

# **Reconstruction of charge number of heavy cosmic rays using Cherenkov Light**

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# Aim of the analysis

- Cosmic Rays Cherenkov Light is imaged by telescopes eg. HESS
- Events currently reconstructed with Hillas Analysis
- However Core position/Charge resolution is poor

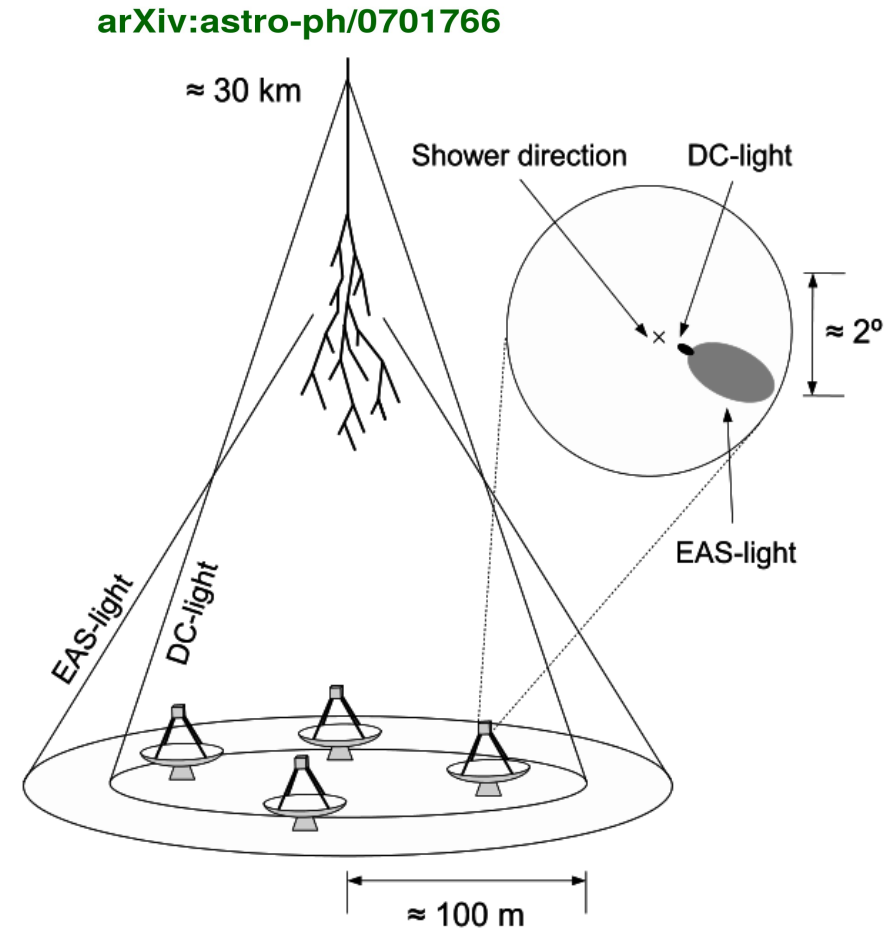


FIG. 1: Schematic representation of the Cherenkov emission from a cosmic-ray primary particle and the light distribution on the ground and in the camera plane of an IACT.

# Lateral Photon Distribution Method

- New reconstruction method, fitting received DC photons to known Lateral Distribution Function.
- Aim is to improve reconstruction of Charge.

arXiv:astro-ph/0701766

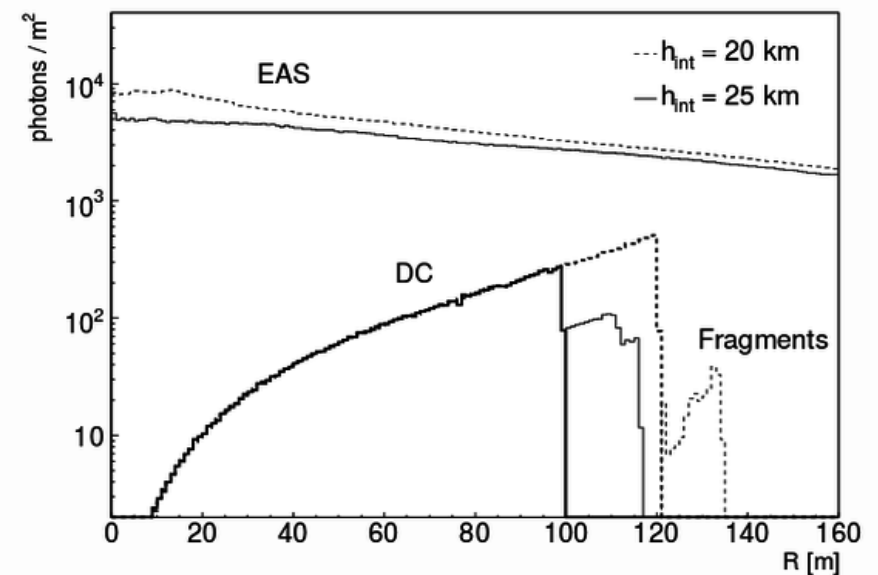


FIG. 2: Simulated intensity distribution on the ground for the EAS-light and DC-light of an individual 50 TeV iron nucleus, as a function of distance from the shower core, for two different first interaction heights (the shower core is defined as the intersection point of the shower axis on the ground). The zenith angle is  $0^\circ$ . The drop in DC-intensity at 100/120 m reflects the first interaction height. The low intensity tail at larger radii is caused by Cherenkov light from fragments of the primary nucleus.

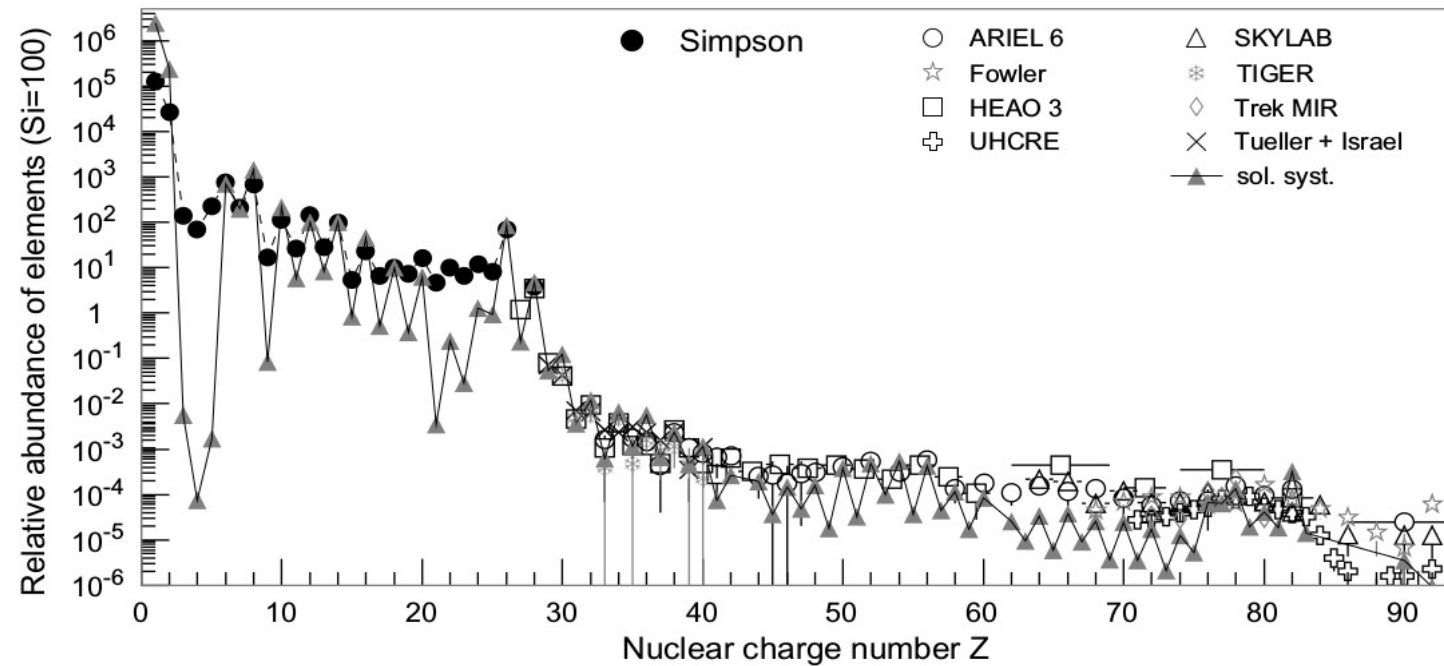


Fig. 3. Abundance of elements in cosmic rays as function of their nuclear charge number  $Z$  at energies around  $1 \text{ GeV}/n$ , normalized to  $\text{Si} = 100$ . Abundance for nuclei with  $Z \leq 28$  according to Simpson (1983). Heavy nuclei as measured by ARIEL 6 (Fowler et al., 1987), Fowler et al. (1977), HEAO 3 (Binns et al., 1989), SKYLAB (Shirk and Price, 1978), TIGER (Lawrence et al., 1999), TREK/MIR (Weaver and Westphal, 2001), Tueller et al. (1981), as well as UHCRE (Donnelly et al., 1999). In addition, the abundance of elements in the solar system is shown according to Lodders (2003).

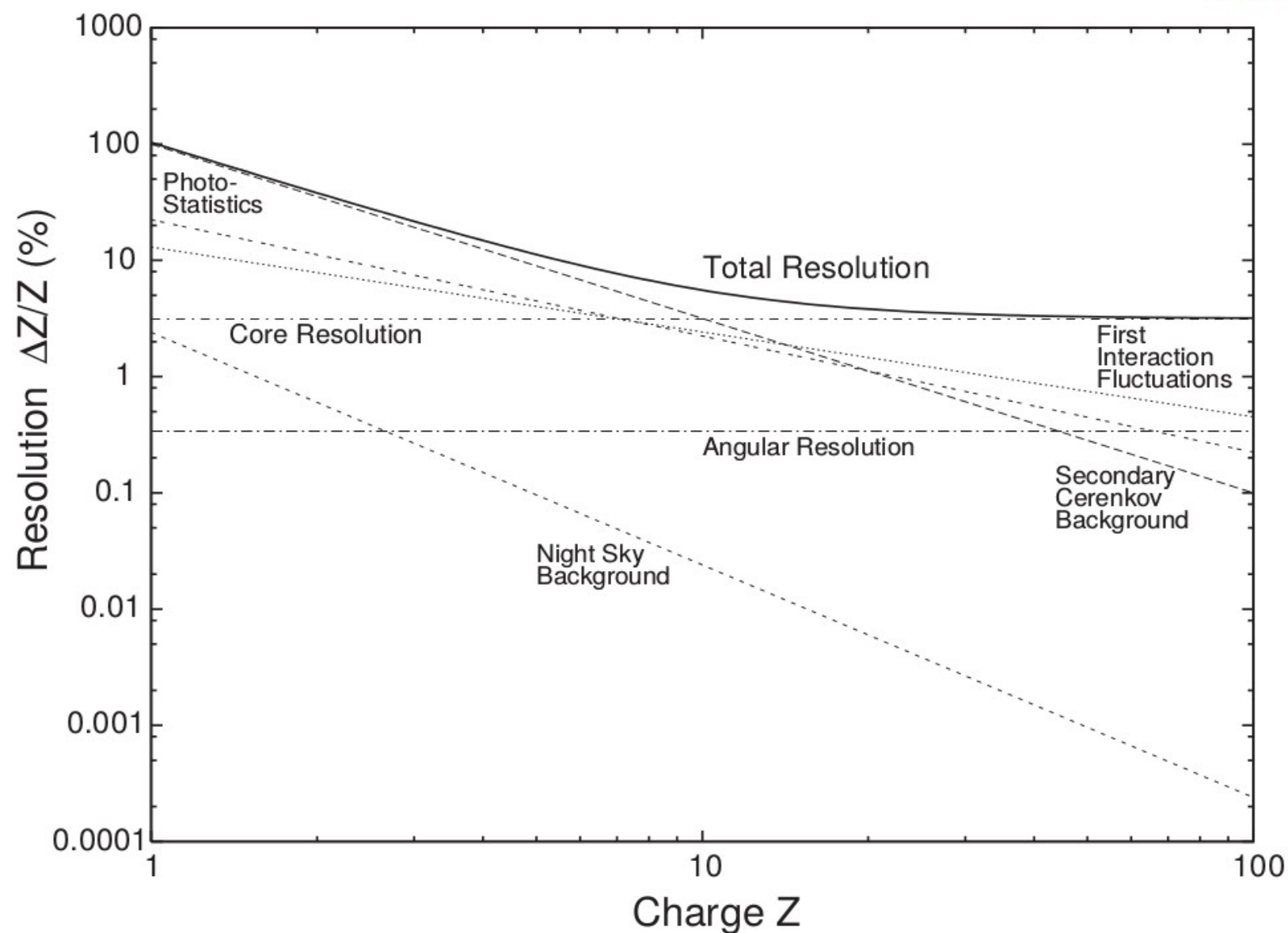
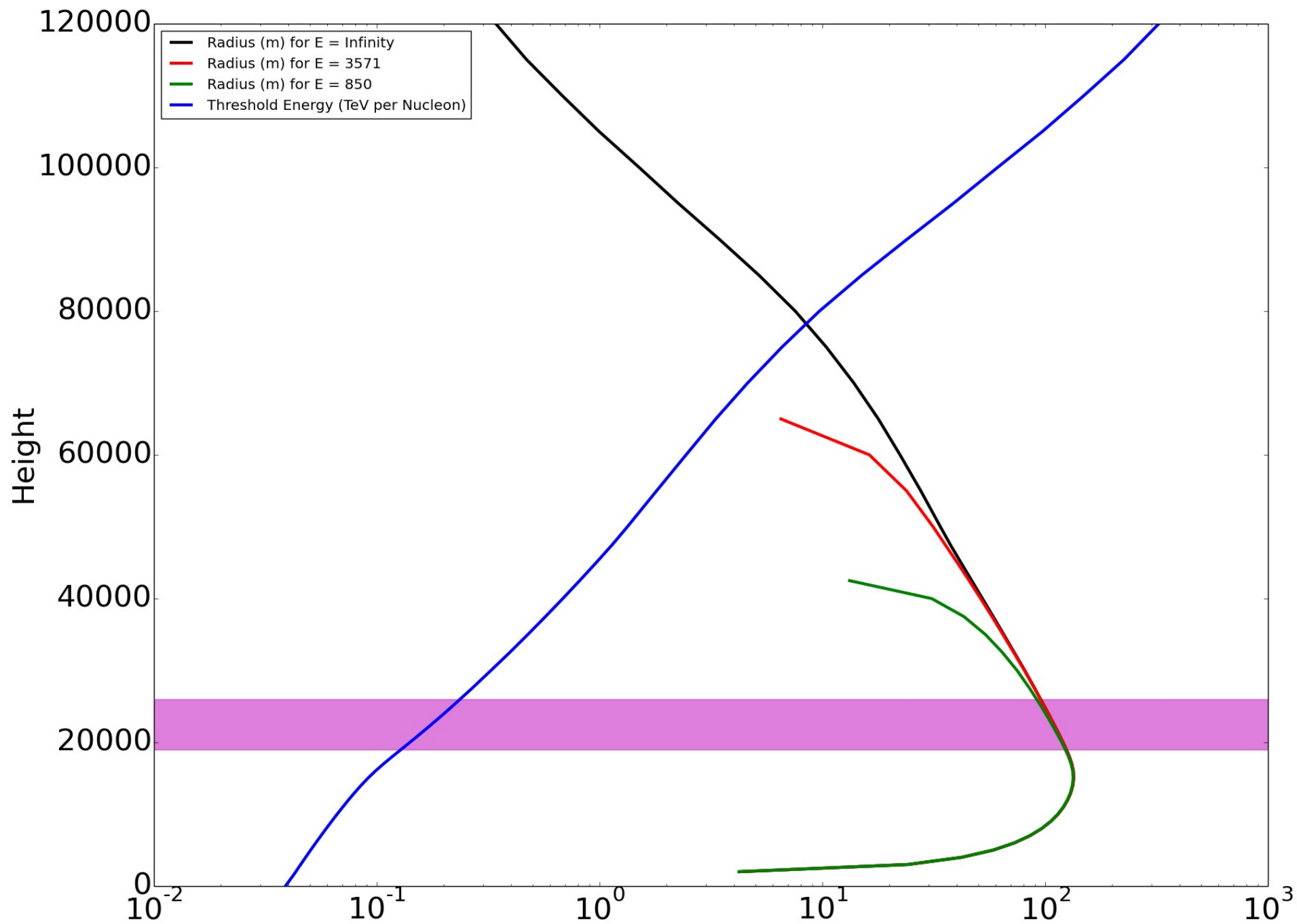
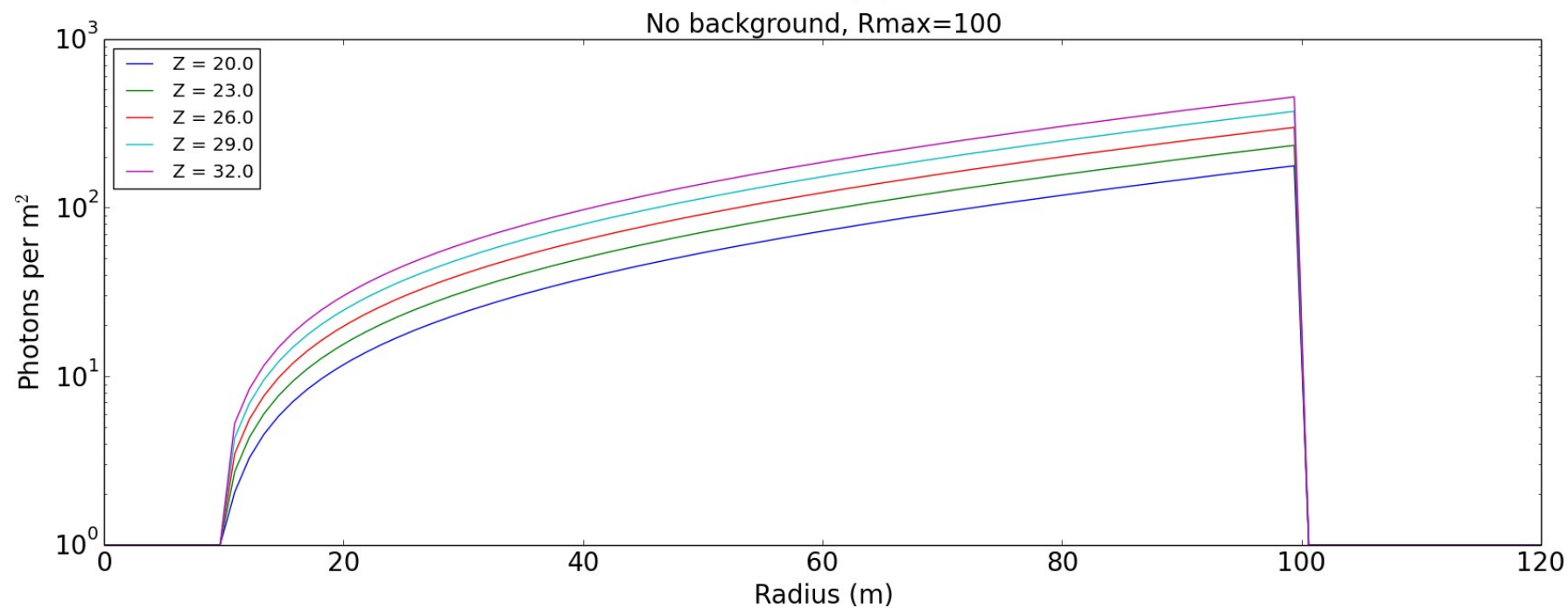
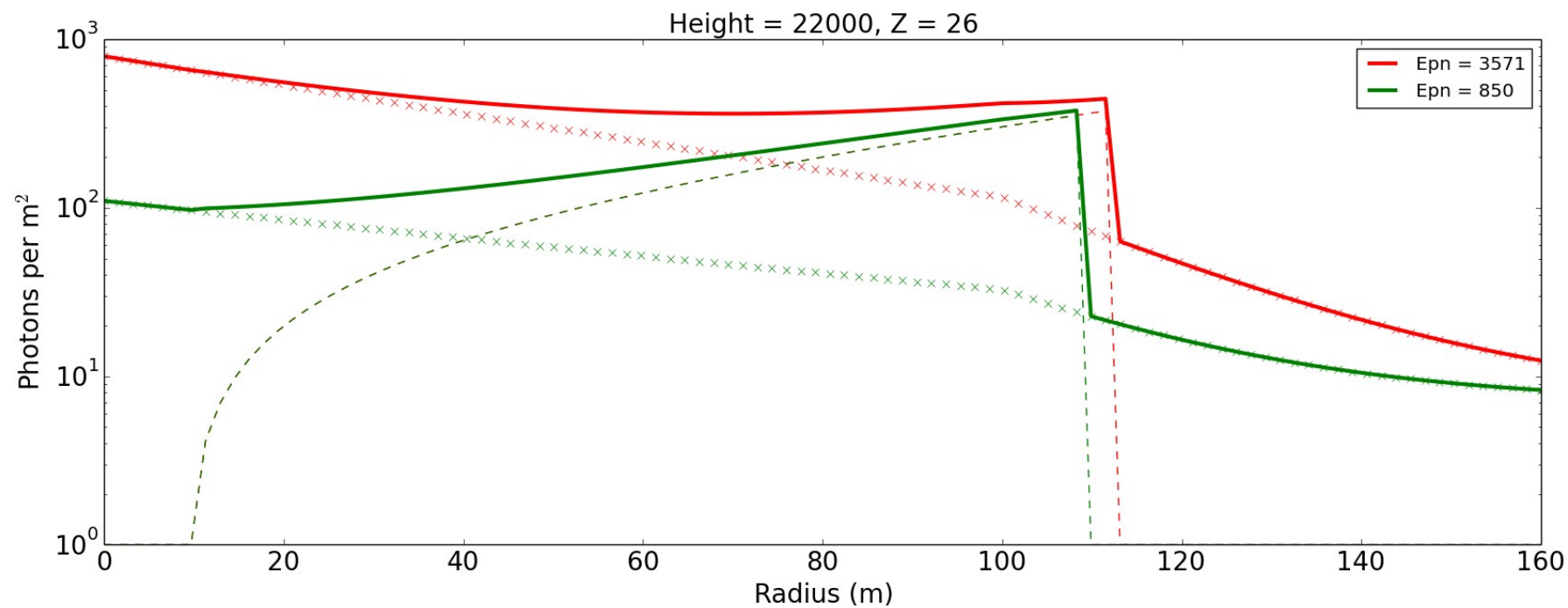


Fig. 11. The expected charge resolution  $\Delta Z/Z$  for a detector of effective area  $100 \text{ m}^2$  and core position resolution 5 m. Horizontal Axis: Primary Charge  $Z$ . Vertical Axis: Charge Resolution  $\Delta Z/Z(\%)$

# Energy per Nucleon statistics



# Lateral Photon Distribution in DC pixel





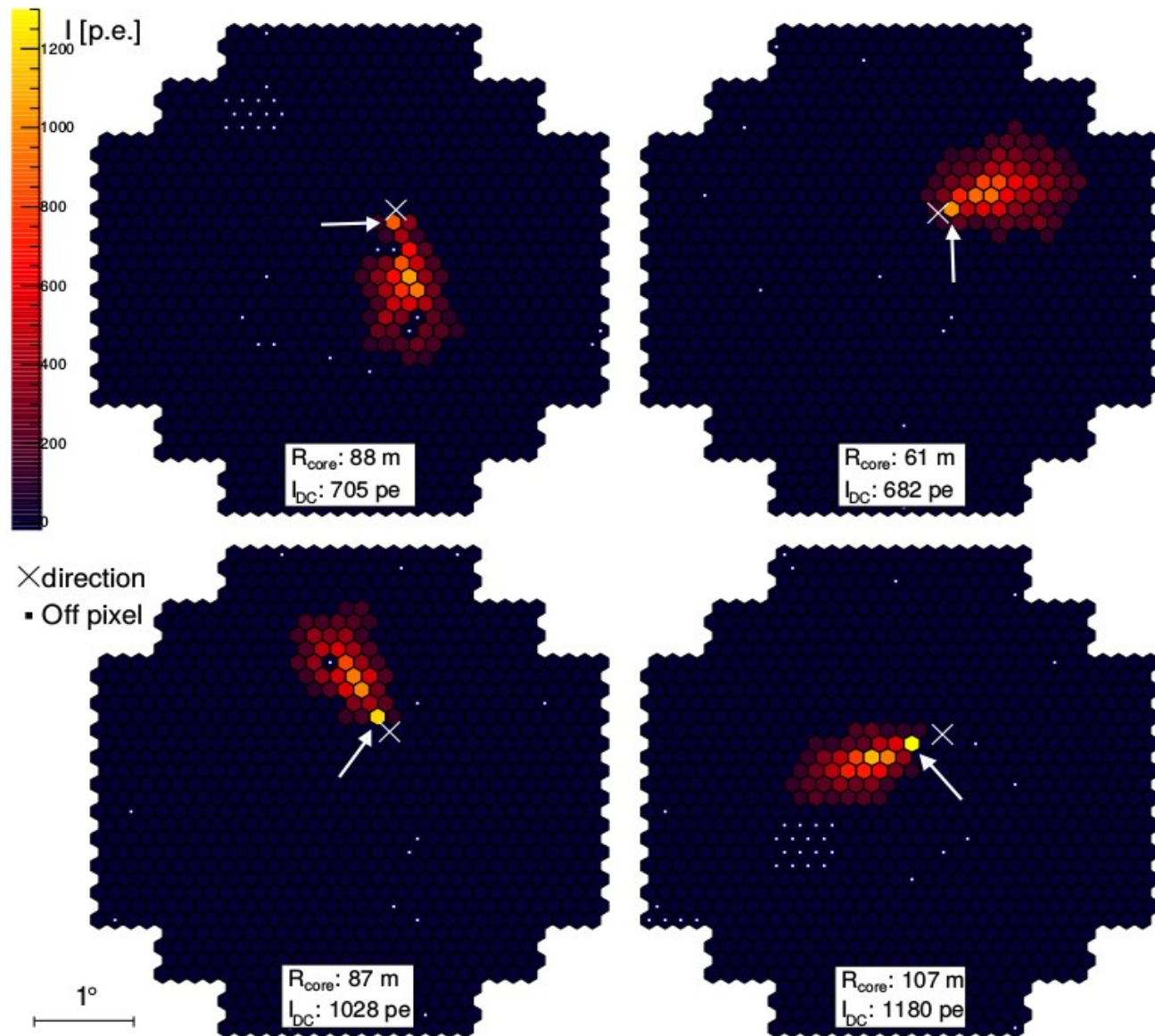


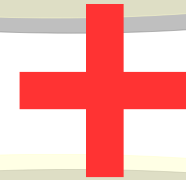
FIG. 5: A measured event with indications of DC-light in all four cameras images (indicated by arrows), after high threshold image cleaning. The reconstructed shower direction is shown by a cross ( $\times$ ) in each image. The reconstructed energy of this event is 50/48 TeV based on QGSJET/SIBYLL simulations. The reconstructed impact parameter and DC-light intensity for each telescope are shown in the lower panels in each image. The energy and impact parameter resolutions are  $\approx 20\%$  and  $\approx 20$  m, respectively. The white points mark disabled pixels.



# Fitting and event reconstruction

- Five variables to reconstruct:
  - x/y Core Position,
  - First Interaction Height,
  - Energy per Nucleon
  - Charge.

$$P_i(N_{i,Received} | X, Y, Z, height, E_{pn}) = \frac{e^{-\lambda_i} \times \lambda_i^{N_i}}{N_i!}$$



$$\ln(N!) \approx N \ln(N) - N + \frac{1}{2} \ln(2\pi N)$$



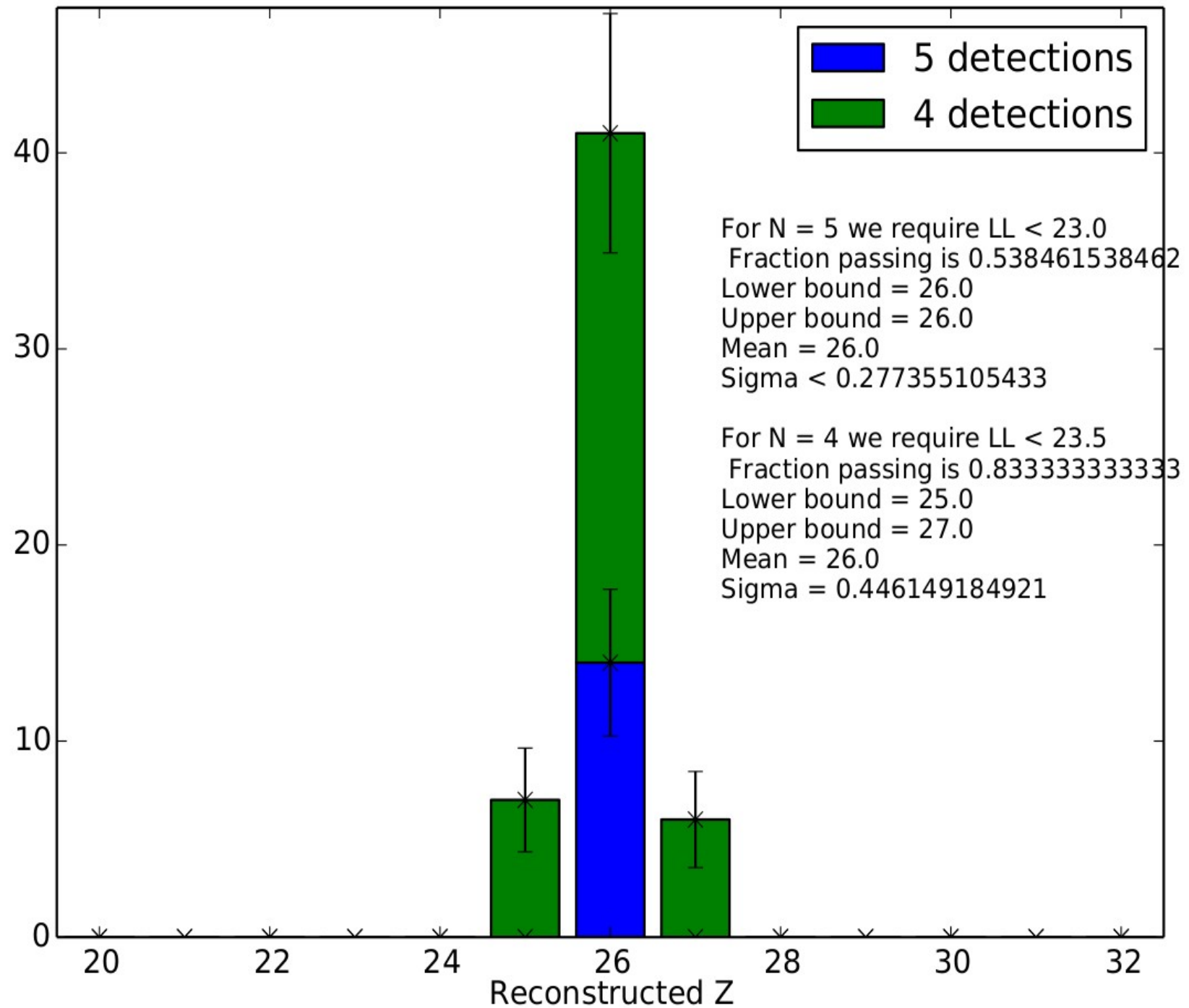
$$-\ln(L) = -\sum_i \ln(P_i) = \sum_i \lambda_i - N_i \ln(\lambda_i) + N_i \ln(N_i) - N_i + \frac{1}{2} \ln(2\pi N_i)$$

# Iterative Minimisation

- Iterate over integer Z
  - 13 Z values
- Select a  $\sim 100\text{m}^2$  region
  - 10 positions
- Scan valid Height/Energy combinations
  - 51 Epn/Height Combos
  - $13 \times 10 \times 51 = 6630$
- **Candidate with smallest log likelihood of the 6630 runs is selected**

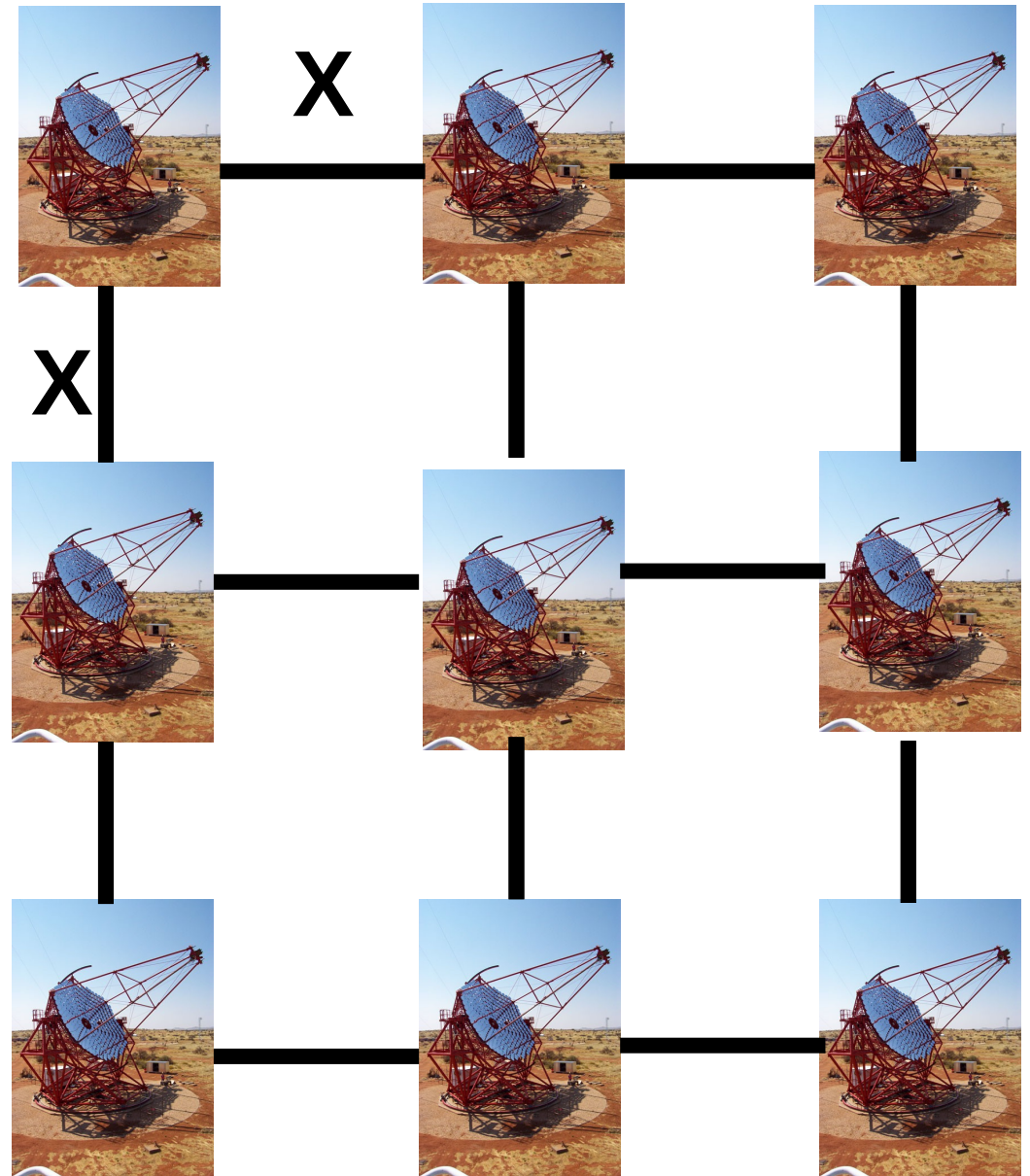
# True Z reconstruction

Z is 26

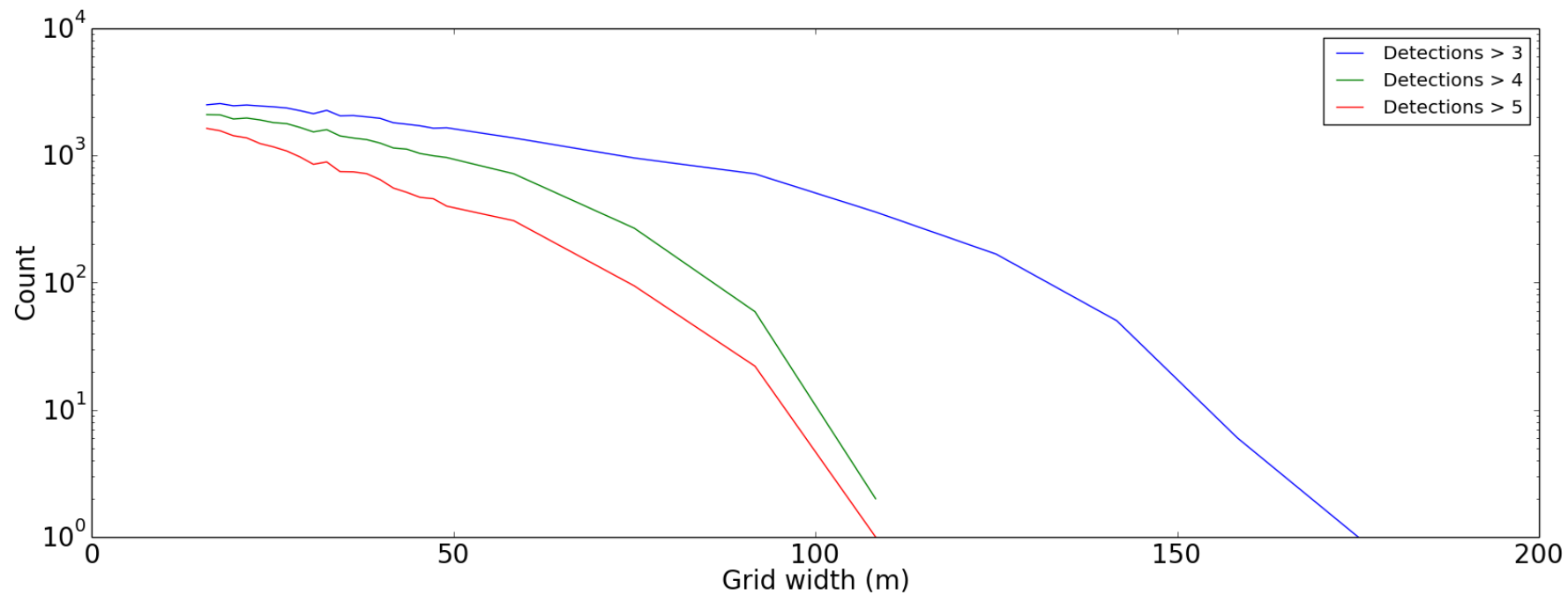
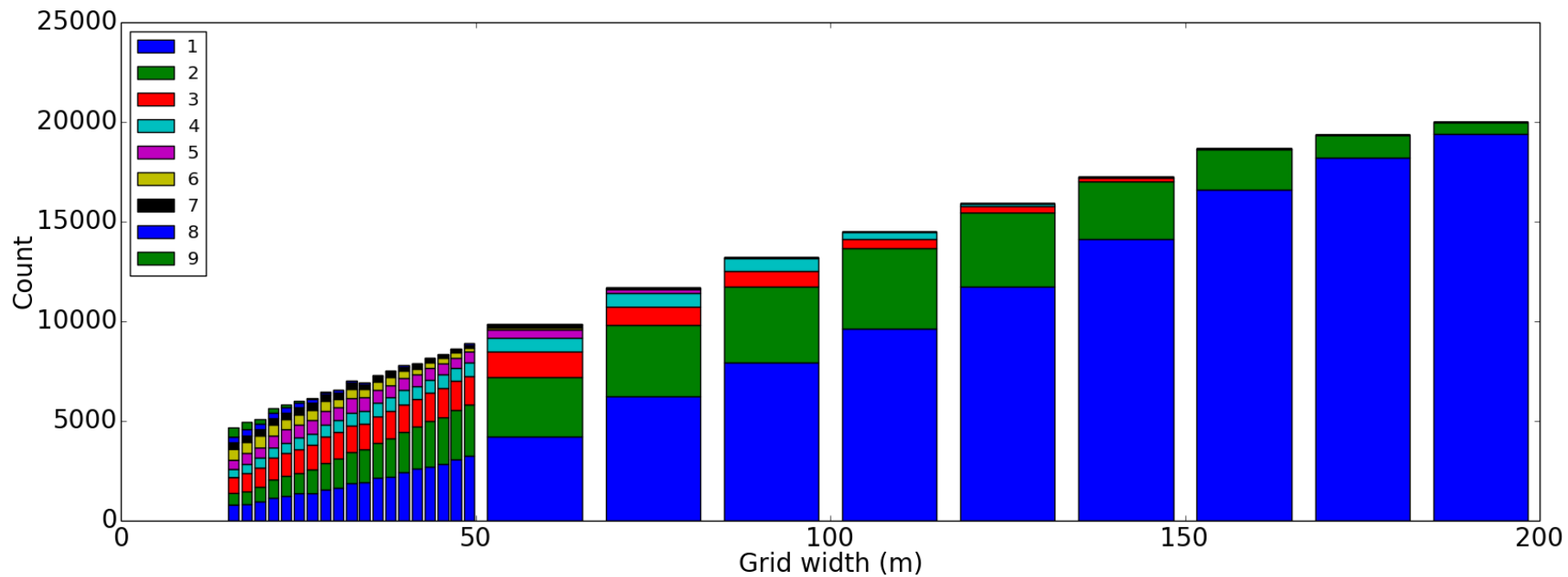


# Optimised Telescope Array

- Grid of 3 x 3 telescopes (variable grid width X)
- Expected counts for 50 hours run time
- Minimise  $\sigma_z$  by balancing competing effects



# Telescope Observations for 50 hours



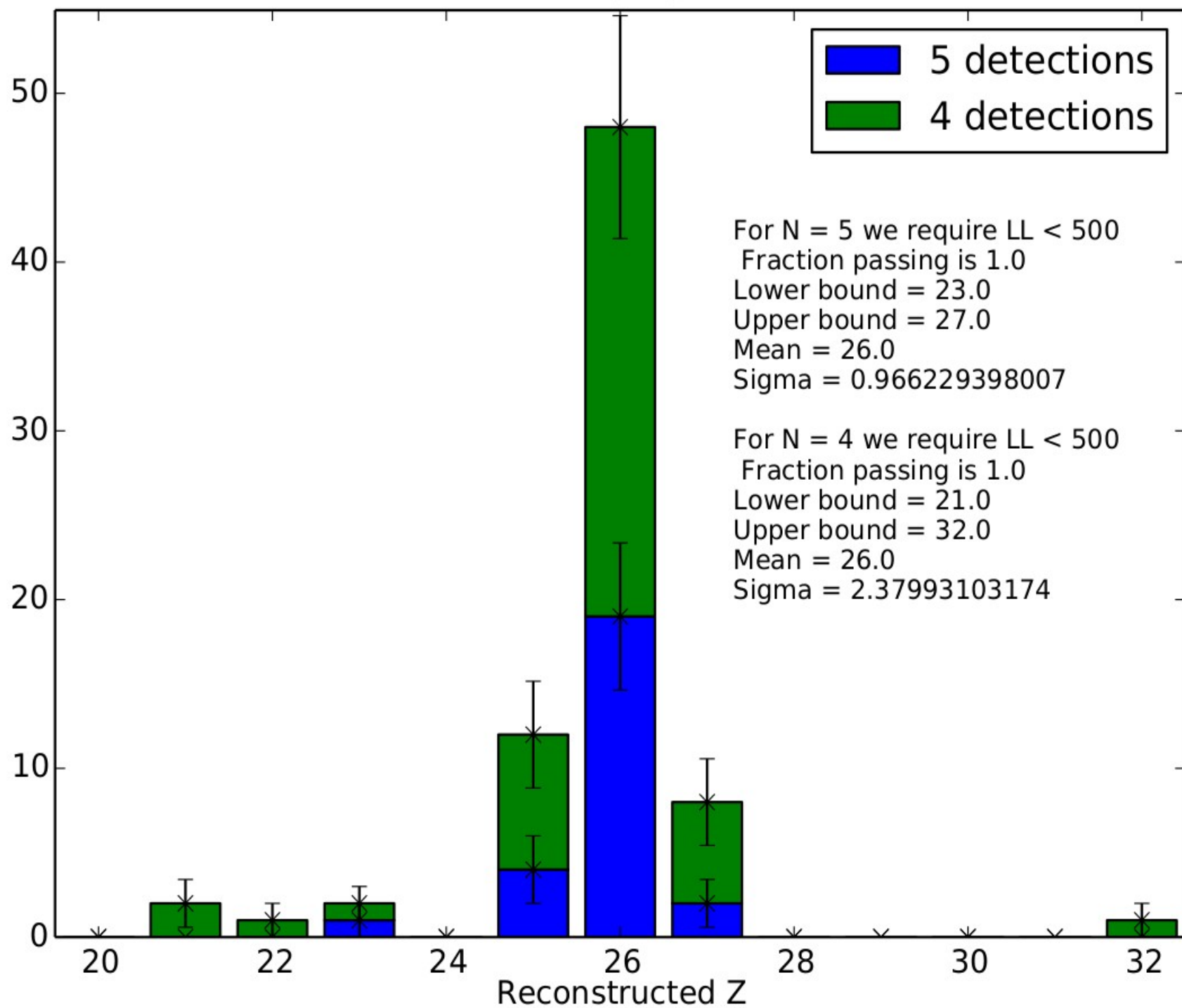
# Summary

- New Technique for Charge Reconstruction, valid for both current and future IACT systems.
- Simulation with HESS-type layout yields a much improved core reconstruction.
- Charge resolution of  $\sigma_z < 0.3$  for five telescope events.
- Ideal future CT experiment would have 9 telescopes with a grid spacing of ~20-40m.
- Consequent event rate would be ~15 events per hour observed by 5 or more telescopes.

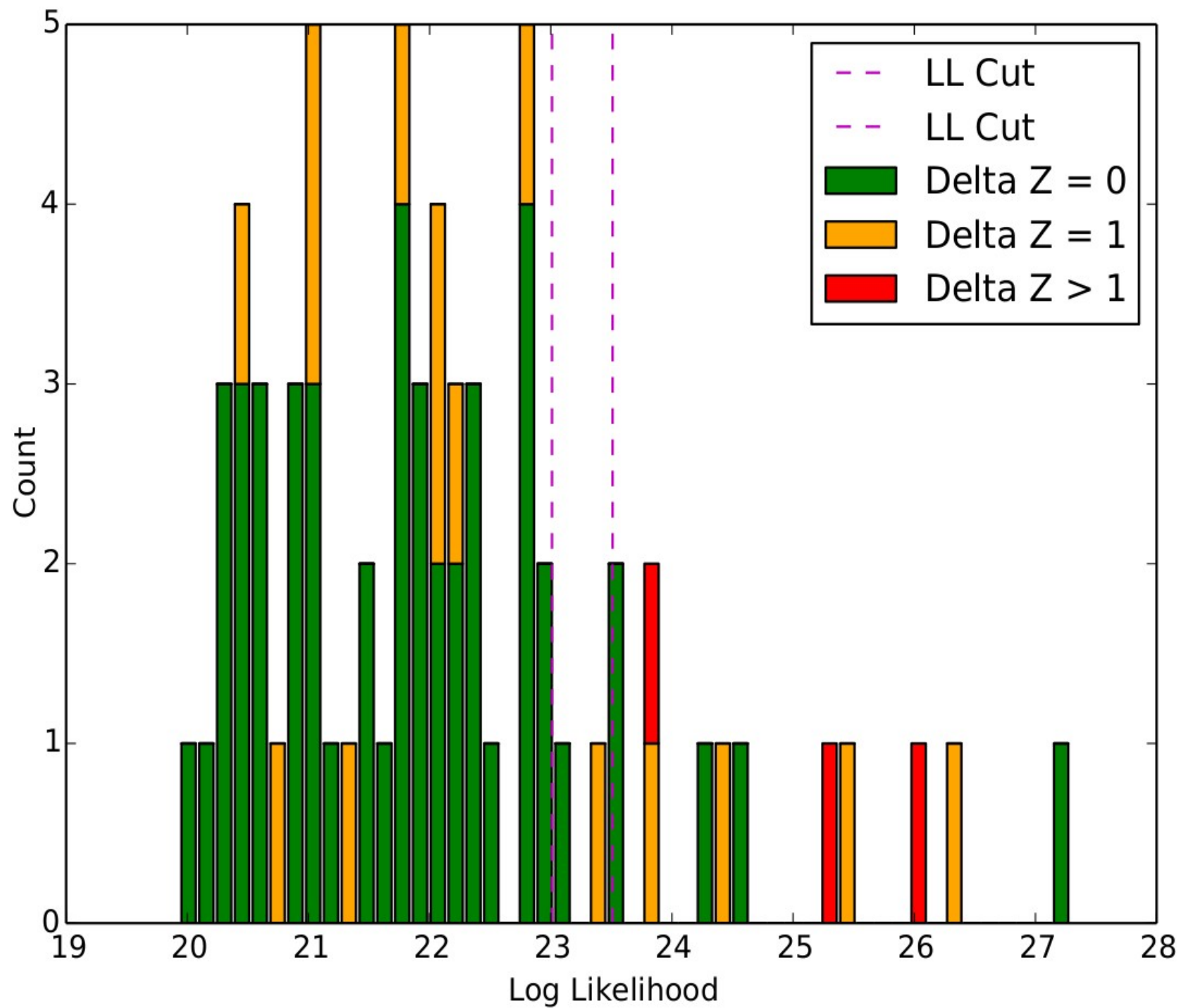


# True Z reconstruction

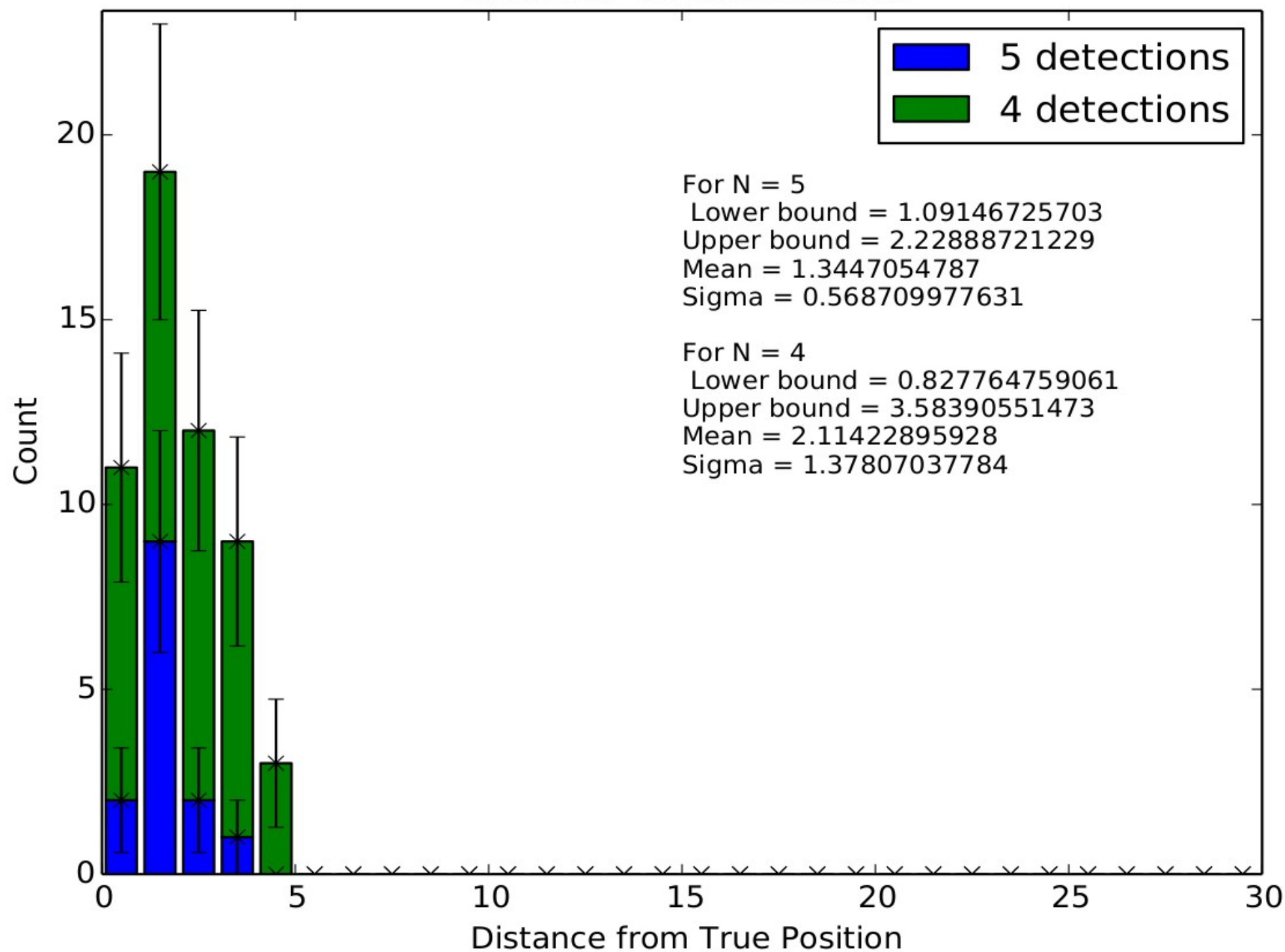
Z is 26



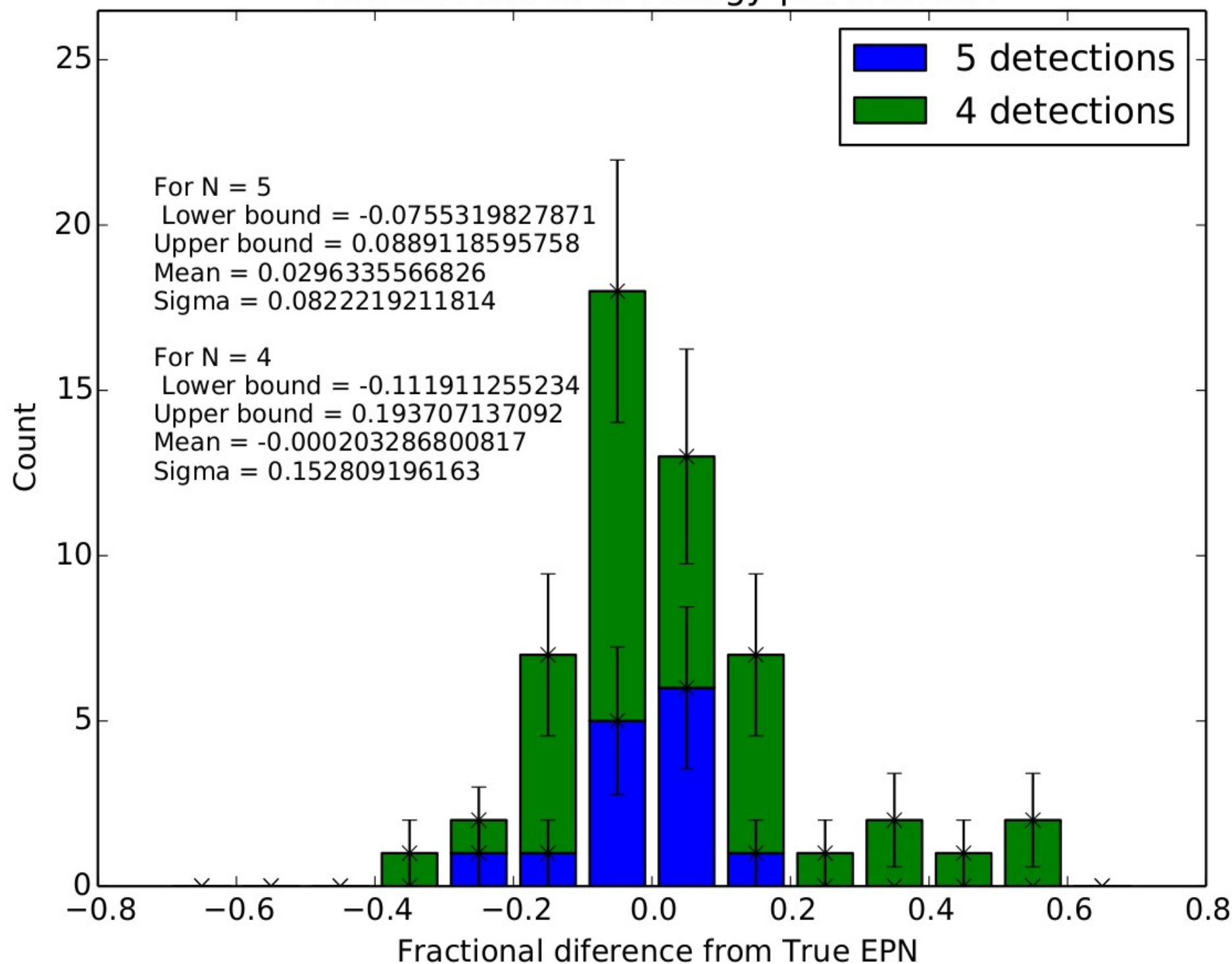
# Likelihood



## Distance Reconstruction



# Reconstruction of Energy per Nucleon



# Height Reconstruction

