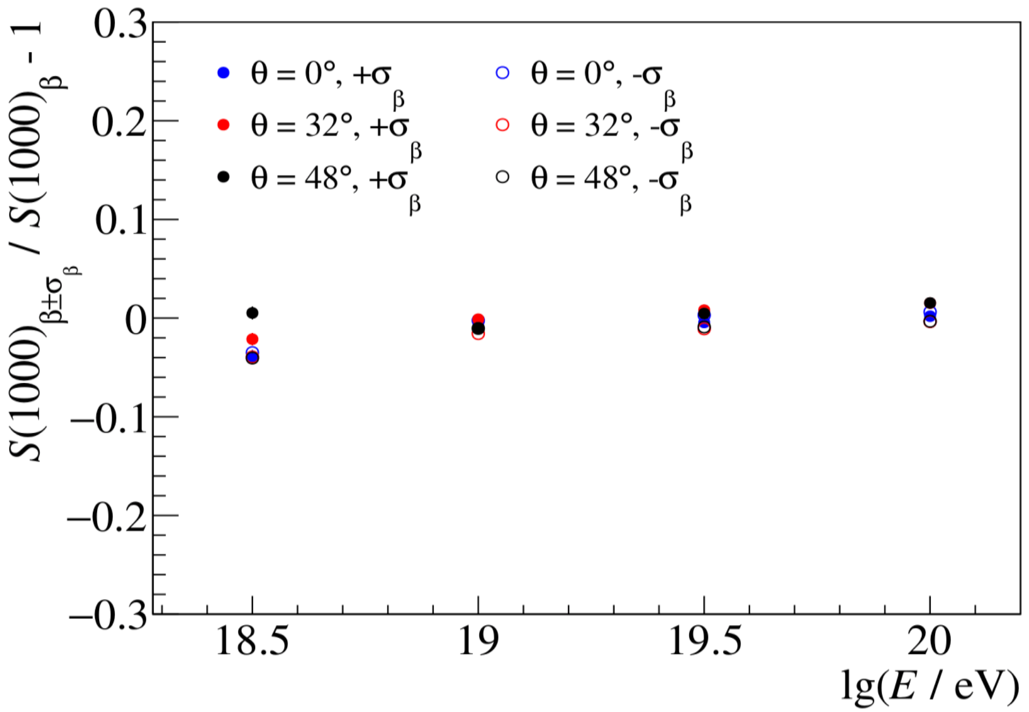


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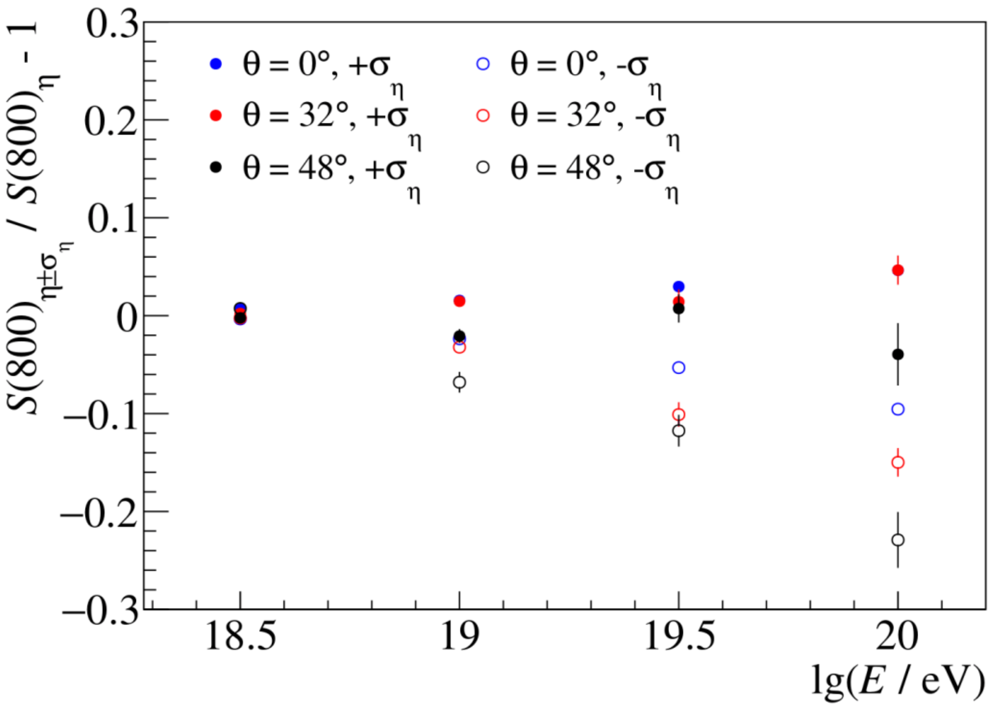

**Take home messages:**

- **Layout of an array has an impact on $r_{opt}$**
- **Difference between triangular and square array is important**
- **$r_{opt}$ dependence should be investigated for planned geometries**
- **Desirable that $r_{opt}$ does not depend on energy**
- **But, WHY is there this dependence?**

  **We are thinking hard about this**

**I know of no other systematic study of Triangular vs Square**

- **Triangular used at MIT, VR, HP, AGASA, Yakutsk……**
- **Square at CASA, KASCADE and SUGAR (Auger North!)**