Cosmic Ray Charge Reconstruction

Analysis of Direct Cherenkov Light Emission

$$\cos\left(\Theta_C\right) = \frac{1}{\eta * \beta}$$

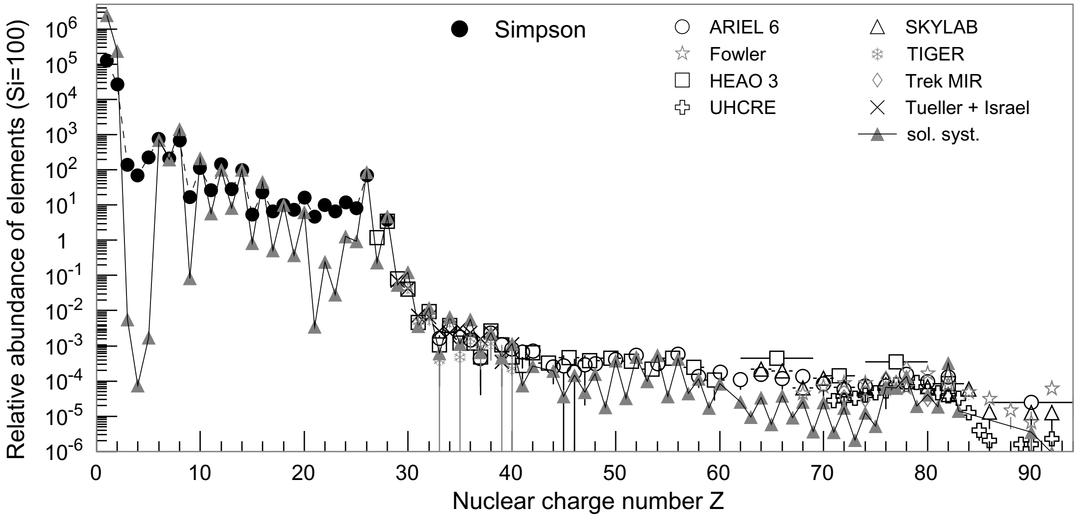


Fig. 3. Abundance of elements in cosmic rays as function of their nuclear charge number Z at energies around 1 GeV/n, normalized to Si = 100. Abundance for nuclei with $Z \leqslant 28$ according to Simpson (1983). Heavy nuclei as measured by ARIEL 6 (Fowler et al., 1987), Fowler et al. (1977), HEAO 3 (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 (Donelly et al., 1999). In addition, the abundance of elements in the solar system is shown according to Lodders (2003).

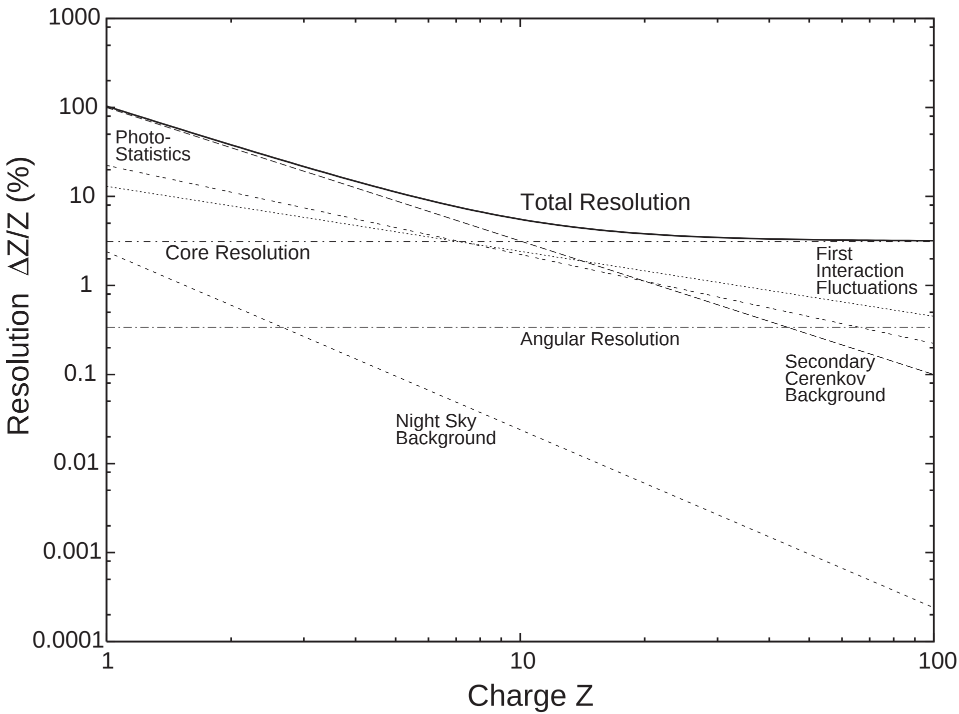
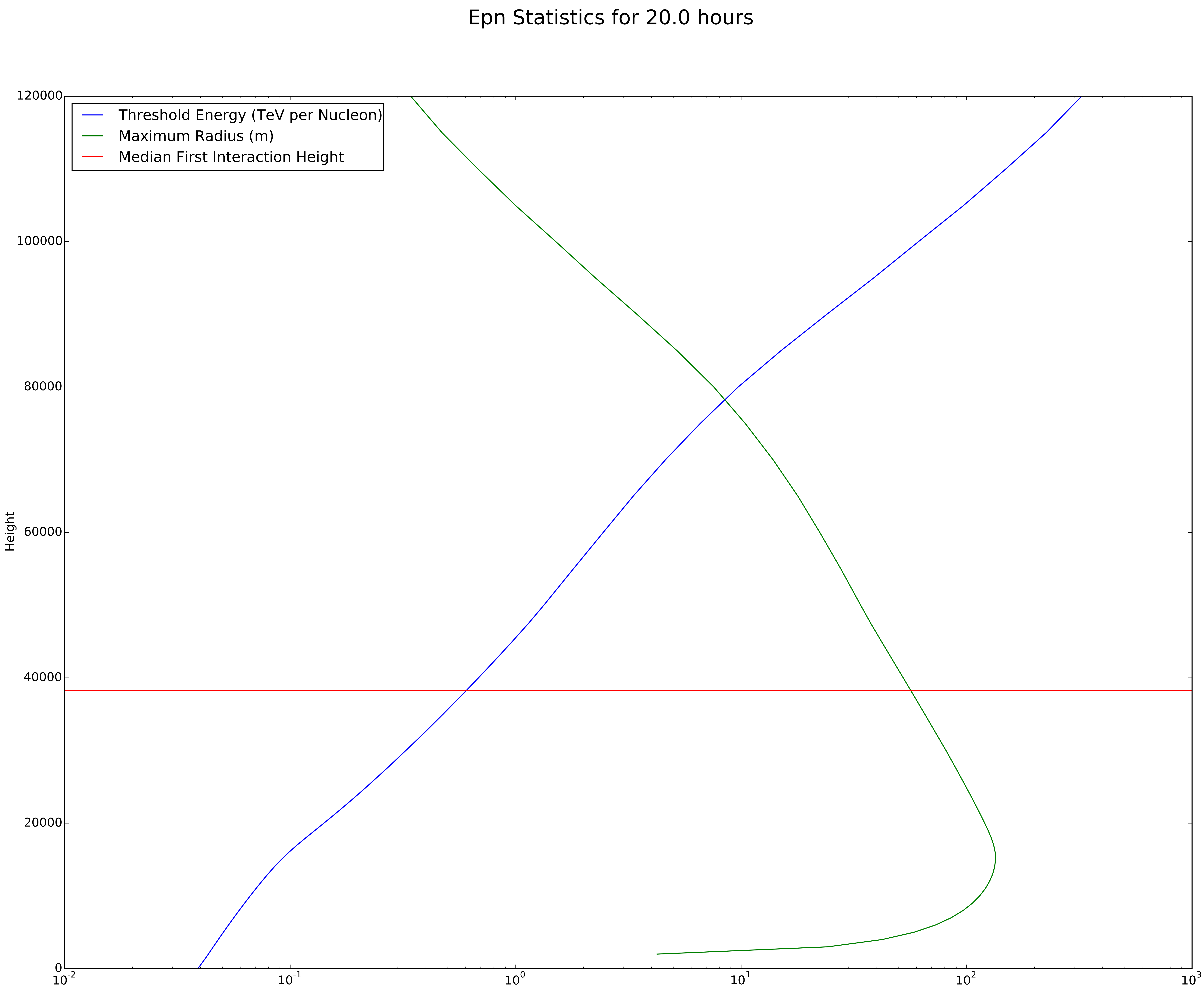


Fig. 11. The expected charge resolution $\Delta Z/Z$ for a detector of effective area 100 m^2 and core position resolution 5 m. Horizontal Axis: Primary Charge Z. Vertical Axis: Charge Resolution $\Delta Z/Z(\%)$


Epn Statistics for 20.0 hours
Threshold Energy (TeV per Nucleon)
Maximum Radius (m)
Median First Interaction Height
Height
120000
100000
80000
60000
40000
20000
0
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

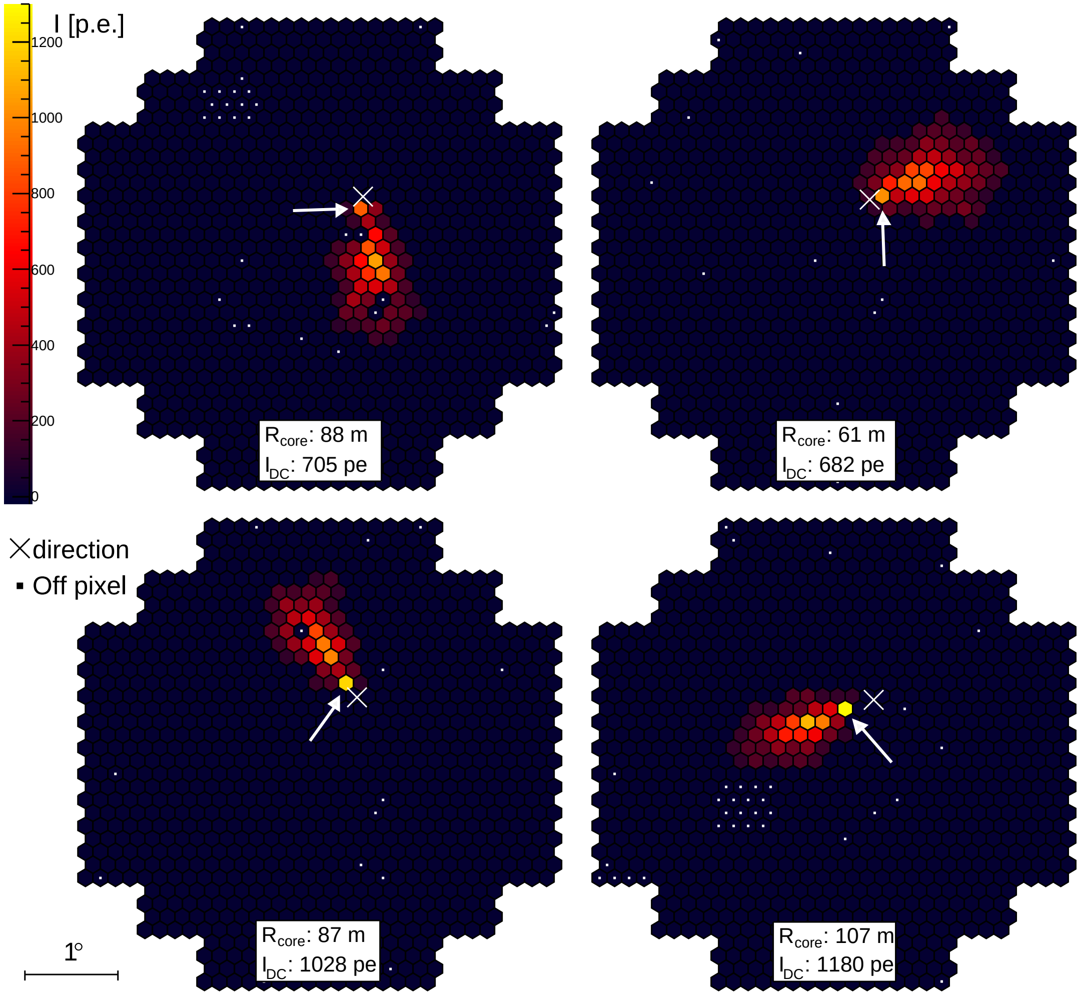
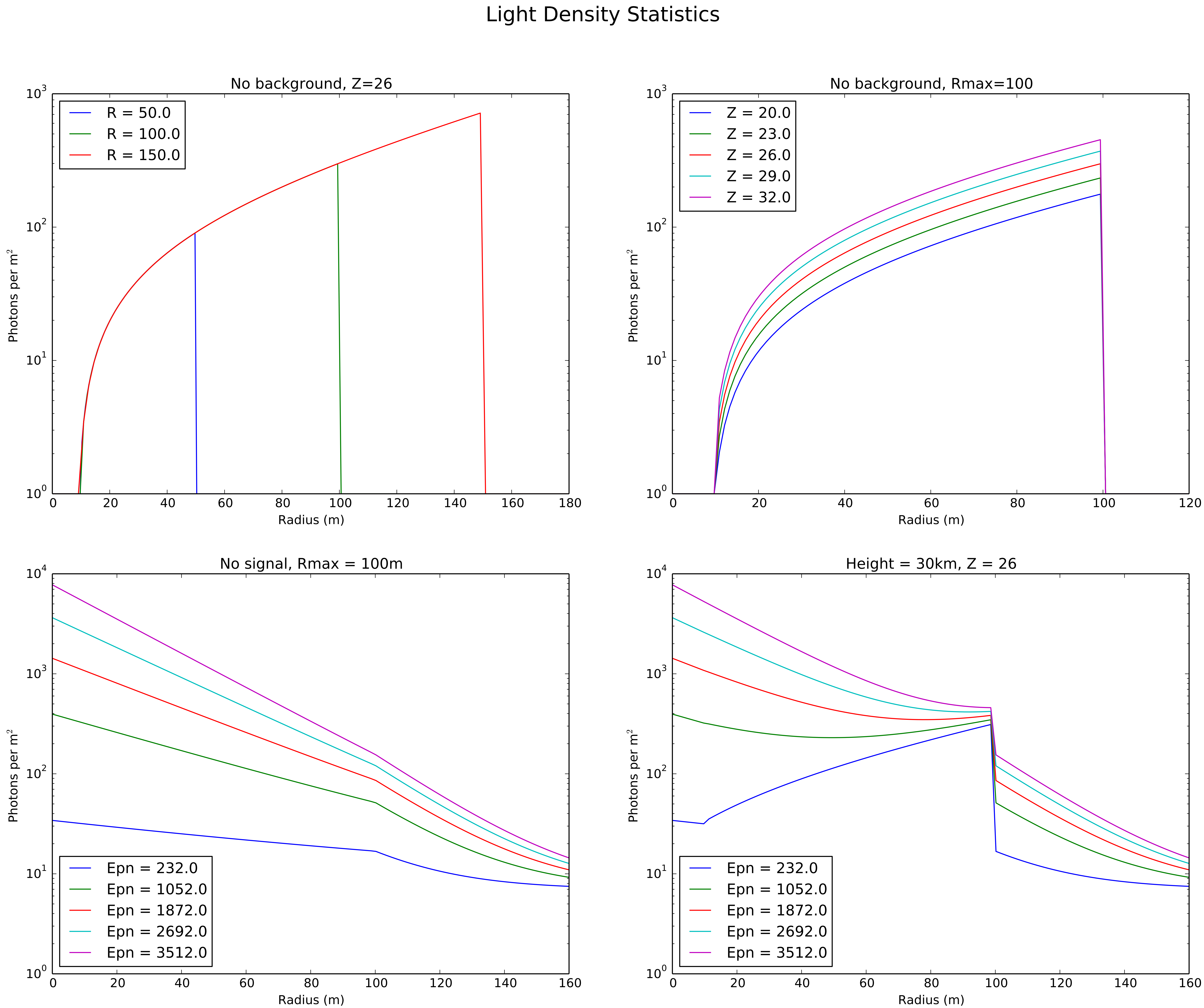


FIG. 5: A measured event with indications of DC-light in all four cameras images (indicated by arrows), after high threshold image cleaning. The reconstructed shower direction is shown by a cross (×) in each image. The reconstructed energy of this event is 50/48 TeV based on QGSJET/SIBYLL simulations. 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 ≈20% and ≈20 m, respectively. The white points mark disabled pixels.



Light Density Statistics
No background, Z=26
R = 50.0
R = 100.0
R = 150.0
Photons per m²
Radius (m)
No background, Rmax=100
Z = 20.0
Z = 23.0
Z = 26.0
Z = 29.0
Z = 32.0
Photons per m²
Radius (m)
No signal, Rmax = 100m
Epn = 232.0
Epn = 1052.0
Epn = 1872.0
Epn = 2692.0
Epn = 3512.0
Photons per m²
Radius (m)
Height = 30km, Z = 26
Epn = 232.0
Epn = 1052.0
Epn = 1872.0
Epn = 2692.0
Epn = 3512.0
Photons per m²
Radius (m)

Likelihood

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

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

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

Fitting and event reconstruction

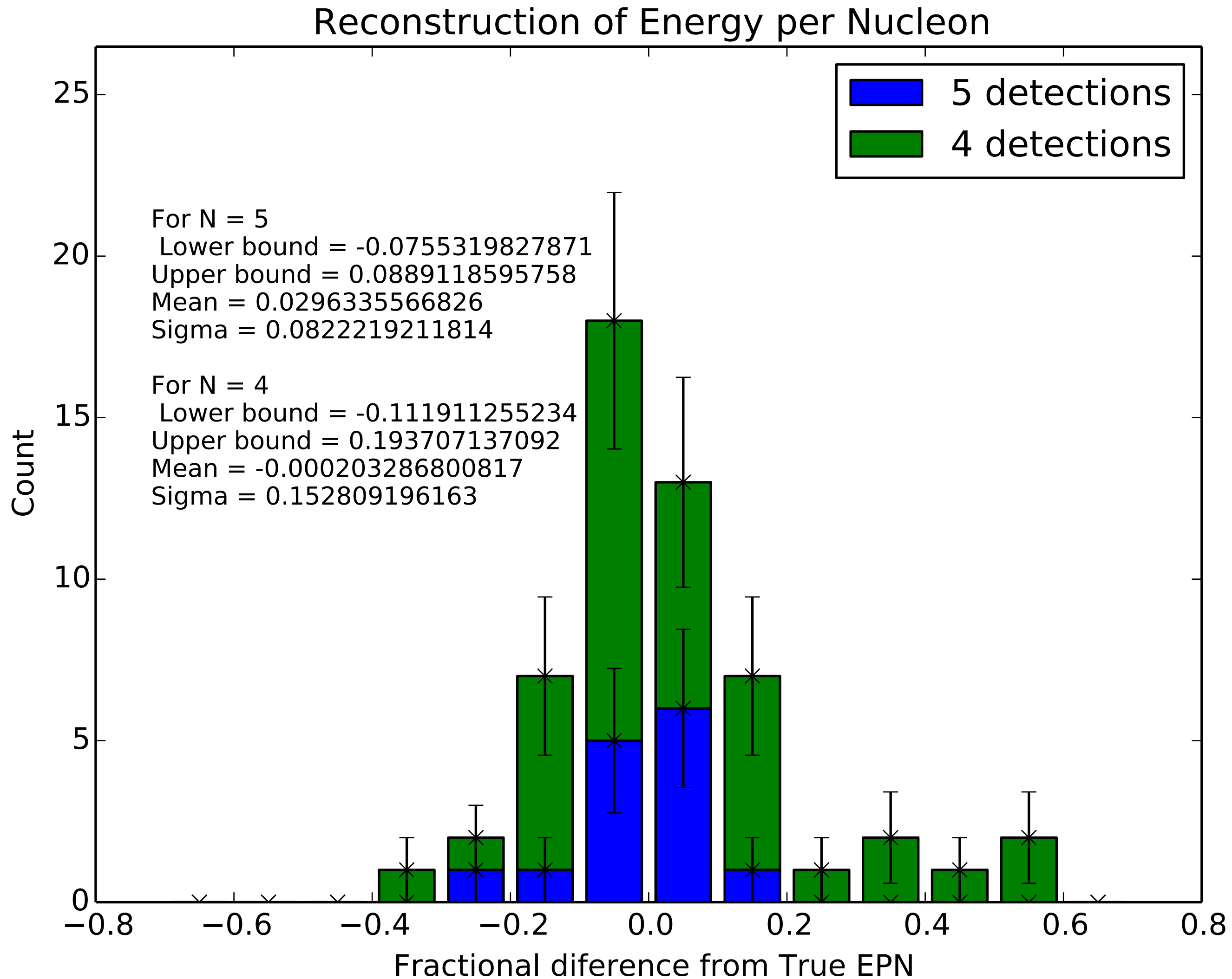
- We need to determine x, y, height, Z and Epn

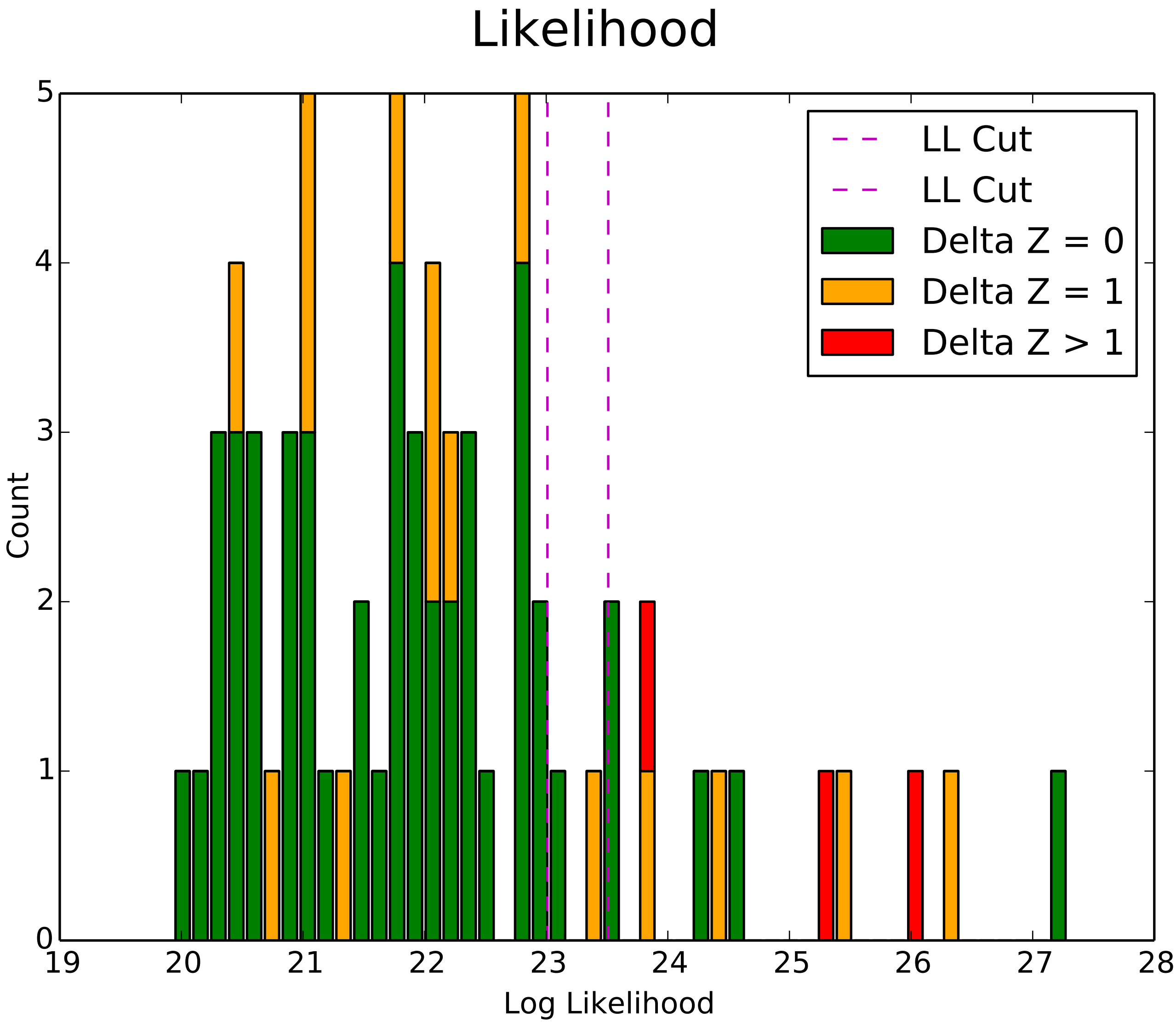
Five variables, but with constraints...

- Z is always an integer
- Non-hits for telescopes provide location information
- The energy must have been greater than the threshold for any chosen height.
- The images provide additional information, used to efficiently sample likely positions for reconstruction

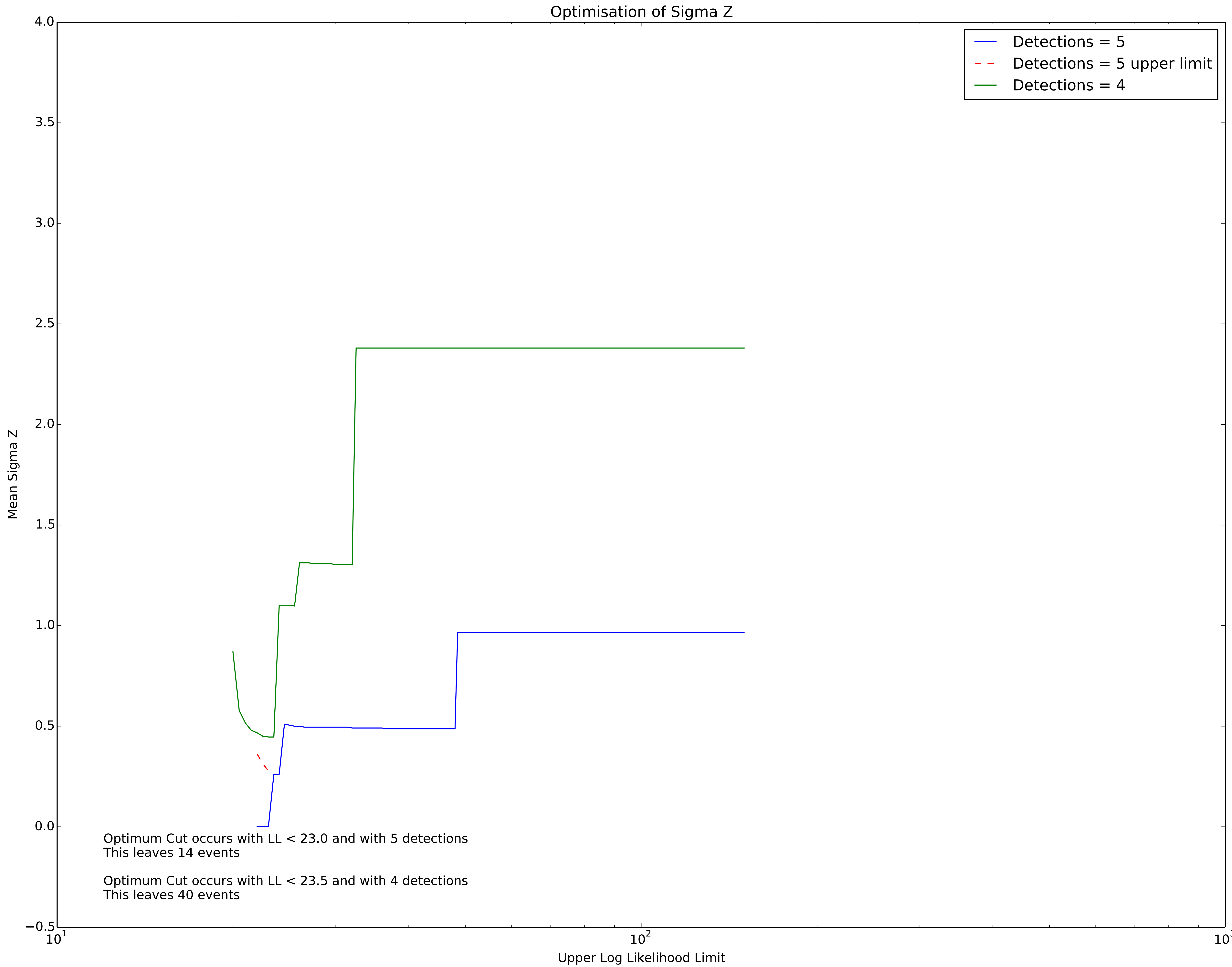
Repeated Minimisation

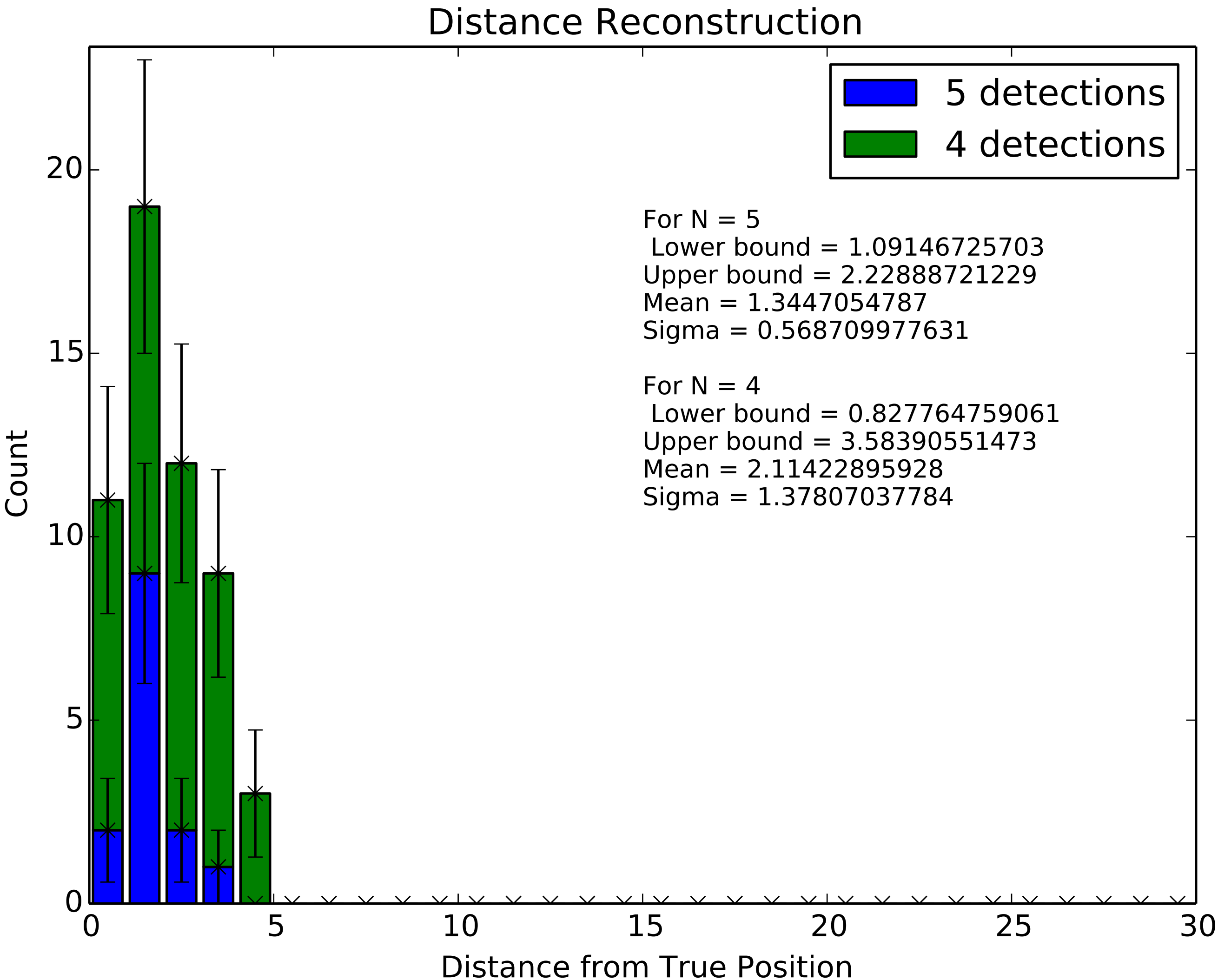
- Fix Z at integer value (Range Z=20-32)
- Use a ~3x3m grid of points in 200m x 200m area
- Select all points within reconstruction target (~10)
- Iteratively minimise over 20 Epn and 3 Height starting values for each starting location
- Run 13 x 10 x 20 x 3 = 7800 minimisations
- Select minimisation candidate with lowest resultant log likelihood as overall minimum


Reconstruction of Energy per Nucleon
5 detections
4 detections
For N = 5
Lower bound = -0.0755319827871
Upper bound = 0.0889118595758
Mean = 0.0296335566826
Sigma = 0.0822219211814
For N = 4
Lower bound = -0.111911255234
Upper bound = 0.193707137092
Mean = -0.000203286800817
Sigma = 0.152809196163
Count
Fractional diference from True EPN
0
5
10
15
20
25
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8

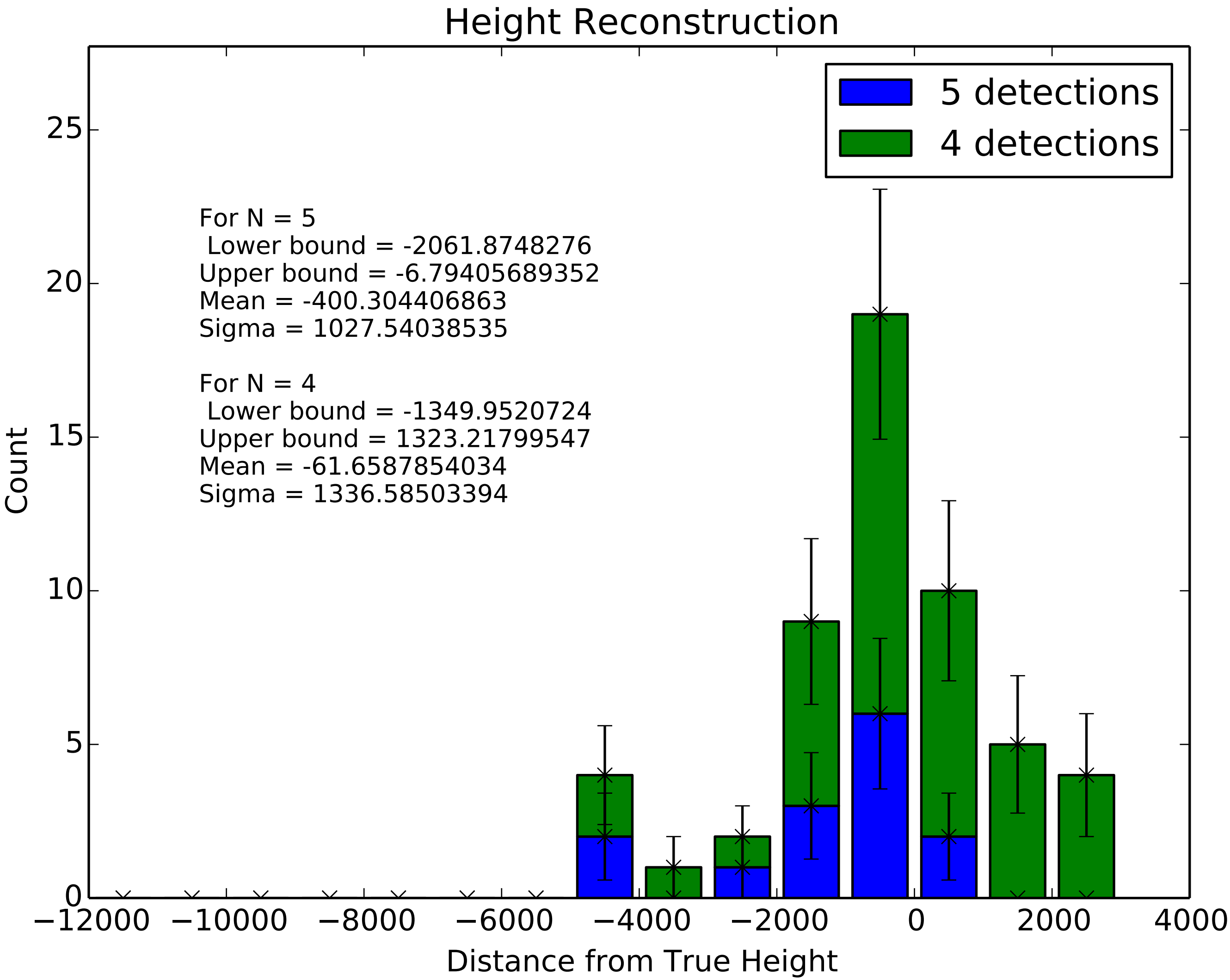


Likelihood
LL Cut
LL Cut
Delta Z = 0
Delta Z = 1
Delta Z > 1
Count
Log Likelihood
0
1
2
3
4
5
19
20
21
22
23
24
25
26
27
28

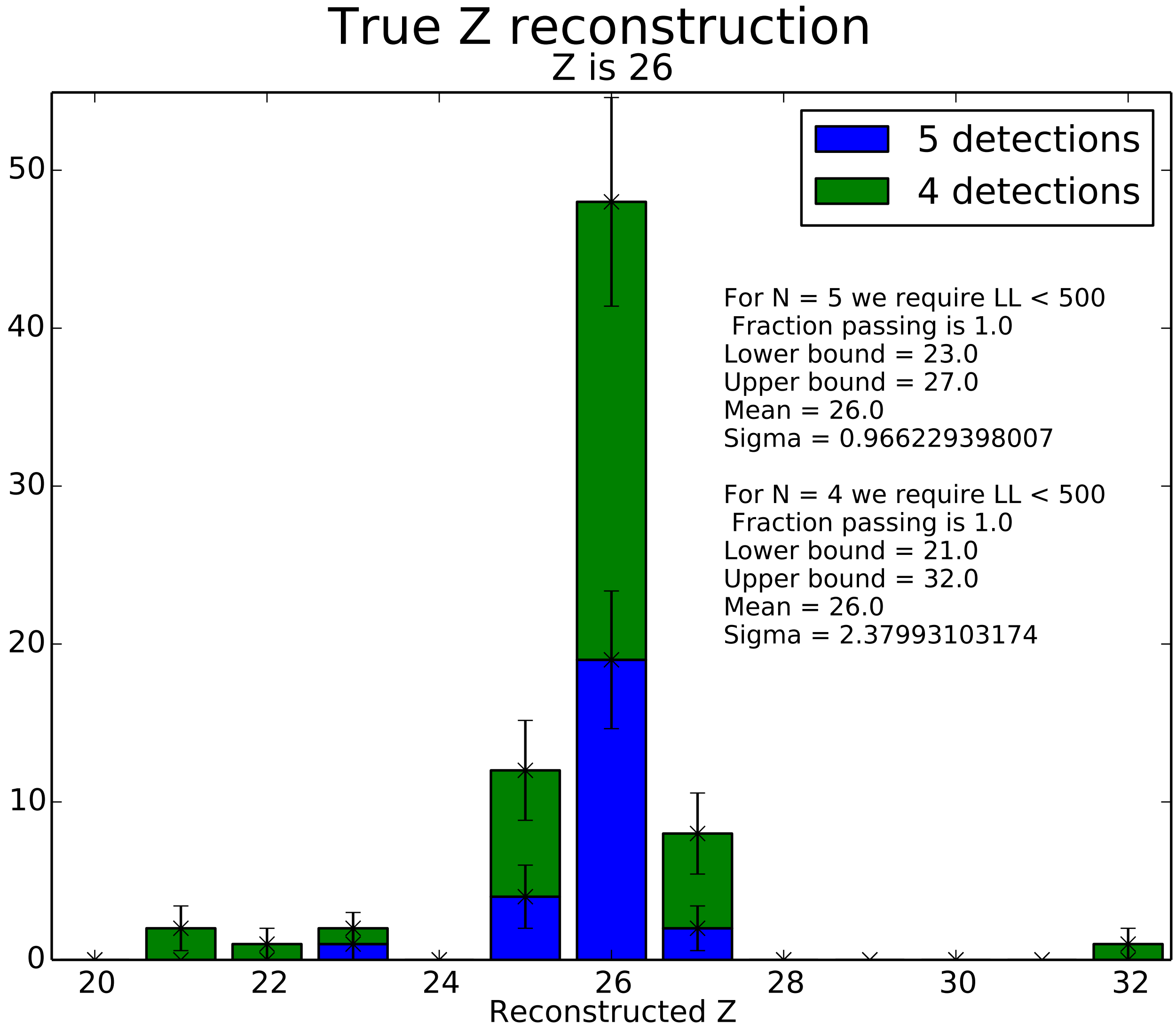

Optimisation of Sigma Z
Detections = 5
Detections = 5 upper limit
Detections = 4
Mean Sigma Z
Upper Log Likelihood Limit
Optimum Cut occurs with LL < 23.0 and with 5 detections
This leaves 14 events
Optimum Cut occurs with LL < 23.5 and with 4 detections
This leaves 40 events



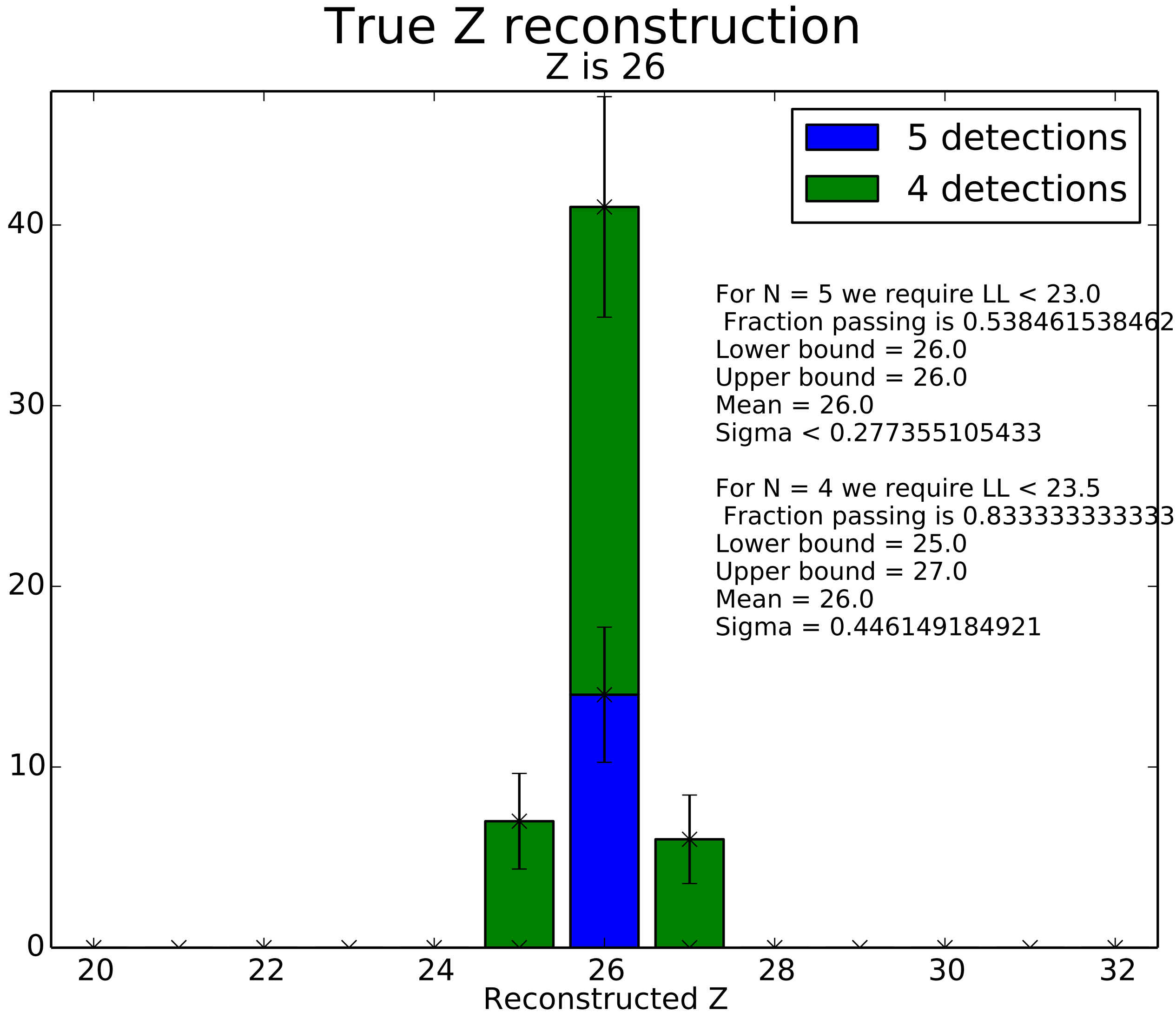
Distance Reconstruction
5 detections
4 detections
For N = 5
Lower bound = 1.09146725703
Upper bound = 2.22888721229
Mean = 1.3447054787
Sigma = 0.568709977631
For N = 4
Lower bound = 0.827764759061
Upper bound = 3.58390551473
Mean = 2.11422895928
Sigma = 1.37807037784
Count
0
5
10
15
20
25
30
Distance from True Position



Height Reconstruction
5 detections
4 detections
For N = 5
Lower bound = -2061.8748276
Upper bound = -6.79405689352
Mean = -400.304406863
Sigma = 1027.54038535
For N = 4
Lower bound = -1349.9520724
Upper bound = 1323.21799547
Mean = -61.6587854034
Sigma = 1336.58503394
Count
Distance from True Height
0
5
10
15
20
25
−12000
−10000
−8000
−6000
−4000
−2000
0
2000
4000



True Z reconstruction
Z is 26
5 detections
4 detections
For N = 5 we require LL < 500
Fraction passing is 1.0
Lower bound = 23.0
Upper bound = 27.0
Mean = 26.0
Sigma = 0.966229398007
For N = 4 we require LL < 500
Fraction passing is 1.0
Lower bound = 21.0
Upper bound = 32.0
Mean = 26.0
Sigma = 2.37993103174
0
10
20
30
40
50
20
22
24
26
28
30
32
Reconstructed Z


True Z reconstruction
Z is 26
5 detections
4 detections
For N = 5 we require LL < 23.0
Fraction passing is 0.538461538462
Lower bound = 26.0
Upper bound = 26.0
Mean = 26.0
Sigma < 0.277355105433
For N = 4 we require LL < 23.5
Fraction passing is 0.833333333333
Lower bound = 25.0
Upper bound = 27.0
Mean = 26.0
Sigma = 0.446149184921
0
10
20
30
40
20
22
24
26
28
30
32
Reconstructed Z