

# Neutron Damage of CCDs in ATLAS Endcap

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# Alignment System & CCDs

CCDs in the ATLAS endcap alignment system can experience a build up of charge in pixels from thermally generated electrons, called dark current, caused by neutron damage.

We measure the dark current in the ATLAS CCDs and model the relationship between dark current and neutron dose with the equation

$$I = \alpha D e^{(T-20^{\circ}\text{C})/(12^{\circ}\text{C})} \text{ counts/px/ms}$$

where,

$I$  is dark current in counts per pixel per millisecond

$D$  is the neutron dose in  $10^{12}$  1-MeVNE  $\text{cm}^{-2}$  (Tn)

$T$  is temperature in centigrade

$\alpha$  is a rate constant that describes the dark current generated per neutron dose in counts/px/ms/Tn

Measurements of the amount of dark current in our system could be used as measure of neutron flux.

# Pre-Production Experiments

## Lowell Experiment:

- In 1998, four TC255P CCD heads were subjected to varying neutron doses (between 2.0Tn and 8.0Tn) over 9 hours with a neutron source at University of Massachusetts at Lowell.

$$I = 0.28 D e^{(T-20^{\circ}\text{C})/(12^{\circ}\text{C})} \text{ counts/px/ms}$$

## PROSPERO Experiment:

- The following year, 8 TC255P CCD heads were sent to the PROSPERO reactor in France. They received neutron doses between 0.5Tn and 10.0Tn.

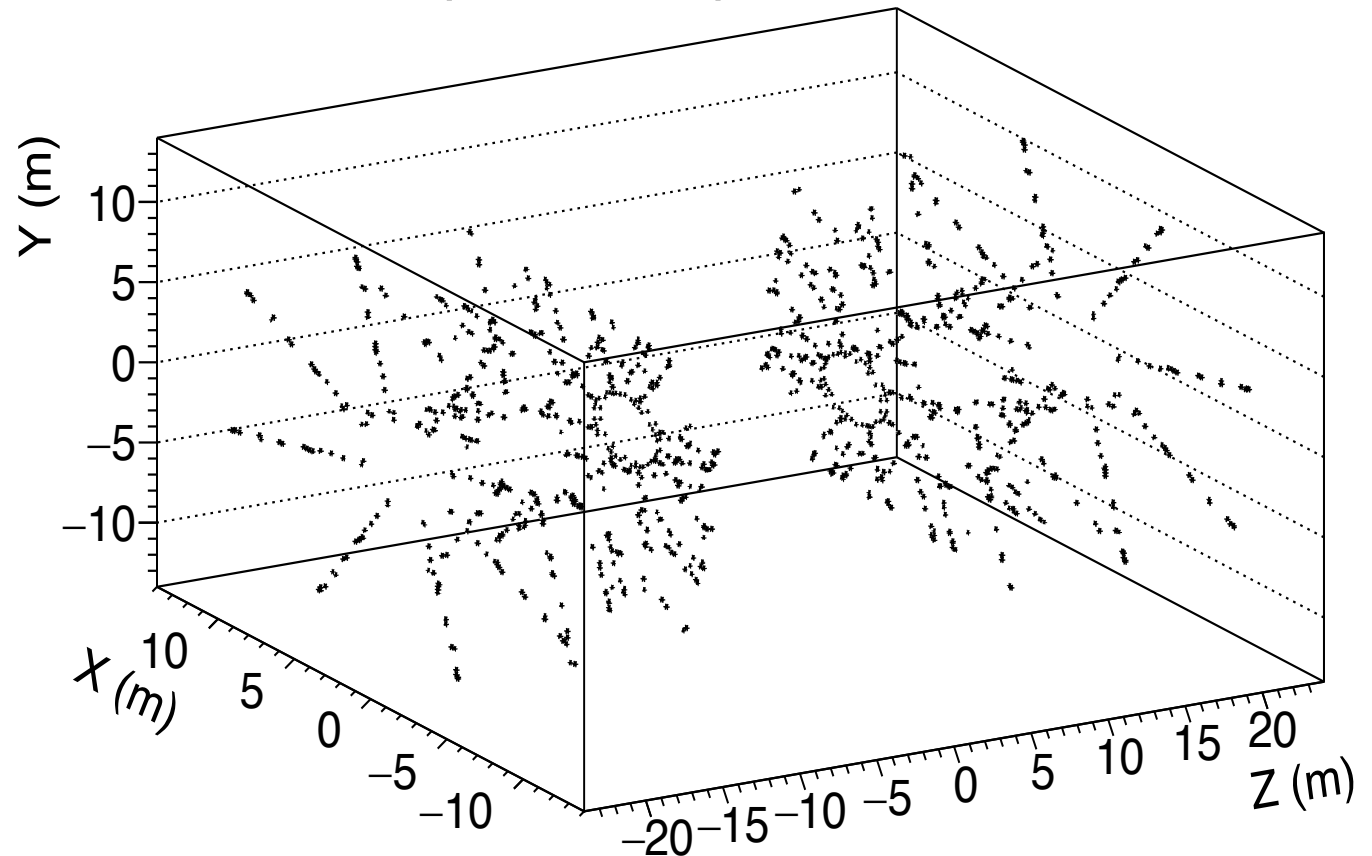
$$I = 0.26 D e^{(T-20^{\circ}\text{C})/(12^{\circ}\text{C})} \text{ counts/px/ms}$$

# Neutron Damage in ATLAS

## Data Set Information

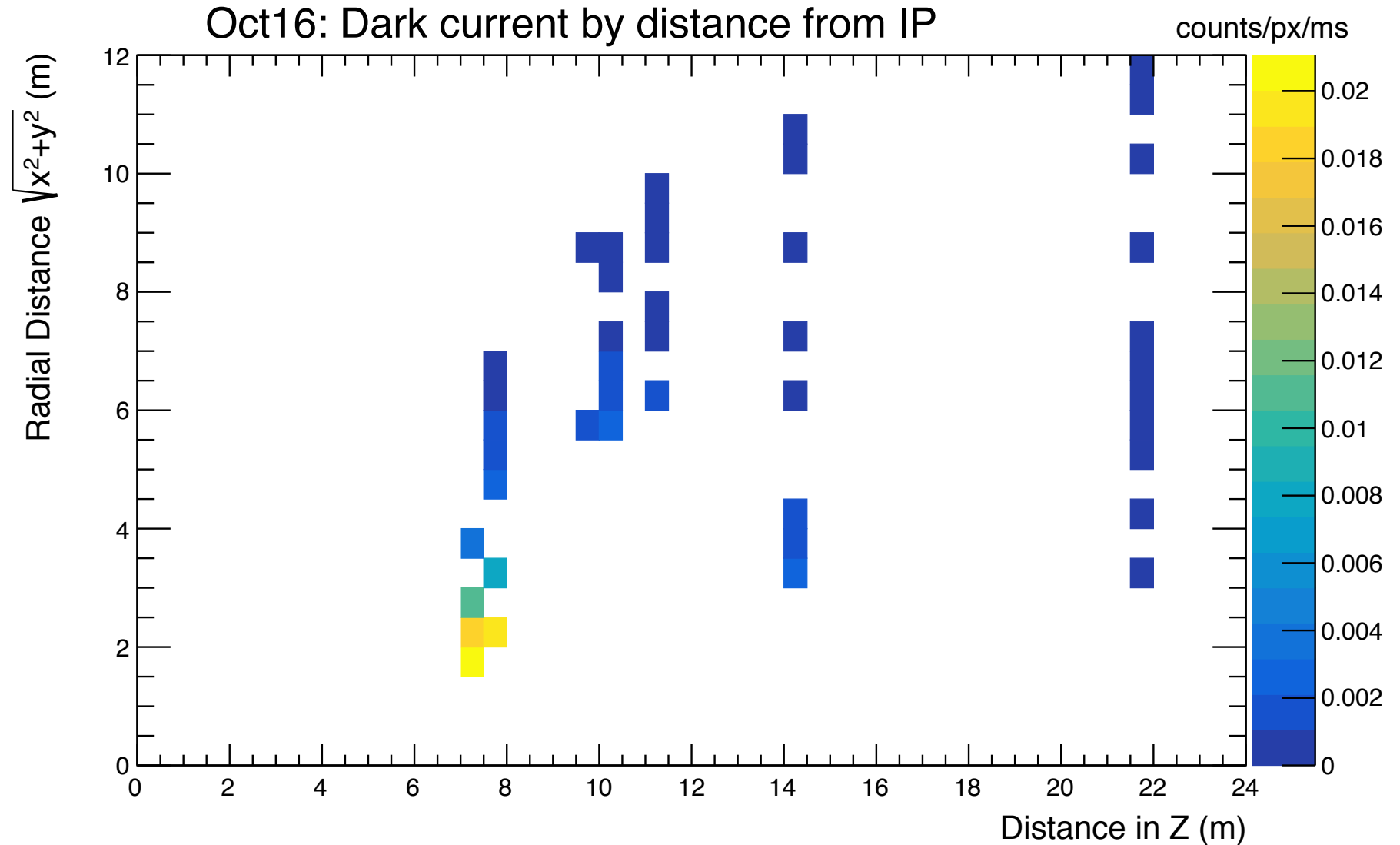
- Images were captured with each CCD and analyzed to find dark current due to neutron damage.
- Each data set contains images from 2670 CCDs.
- 30 data sets collected between 2016 - 2018.
- Record the average temperature in the ATLAS cavern for each data set.

ATLAS Endcap CCD Map



# Neutron Damage in ATLAS

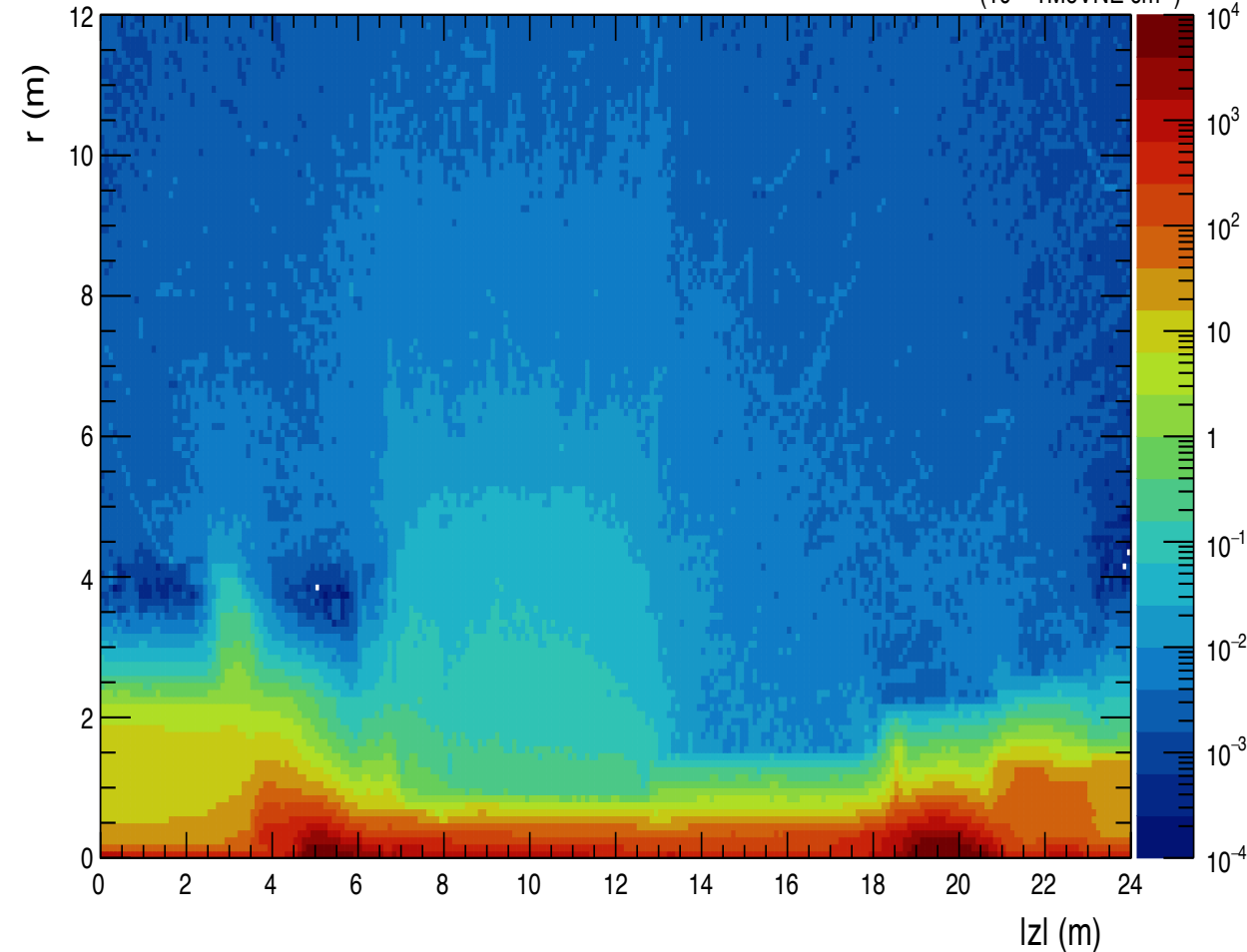
- We measured all dark current (using bright pixels) present in our CCDs in ATLAS on October 16, 2018.
- The dark current decreases with distance from IP along the beam line and radius from the beam line as expected.



# Neutron Damage in ATLAS - FLUGG

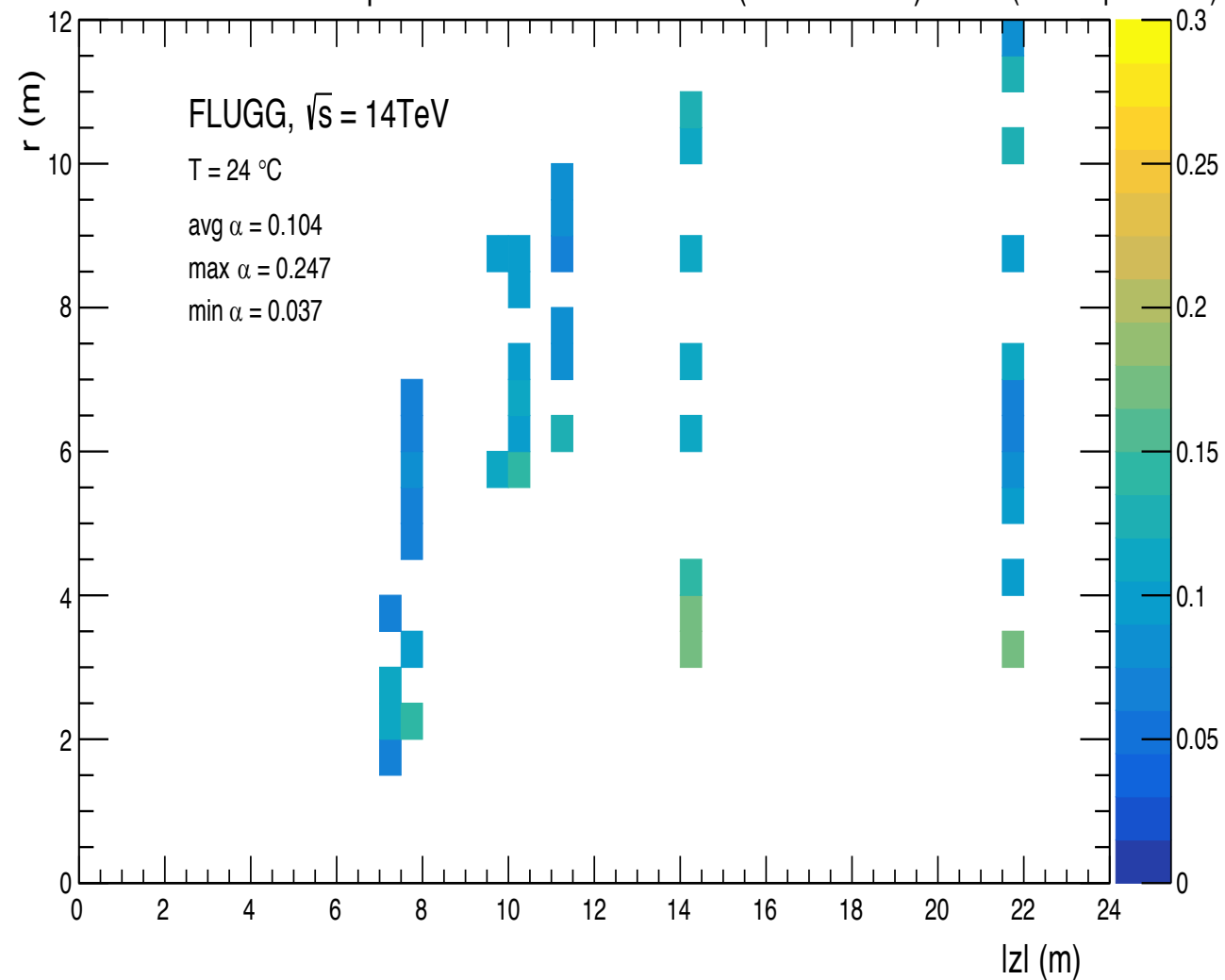
Simulated Neutron Dose (after 154 fb<sup>-1</sup>)

FLUGG,  $\sqrt{s} = 14\text{TeV}$   
(10<sup>12</sup> 1MeVNE cm<sup>-2</sup>)



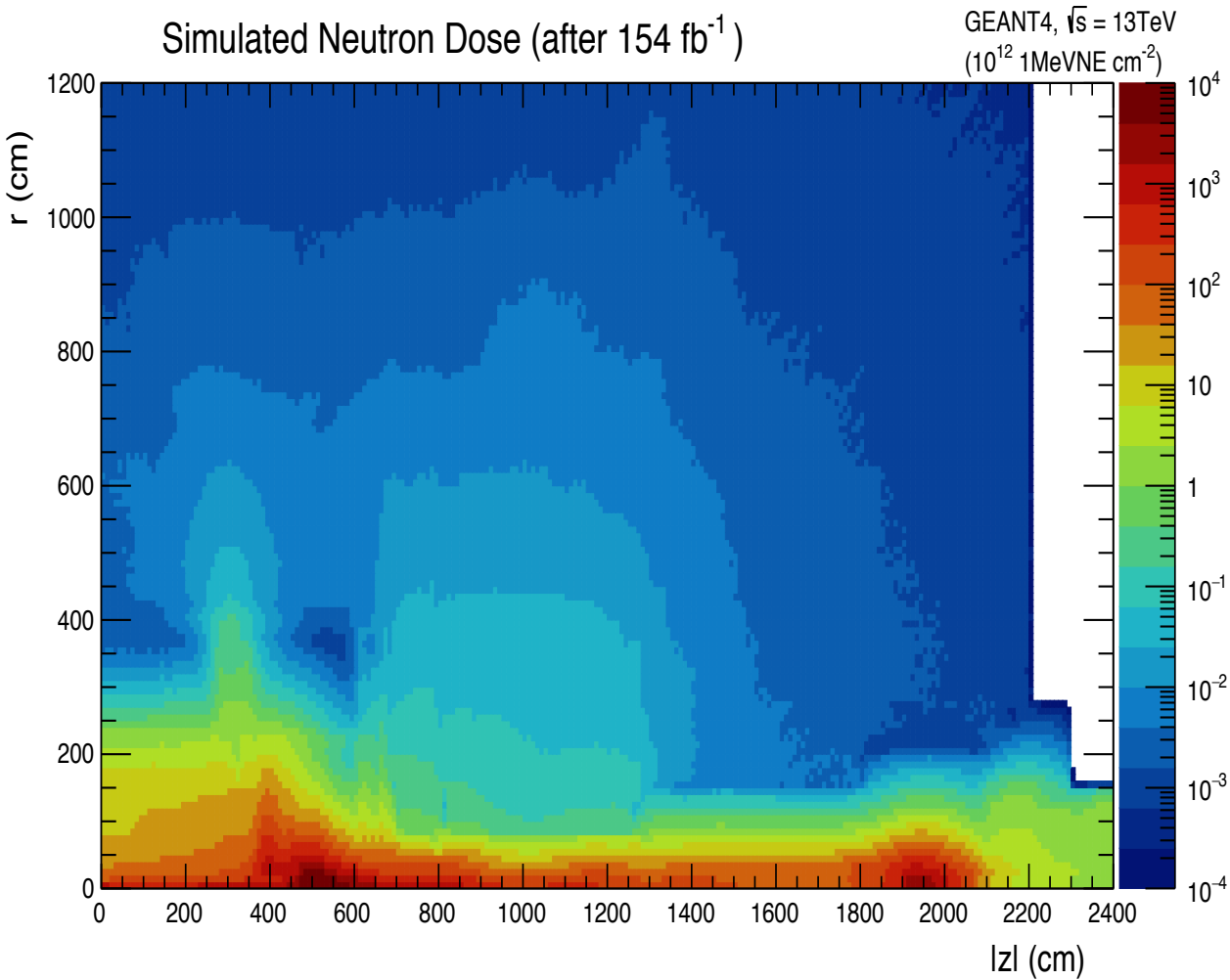
Oct16: Dark Current per 10<sup>12</sup> 1MeVNE cm<sup>-2</sup> Dose (after 154 fb<sup>-1</sup>)

$\alpha$   
(counts/px/ms/Tn)

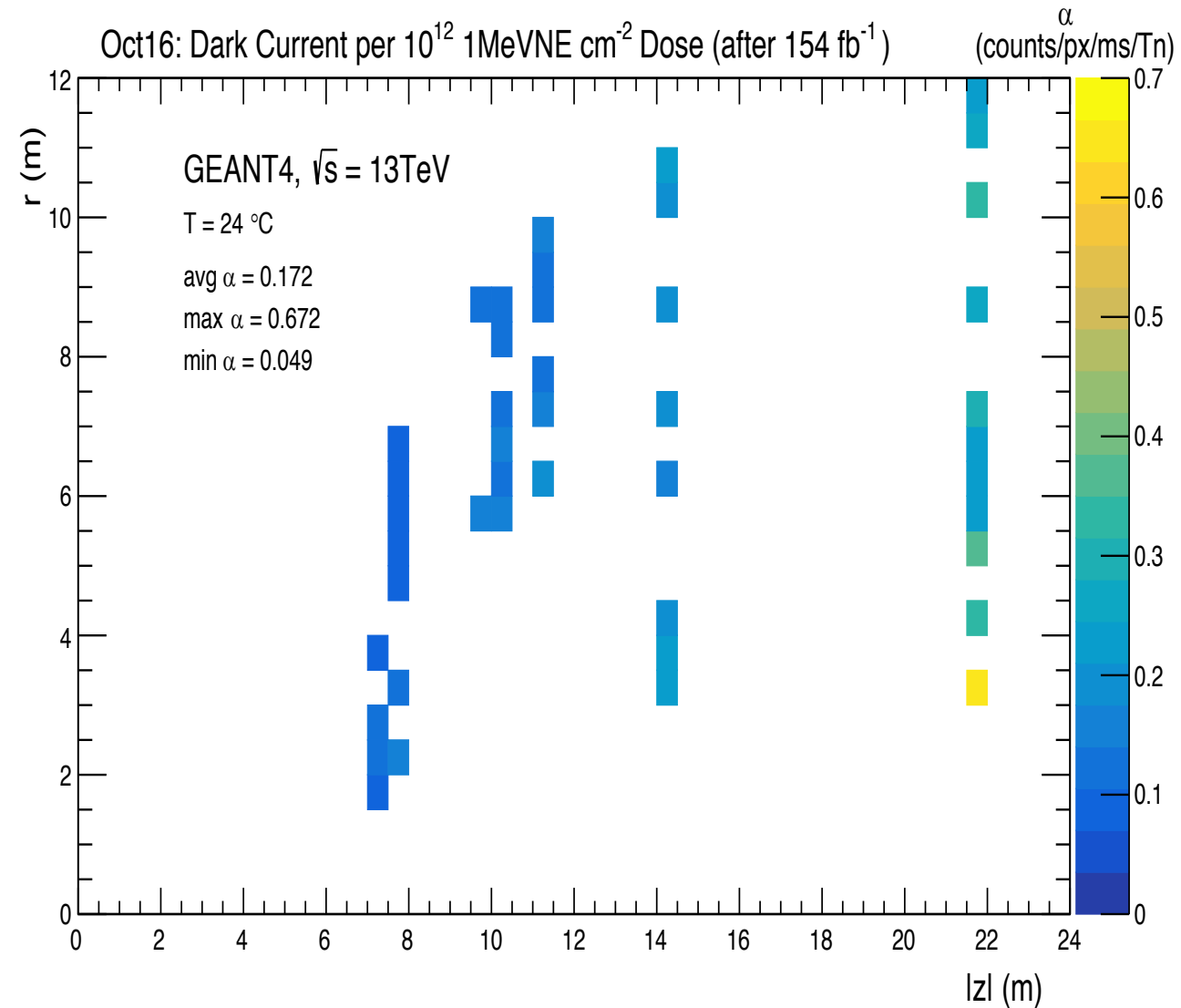


<http://young.web.cern.ch/young/RadiationMap/>

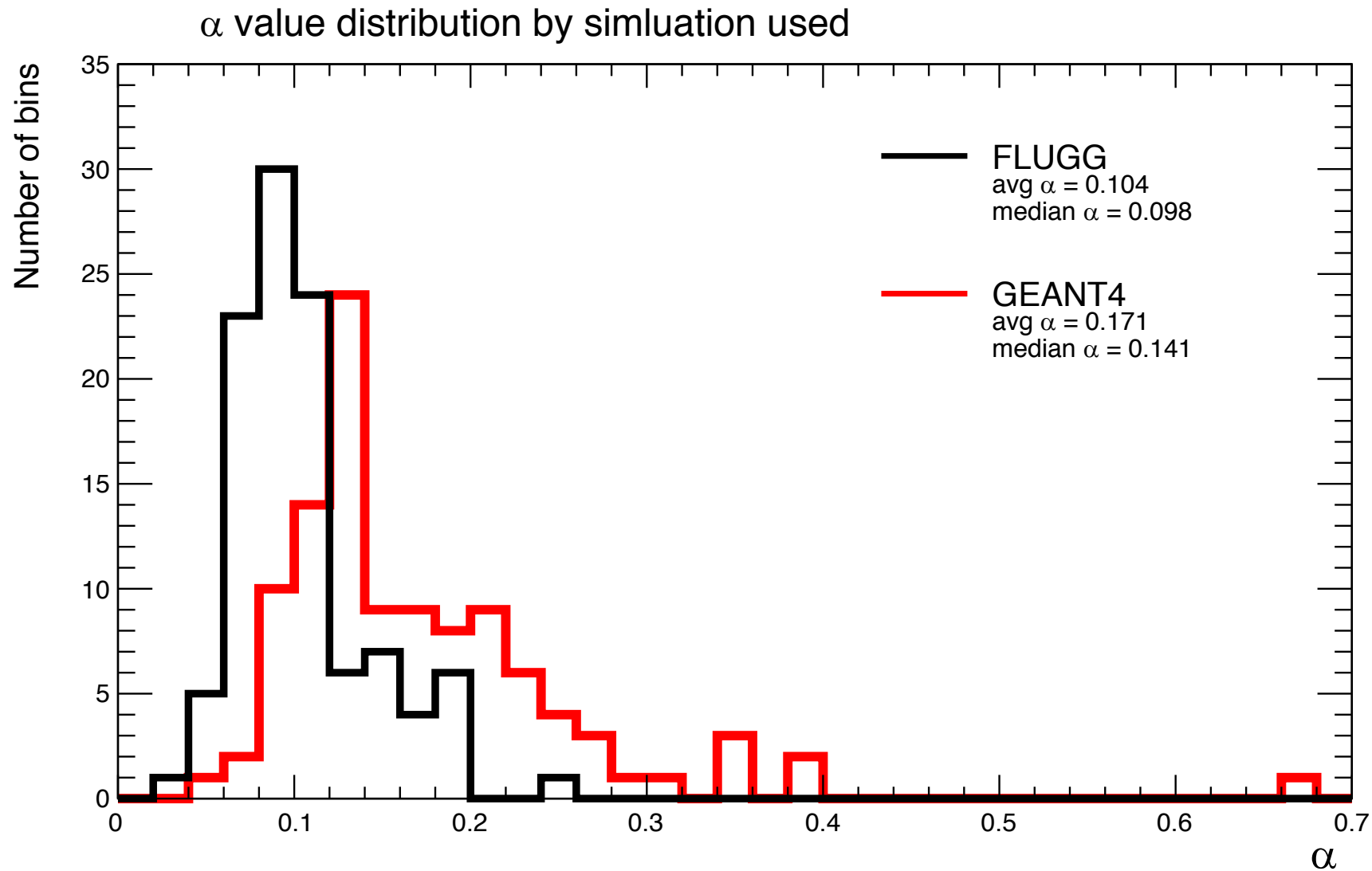
# Neutron Damage in ATLAS – GEANT4



[http://radsim.cern.ch/RadiationSimulation/G4\\_Run2](http://radsim.cern.ch/RadiationSimulation/G4_Run2)  
[NIEL\\_0\\_1200\\_0\\_2400\\_1\\_78.txt](#)



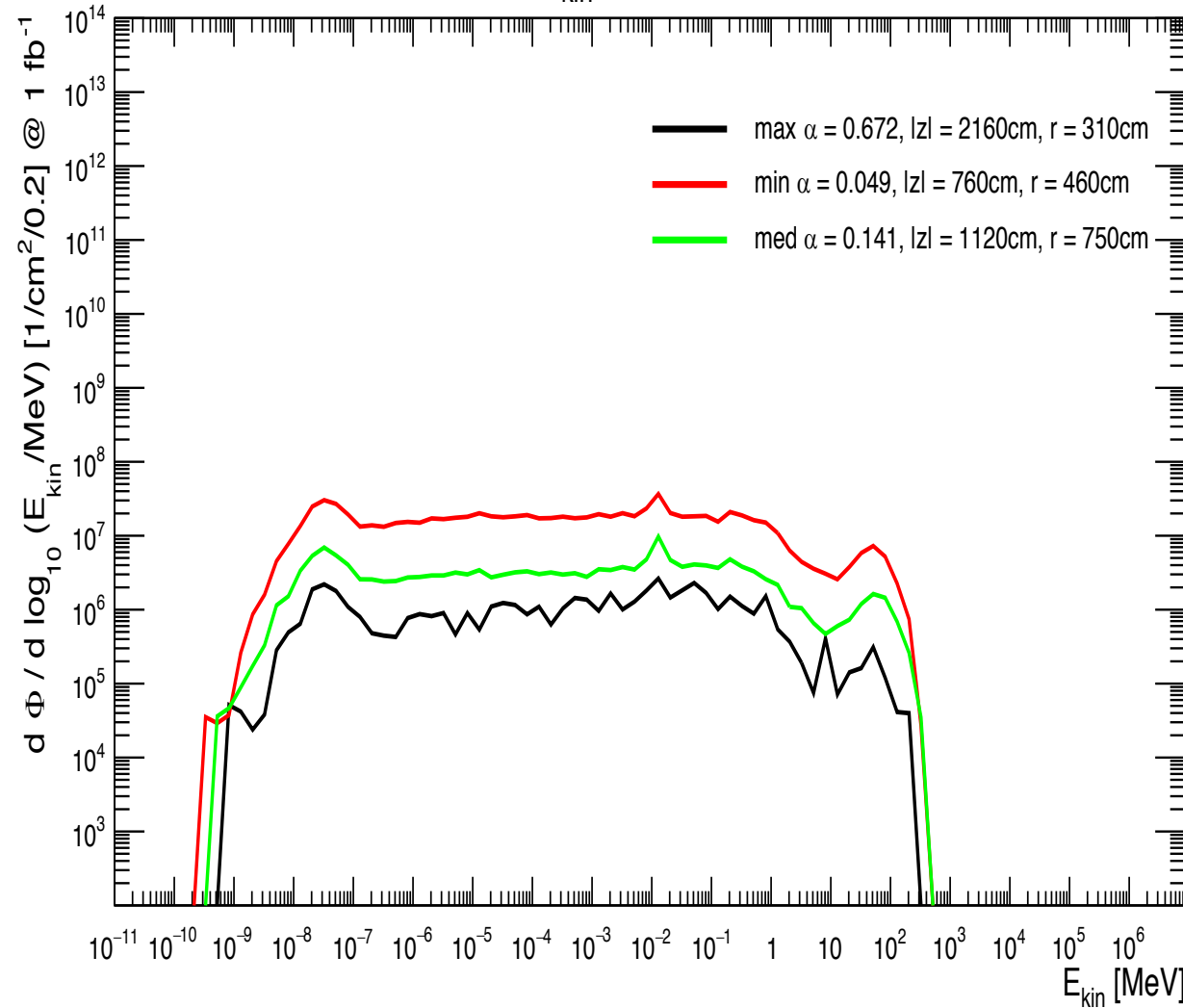
# $\alpha$ Values - FLUGG vs. GEANT4



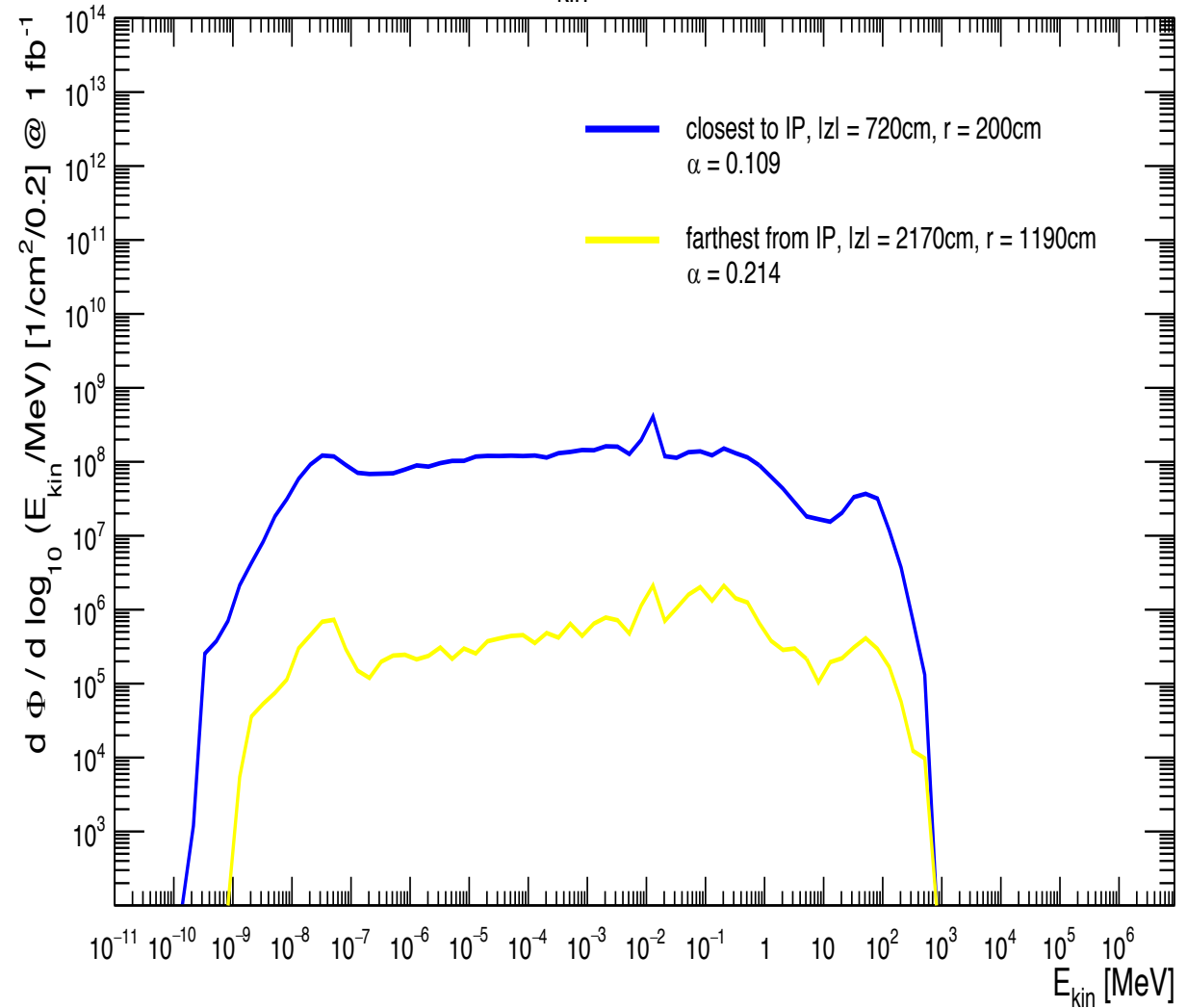


# Neutron Spectra

Neutron Fluences vs.  $E_{kin}$  GEANT4,  $\sqrt{s} = 13\text{TeV}$



Neutron Fluences vs.  $E_{kin}$  GEANT4,  $\sqrt{s} = 13\text{TeV}$



# Conclusion

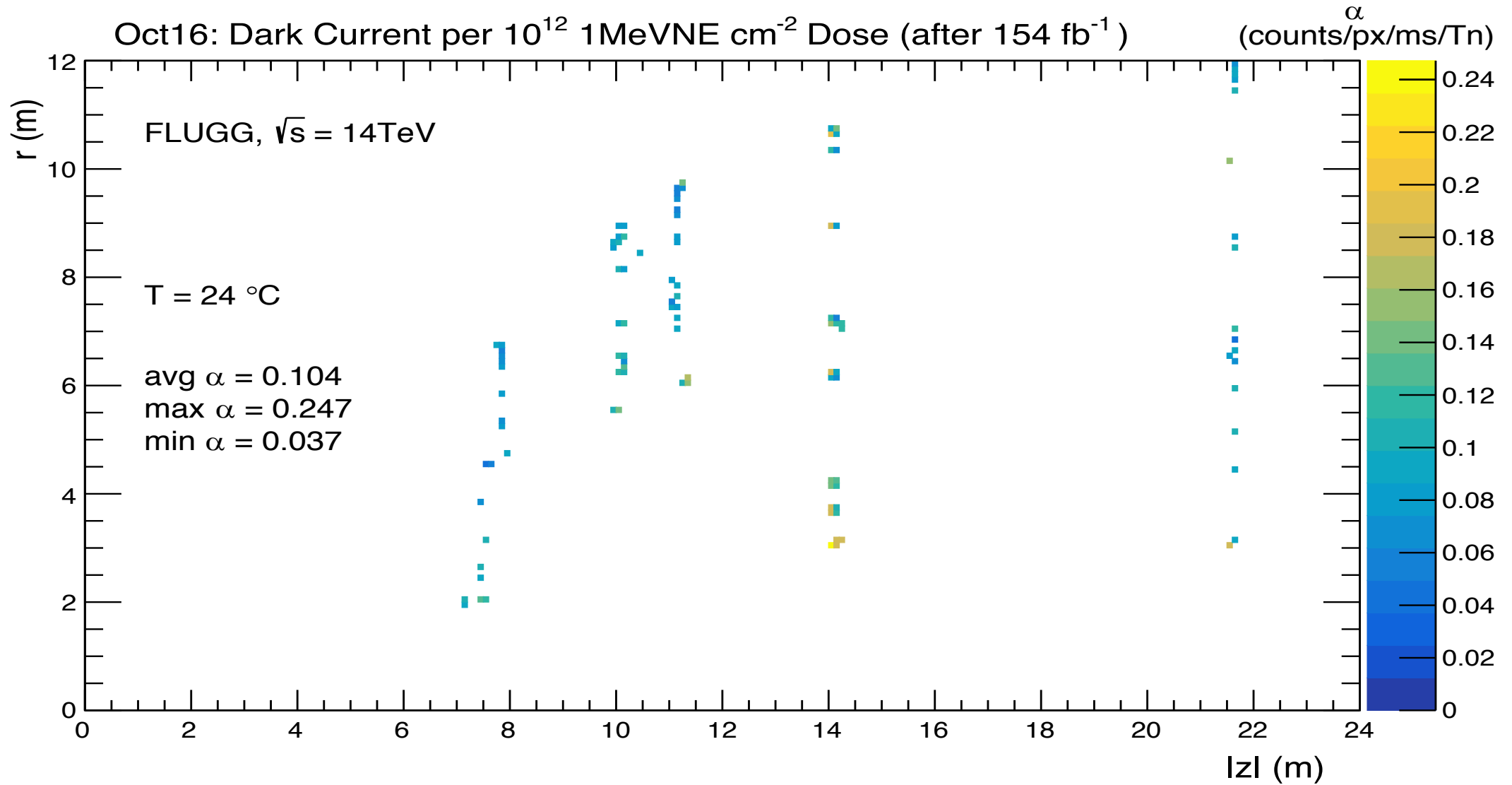
- We measured dark current in 2670 ATLAS endcap CCDs. Using simulated neutron flux data, we calculated dark current per neutron dose received. We compared these measurements to the results obtained in past, controlled experiments:

Experiment	$\alpha$ (count/px/ms/dose)
1998 Lowell	0.28
1999 PROSPERO	0.26
2018 ATLAS - FLUGG	0.104
2018 ATLAS – GEANT4	0.172

# Backup

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# Neutron Damage in ATLAS - FLUGG



# Neutron Damage in ATLAS – GEANT4

