Ten years of Radiation Environment Monitors on ISS

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Radiation Environment Monitors

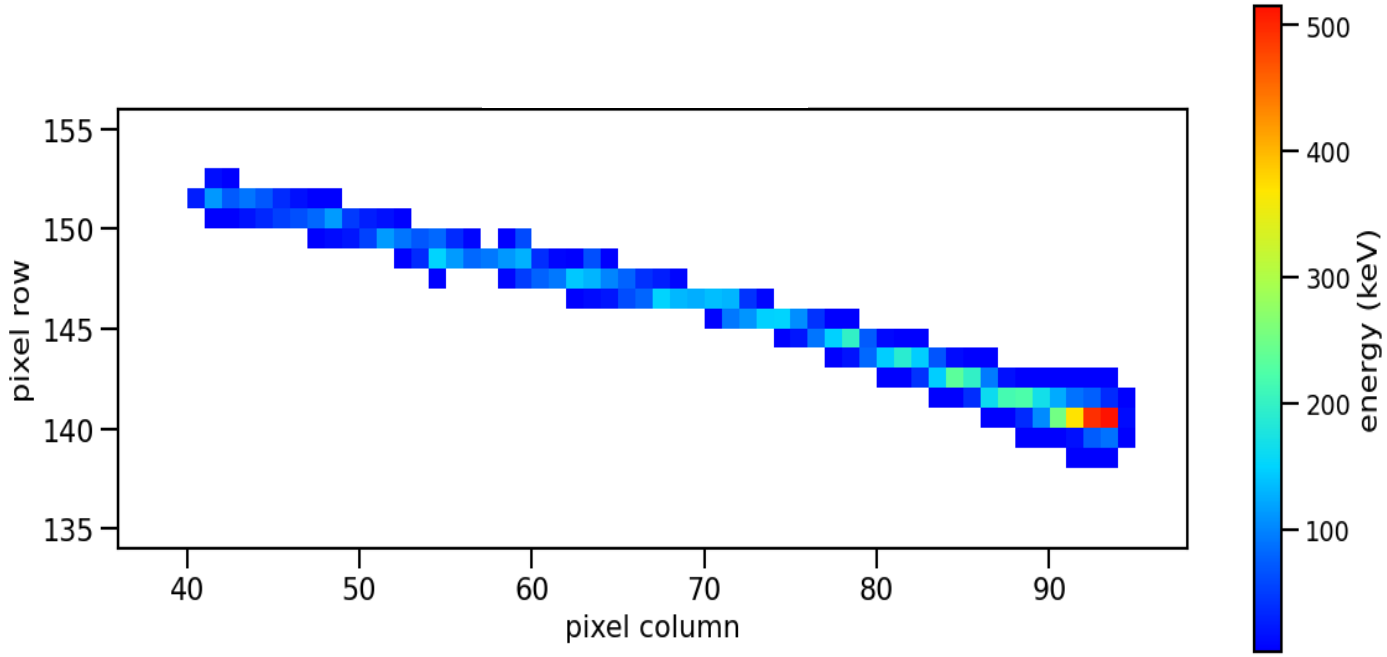
- Timepix, hybrid detector
- Minipix readout
- 500 μm Si sensor
- 256 x 256 pixels – solid-state nuclear emulsion analog
- pixel pitch = 55 μm
- time-over-threshold energy resolution (5 keV threshold)
- frame length from ms to ∞
- adaptive shutter algorithm
- connected to SSCs via USB cables, but fixed (≈) in position

Technology demo from 2012 to 2019, 7 units operational from February 10th 2019

Radiation Environment Monitors

- Each particle crossing the Timepix is individually recorded, giving
  - deposited energy
  - direction of travel of the (charged) particle
  - length of the particle track
  - a detailed image of the track

- Attributes we can identify include
  - dose
  - LET
  - particle ID (e. g. atomic number)
  - particle velocity

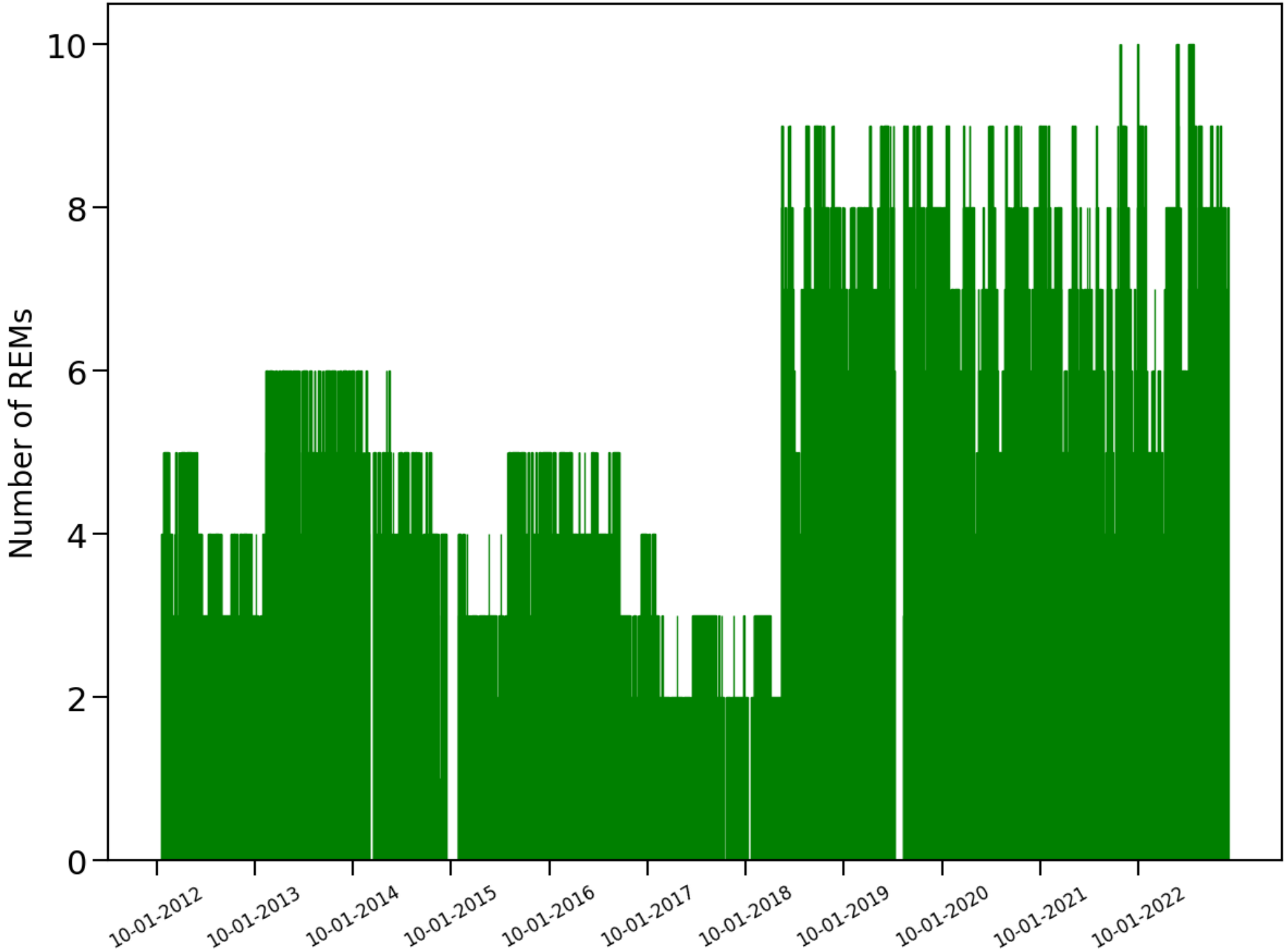


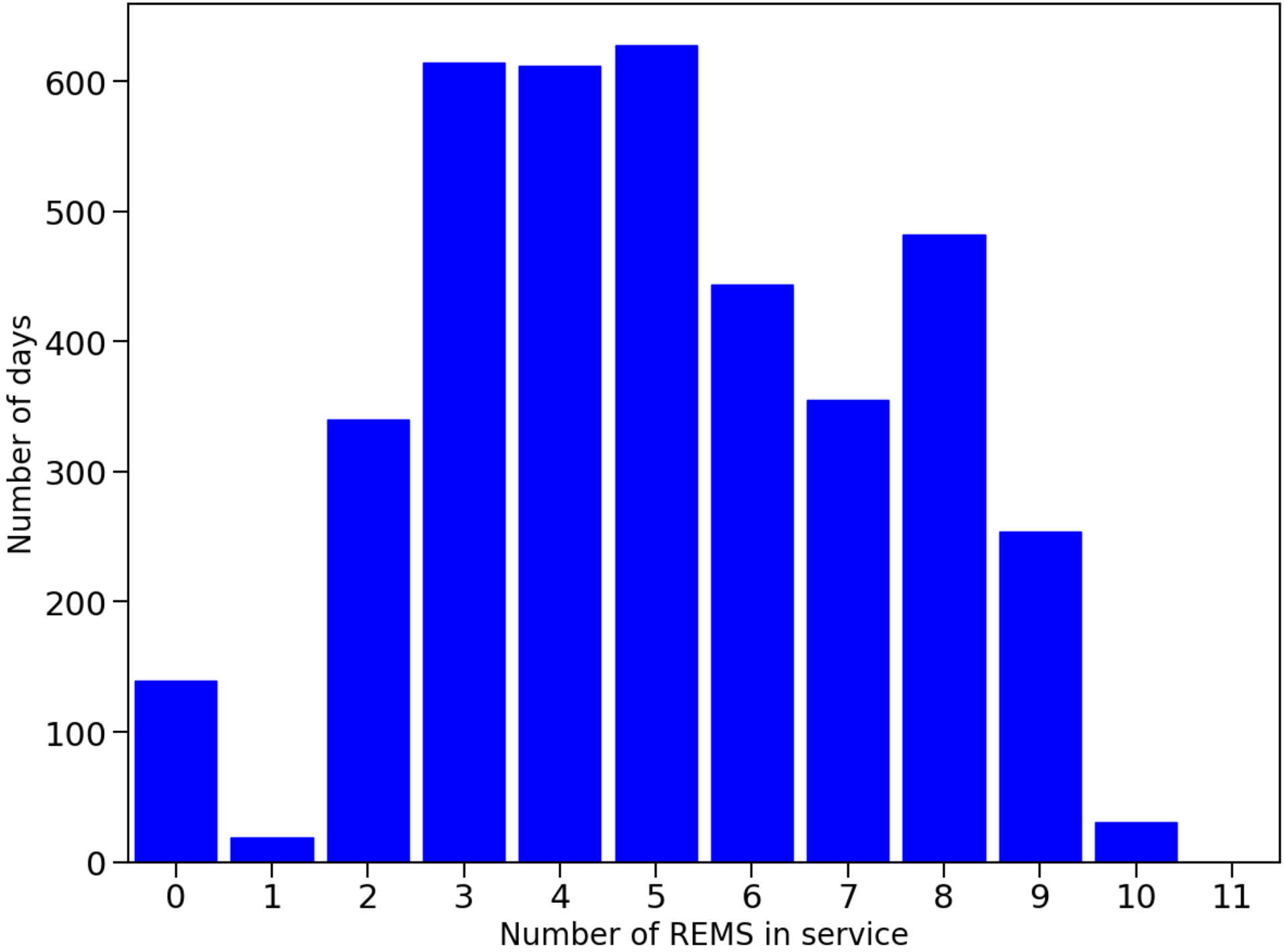
Statistics

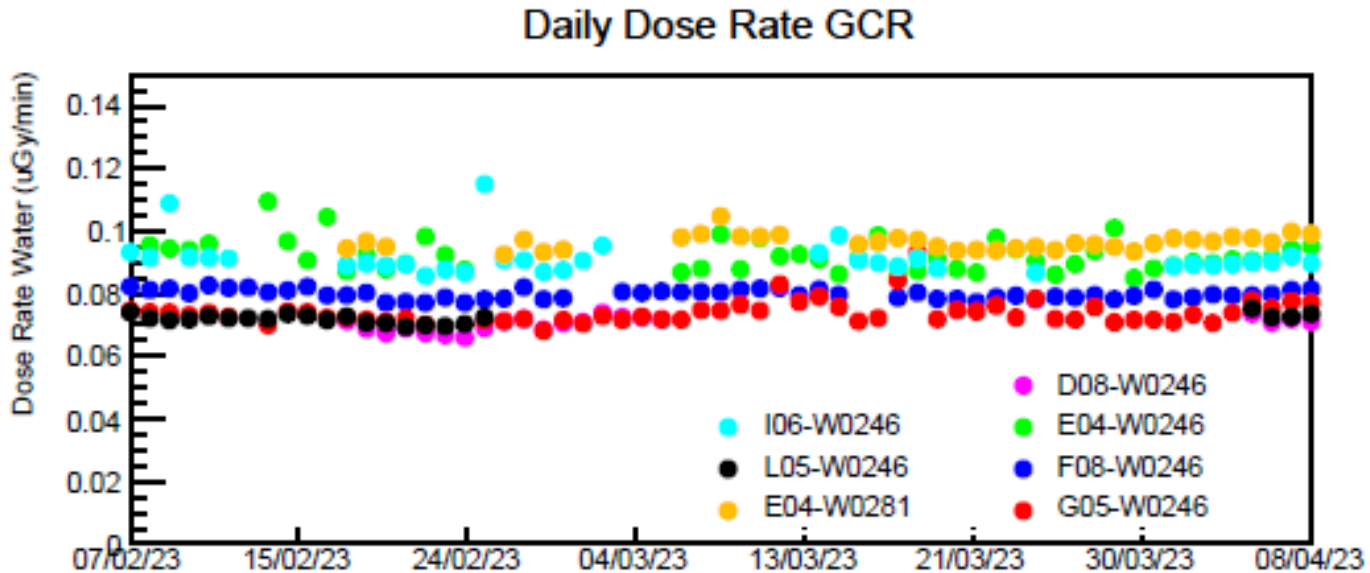
Since the first ISS REM unit was switched on, on October 20th, 2012*

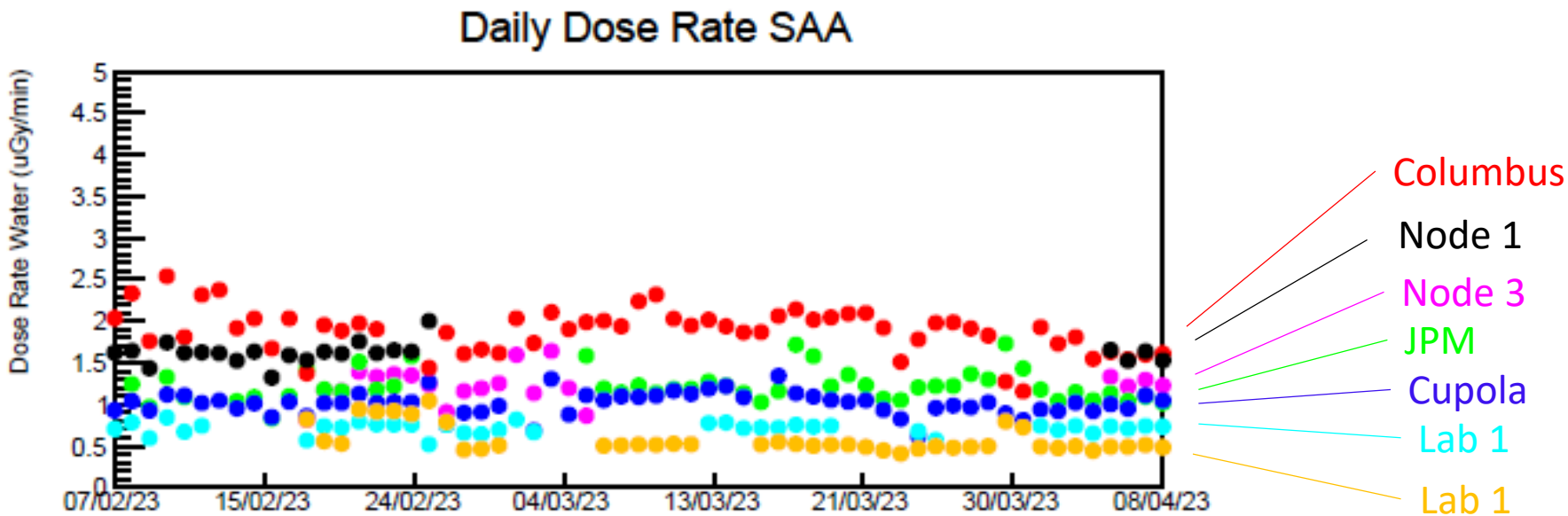
Livetime =	17,937 days, 8 hours, 43 minutes, 26.90 seconds
Total frames =	405,832,053
Total clusters =	9,726,167,287
Total Pixels =	150,715,020,874
Days without coverage =	140 days (out of 3968, i.e. 96.5% of days covered)
Longest non-covered period =	43 days (prior to becoming operational in 2019)

*Excludes non-REM Timepix devices, such as HERA & MPT

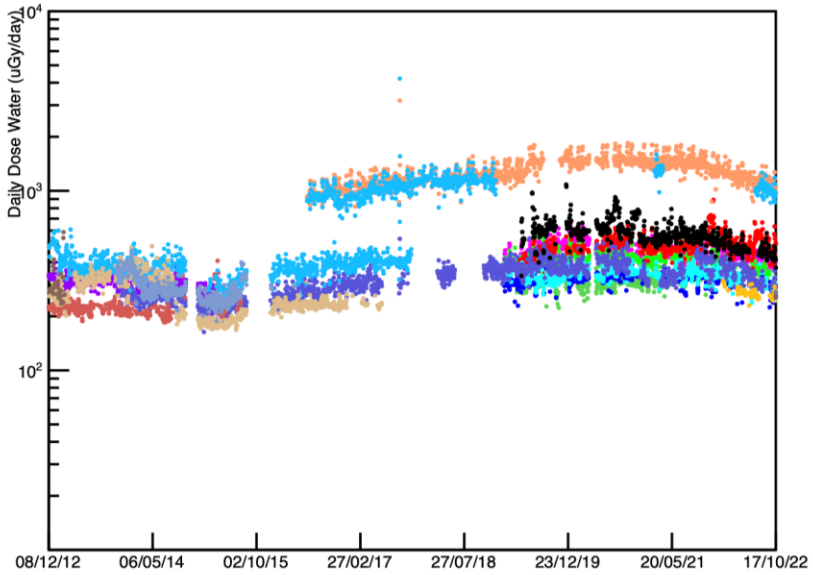

Number of REMs
0
2
4
6
8
10
10-01-2012
10-01-2013
10-01-2014
10-01-2015
10-01-2016
10-01-2017
10-01-2018
10-01-2019
10-01-2020
10-01-2021
10-01-2022


Number of days
0
100
200
300
400
500
600
0
1
2
3
4
5
6
7
8
9
10
11
Number of REMS in service

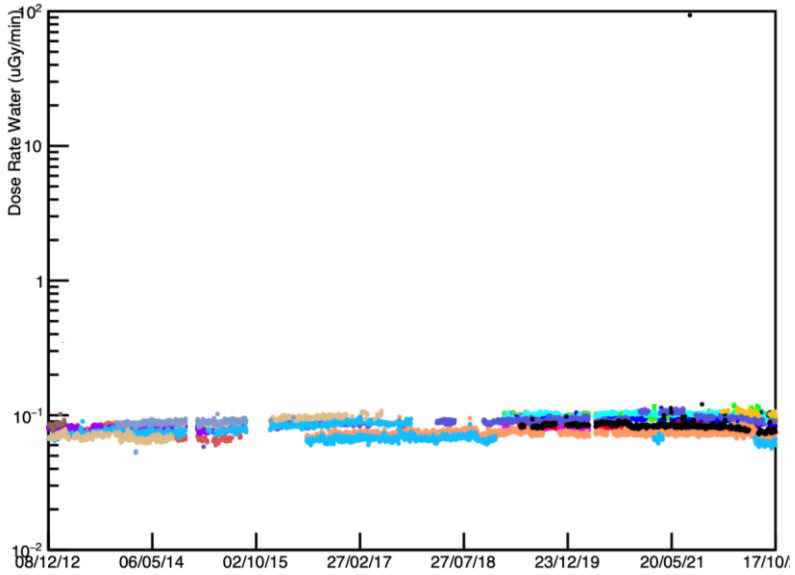

Daily Dose Rate GCR
Dose Rate Water (uGy/min)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
07/02/23
15/02/23
24/02/23
04/03/23
13/03/23
21/03/23
30/03/23
08/04/23
I06-W0246
L05-W0246
E04-W0281
D08-W0246
E04-W0246
F08-W0246
G05-W0246


Daily Dose Rate SAA
Dose Rate Water (uGy/min)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
07/02/23
15/02/23
24/02/23
04/03/23
13/03/23
21/03/23
30/03/23
08/04/23
Columbus
Node 1
Node 3
JPM
Cupola
Lab 1
Lab 1

Daily Dose Water

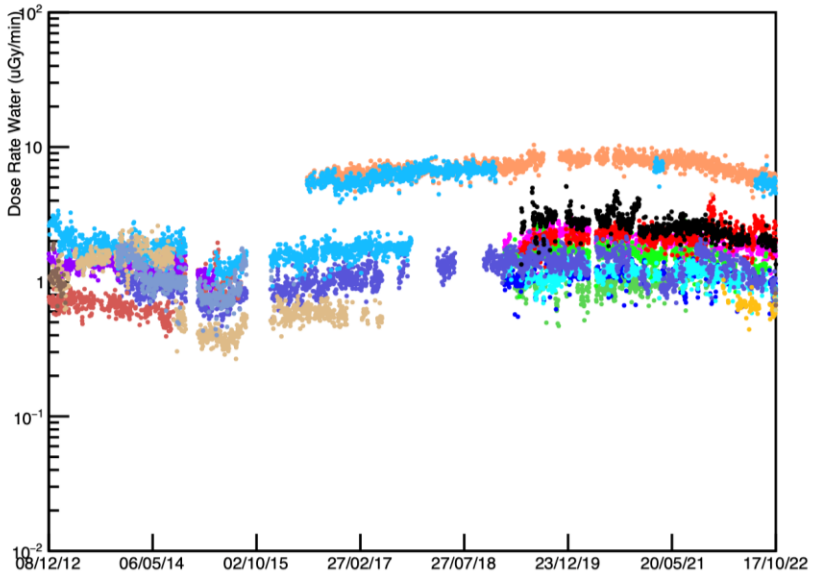


Daily Dose Rate GCR

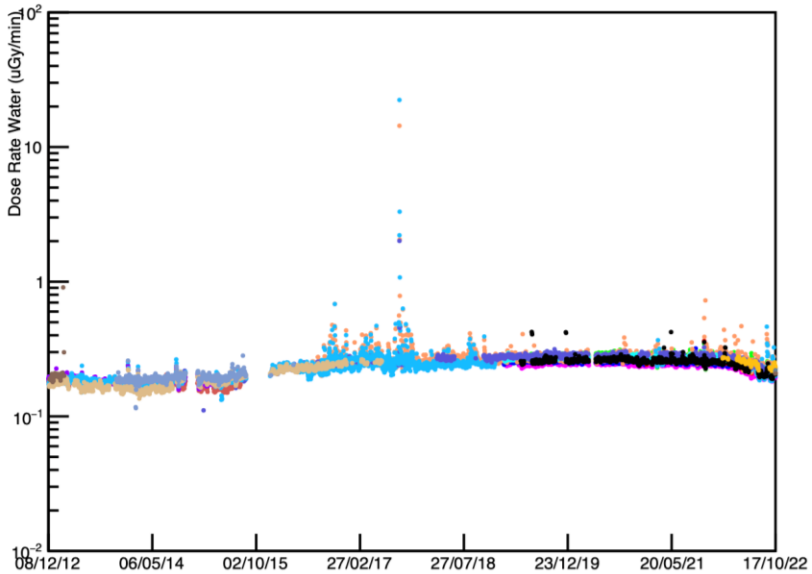


C03-W0332
E02-W0332
A06-W0281
J06-W0292
J03-W0253
G03-W0253
I03-W0094
I04-W0094
G03-W0094
D03-W0094
E06-W0087
G01-W0099
B08-W0246
D08-W0246
E04-W0246
F08-W0246
G05-W0246
H10-W0099
H06-W0099
I06-W0246
J02-W0156
L05-W0246
E04-W0281
L05-W0299

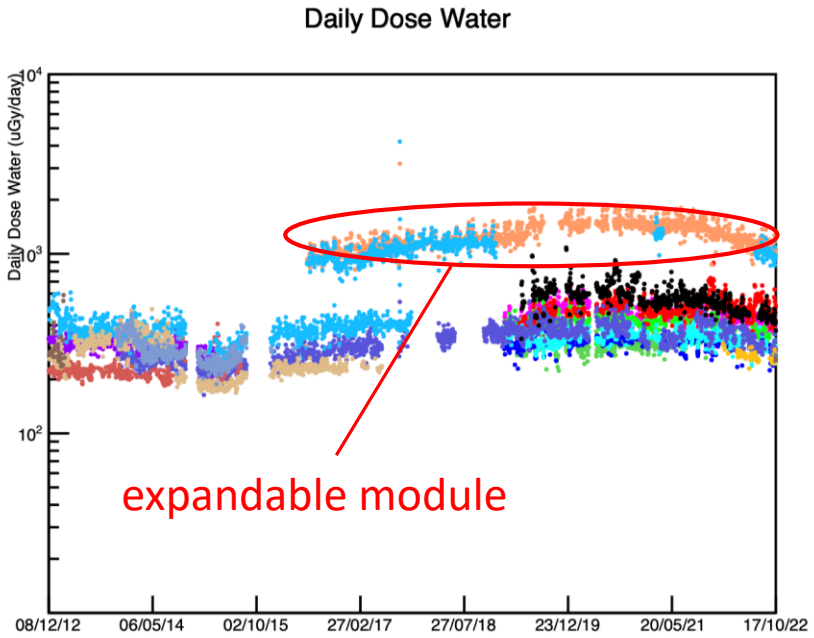
Daily Dose Rate SAA

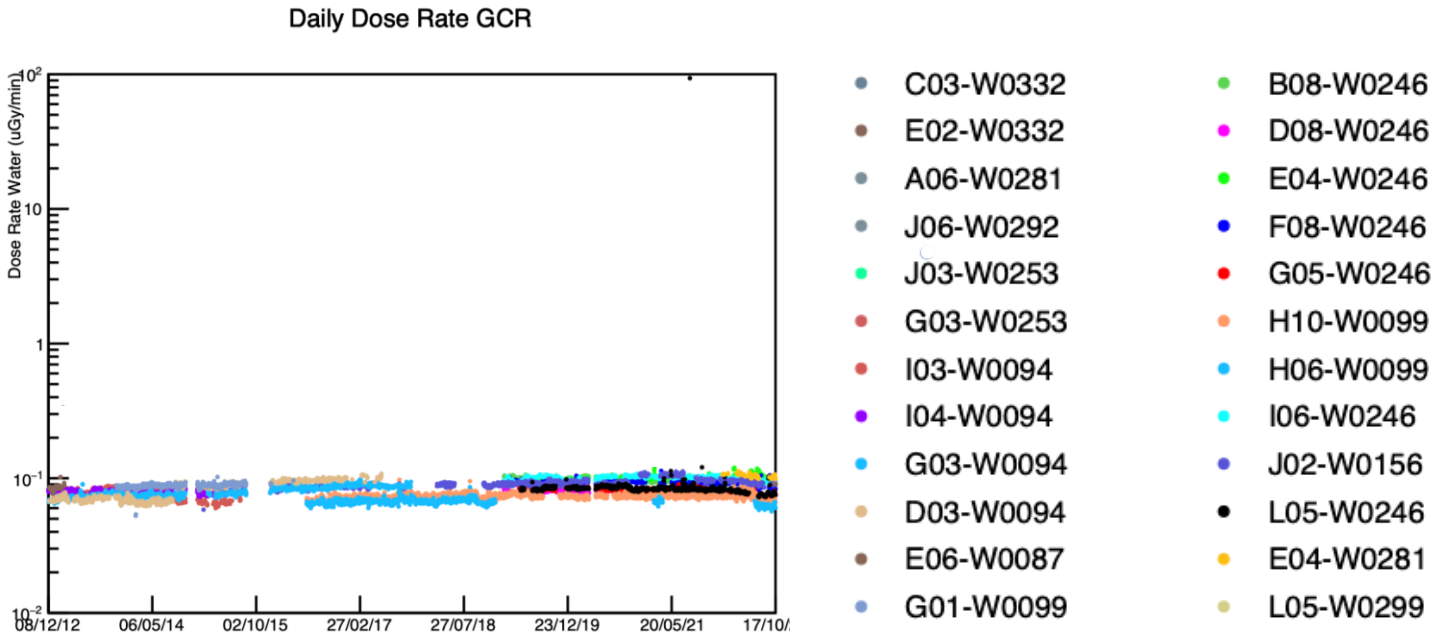


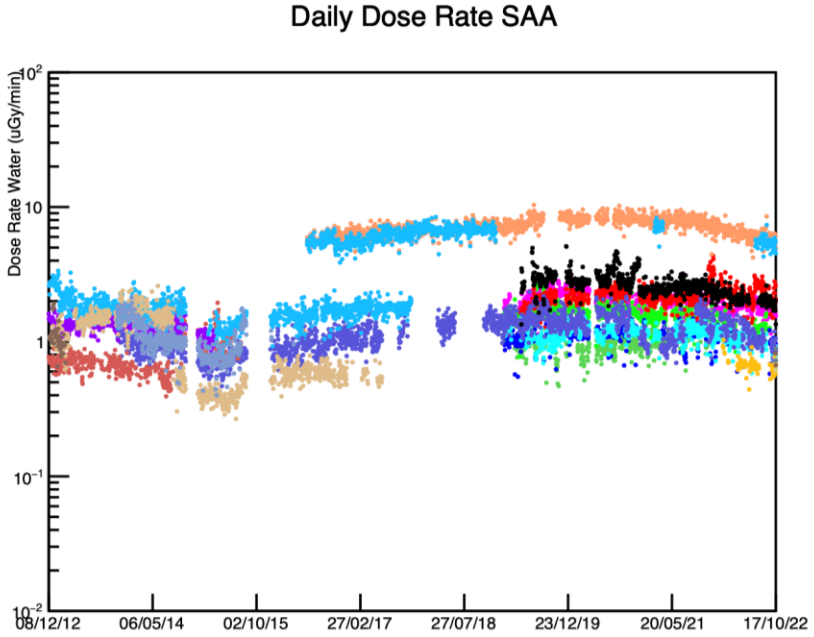
Daily Dose Rate Polar

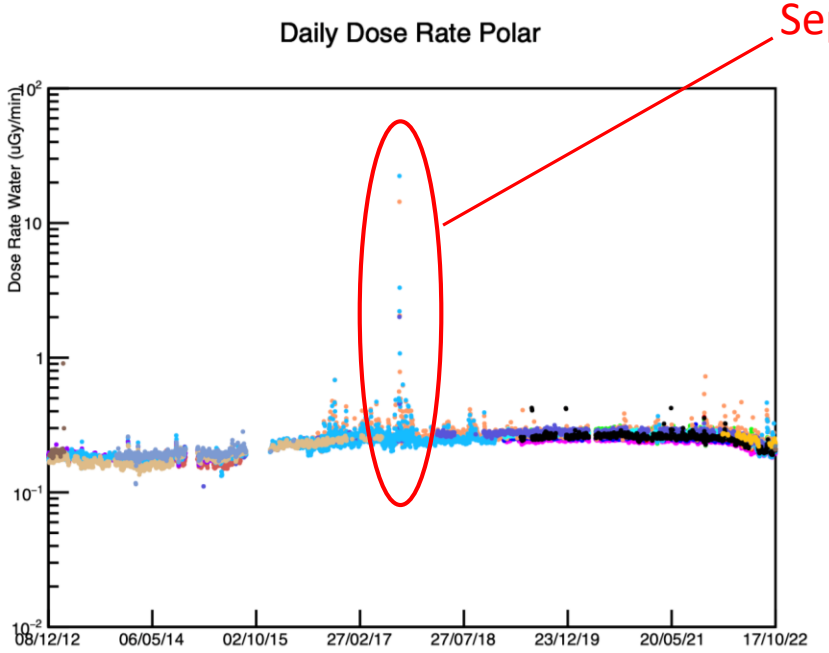


SAA = L < 3, B < 23 μT
Polar = L > 3
GCR = all other points









SAA = L < 3, B < 23 μT
Polar = L > 3
GCR = all other points

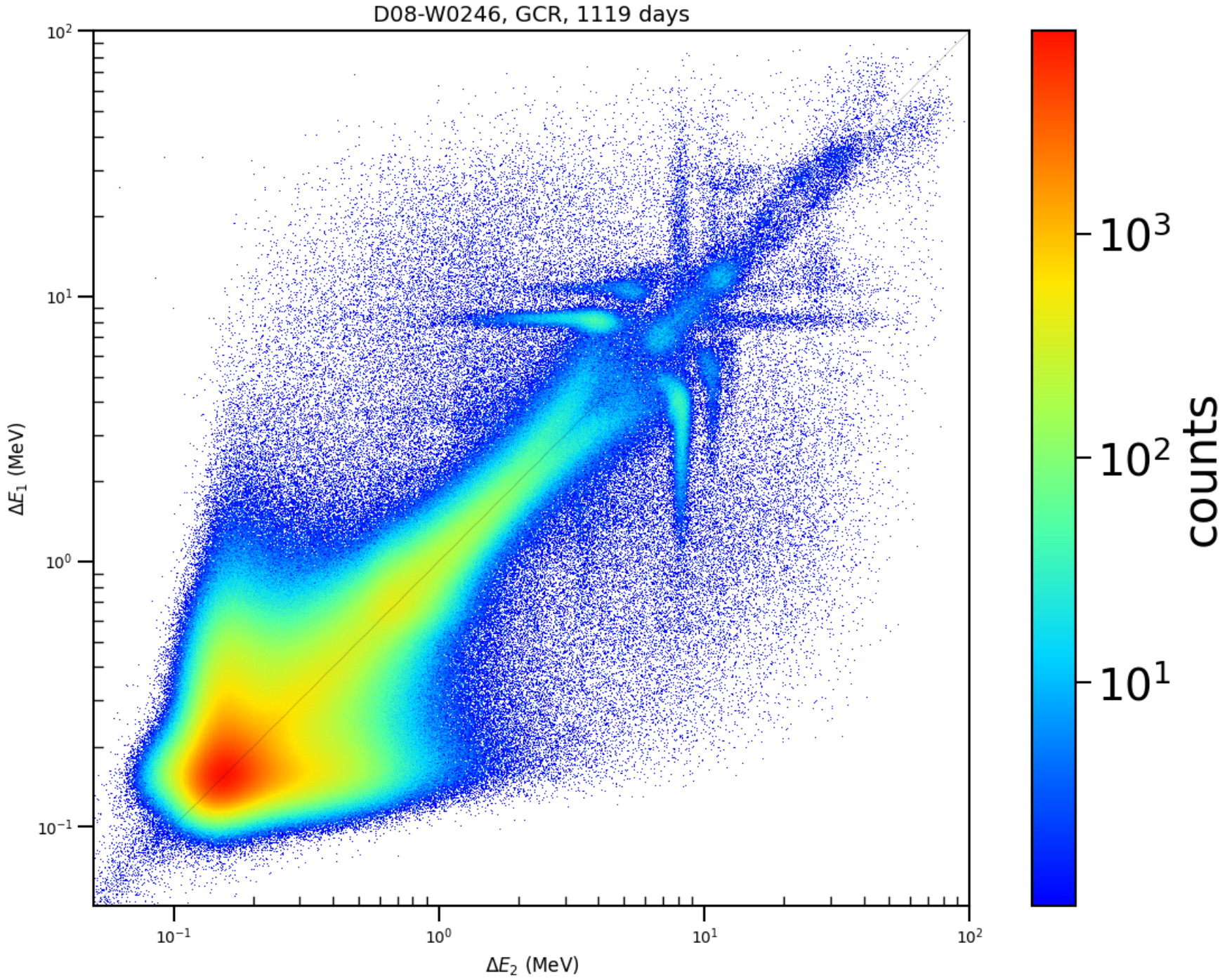
Single-layer telescope / isotope analysis

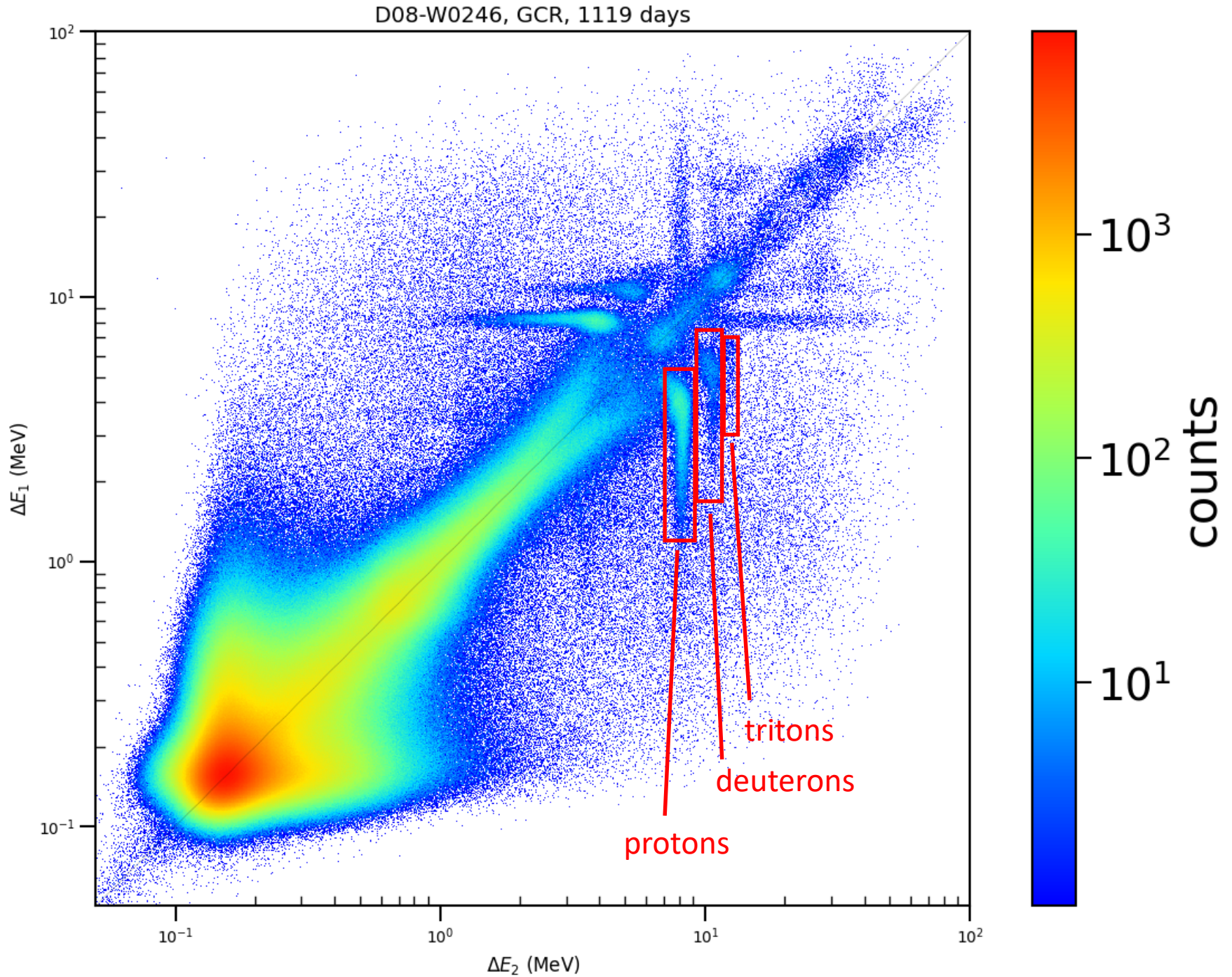
‘Light ion isotope identification in space using pixel detector based single layer telescope,’ Kroupa *et al*., Applied Physics Letters 113, 174101, (2018)

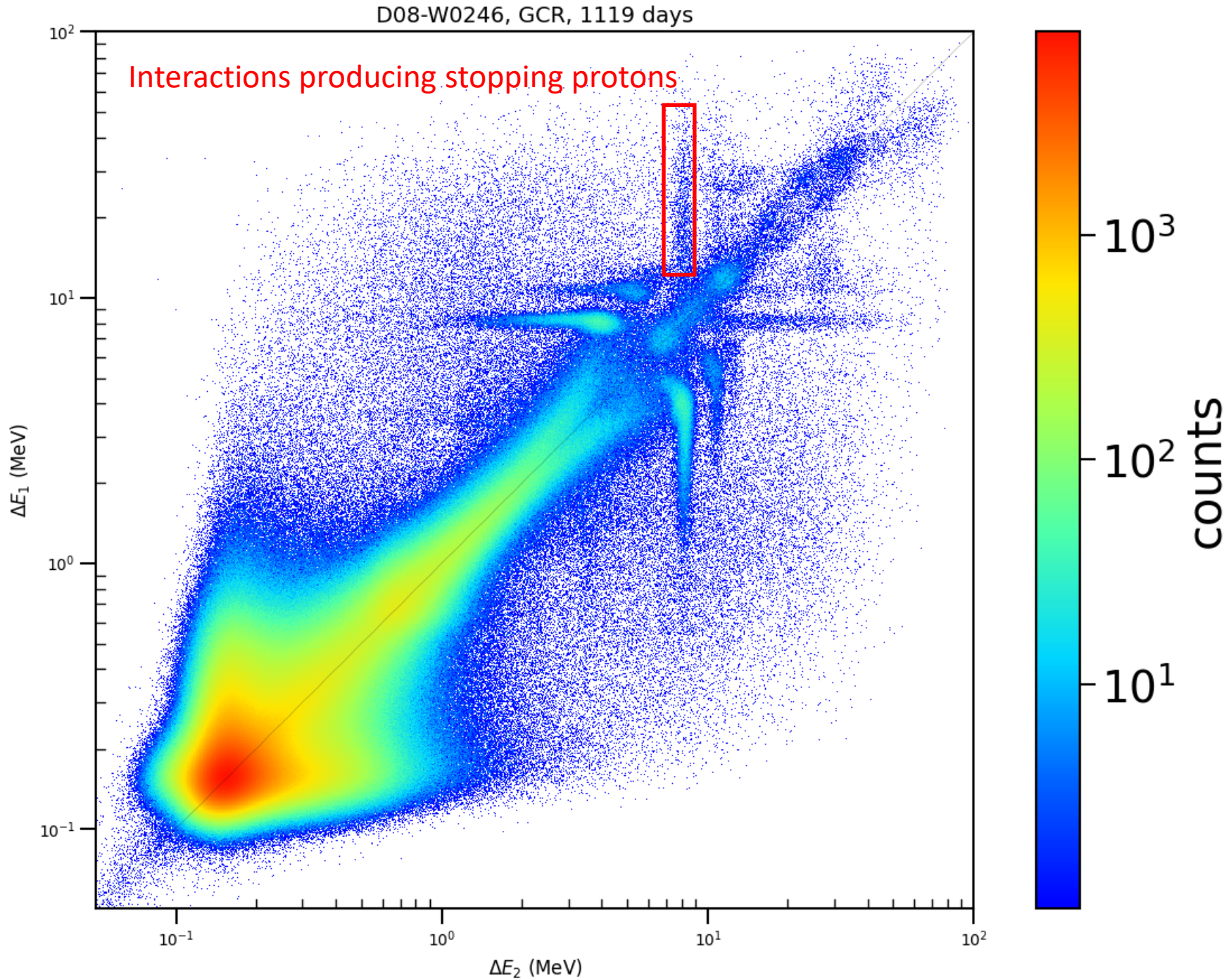
2 segments of track, one at each end

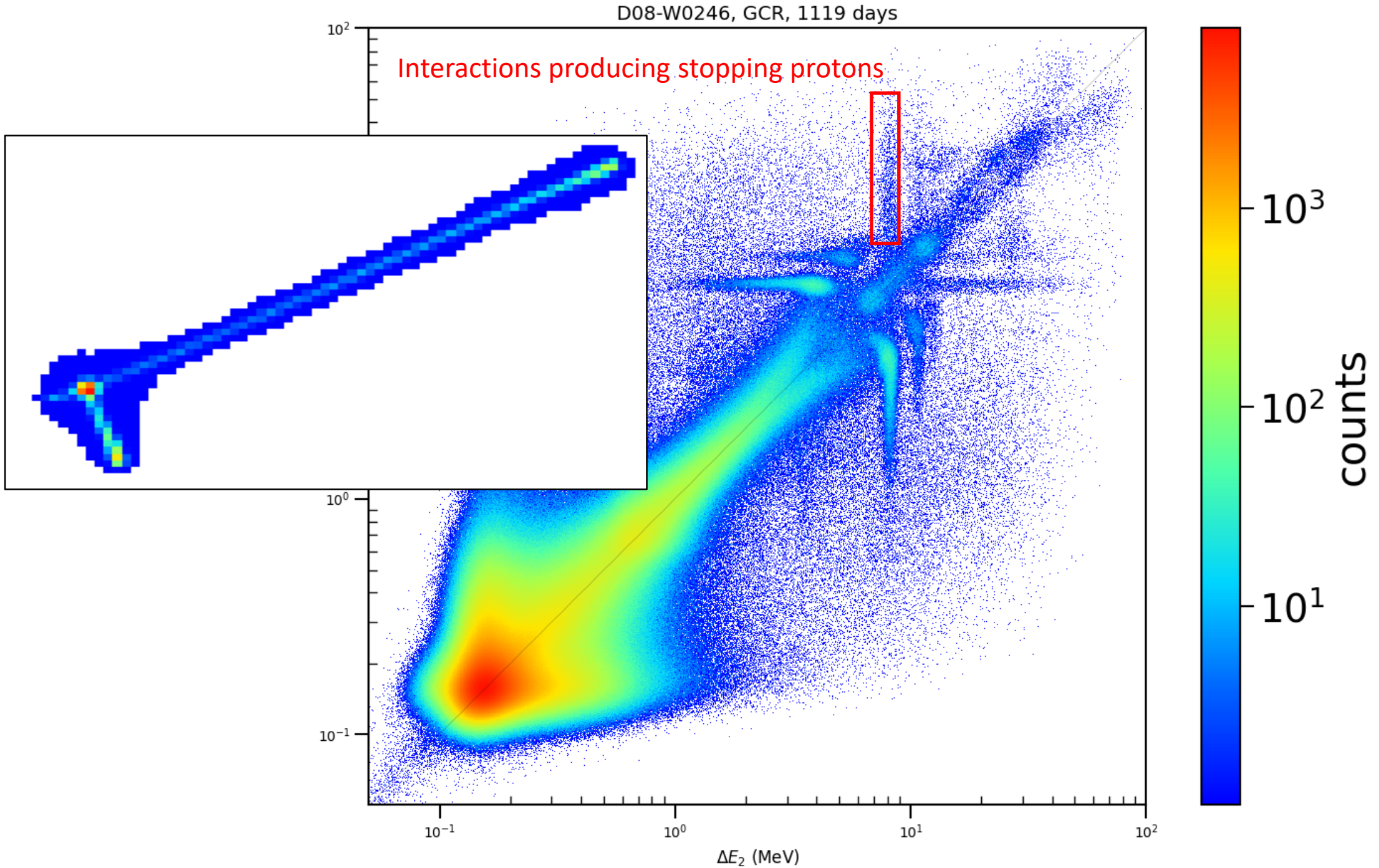
each segment 500 µm (minimum angle of incidence = 60˚)

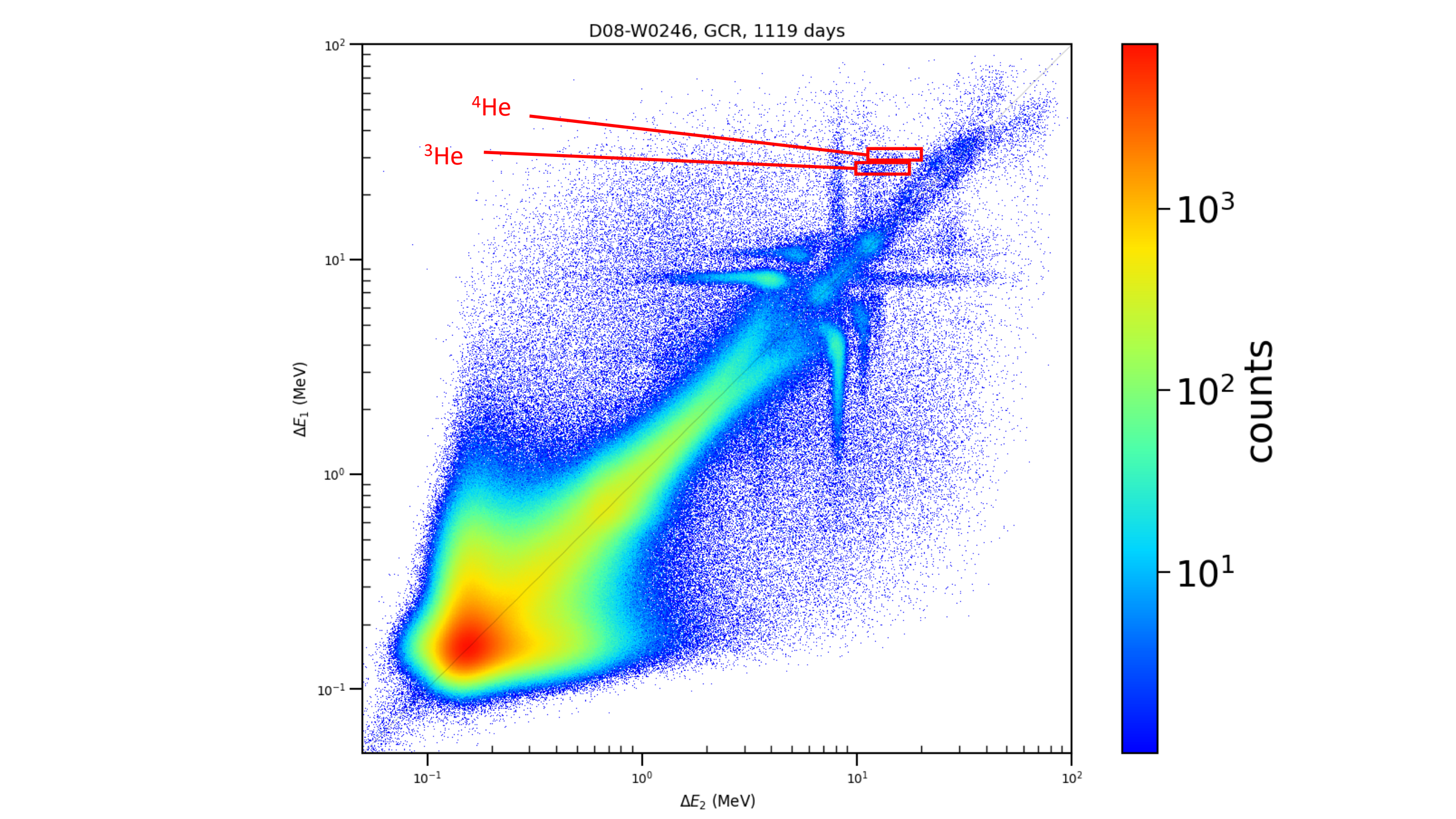
treat each segment as the measurement of a virtual telescope layer

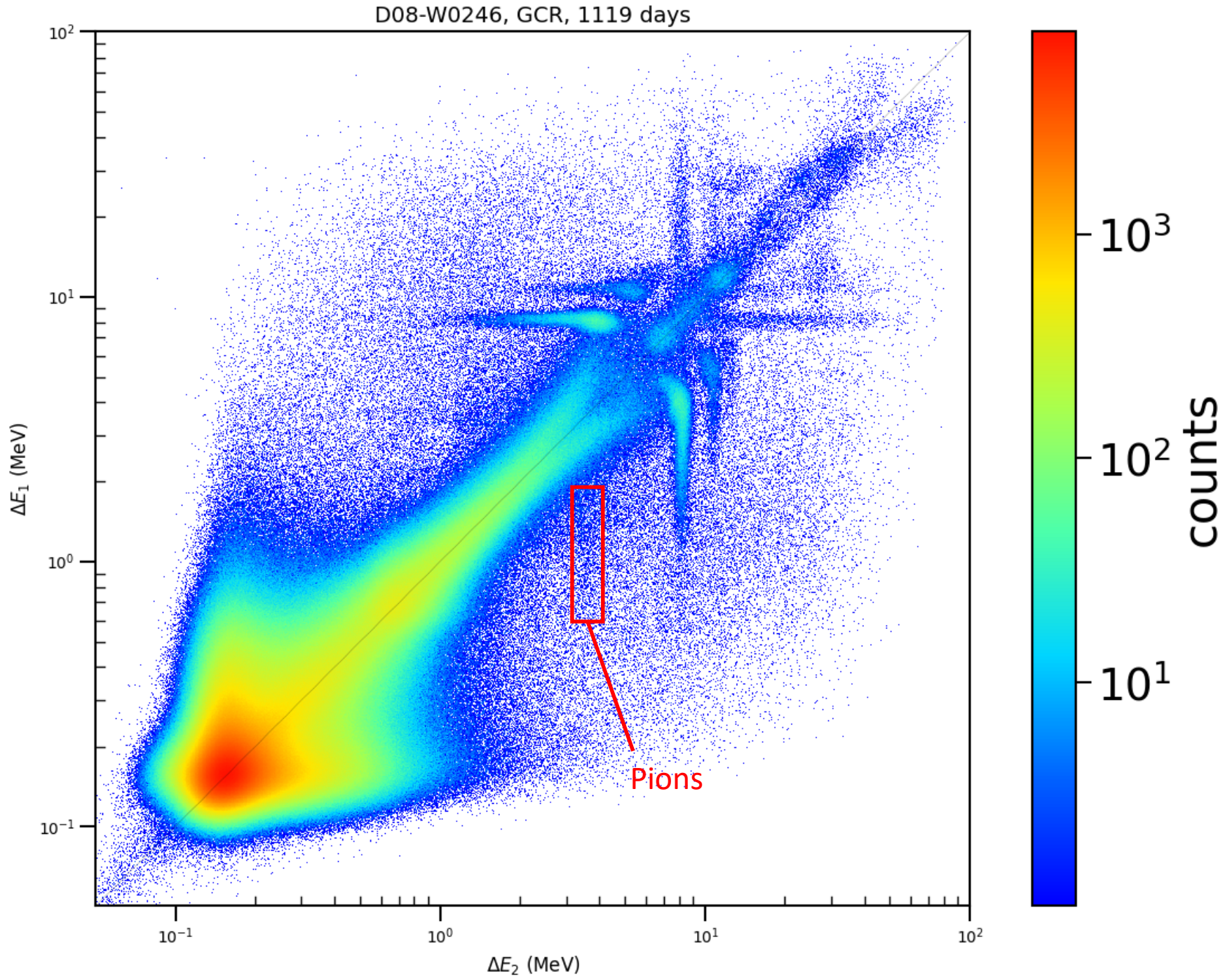



D08-W0246, GCR, 1119 days
10^2
10^1
10^0
10^{-1}
ΔE_1 (MeV)
10^{-1}
10^0
10^1
10^2
ΔE_2 (MeV)
protons
deuterons
tritons
10^3
10^2
10^1
counts


D08-W0246, GCR, 1119 days
Interactions producing stopping protons
10^2
10^1
10^0
10^{-1}
ΔE_1 (MeV)
10^{-1}
10^0
10^1
10^2
ΔE_2 (MeV)
10^3
10^2
10^1
counts


D08-W0246, GCR, 1119 days
Interactions producing stopping protons
10^2
10^0
10^{-1}
10^{-1}
10^0
10^1
10^2
ΔE_2 (MeV)
10^3
10^2
10^1
counts

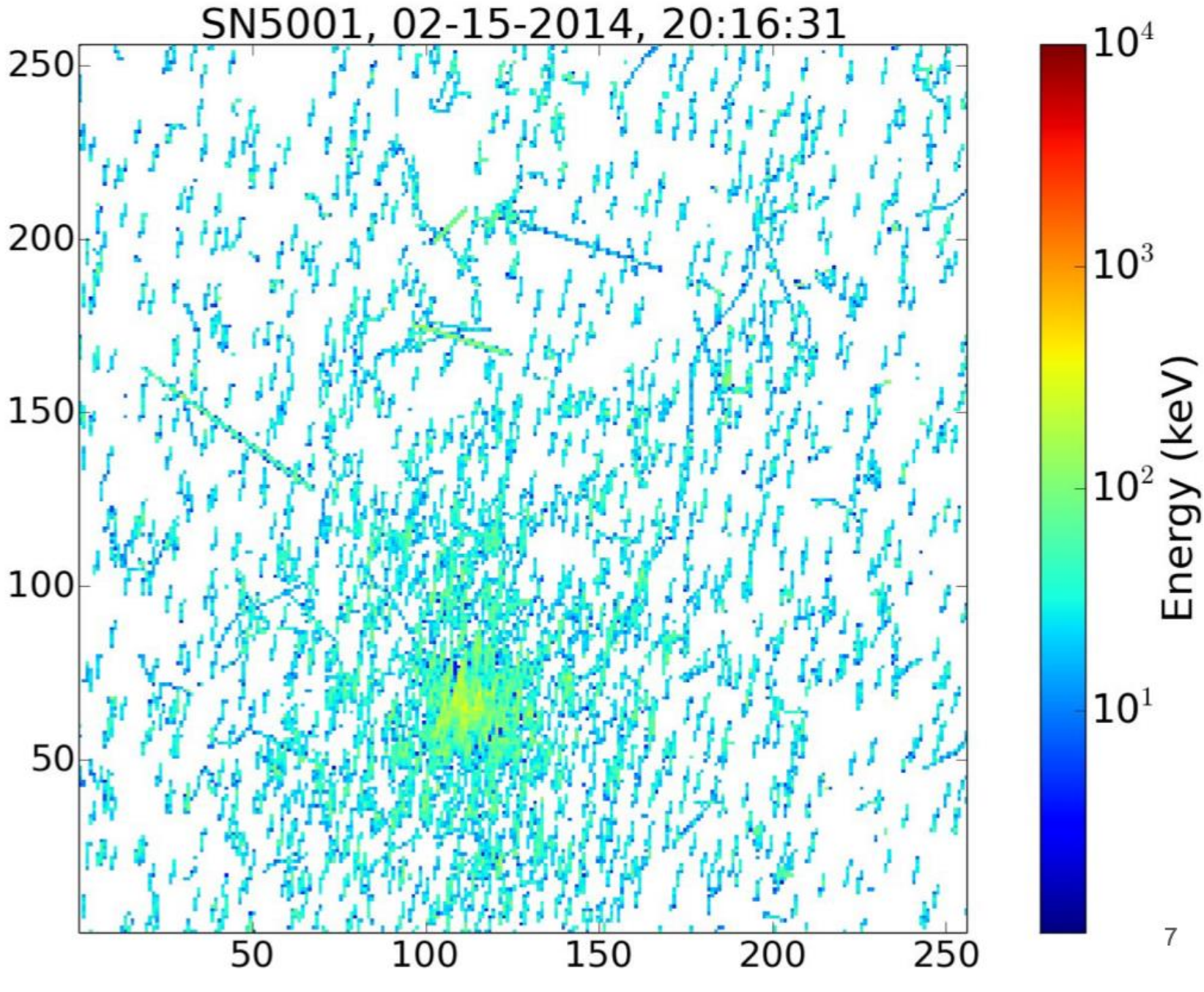

D08-W0246, GCR, 1119 days
^{4}He
^{3}He
10^2
10^1
10^0
10^{-1}
ΔE_1 (MeV)
10^{-1}
10^0
10^1
10^2
ΔE_2 (MeV)
10^3
10^2
10^1
counts

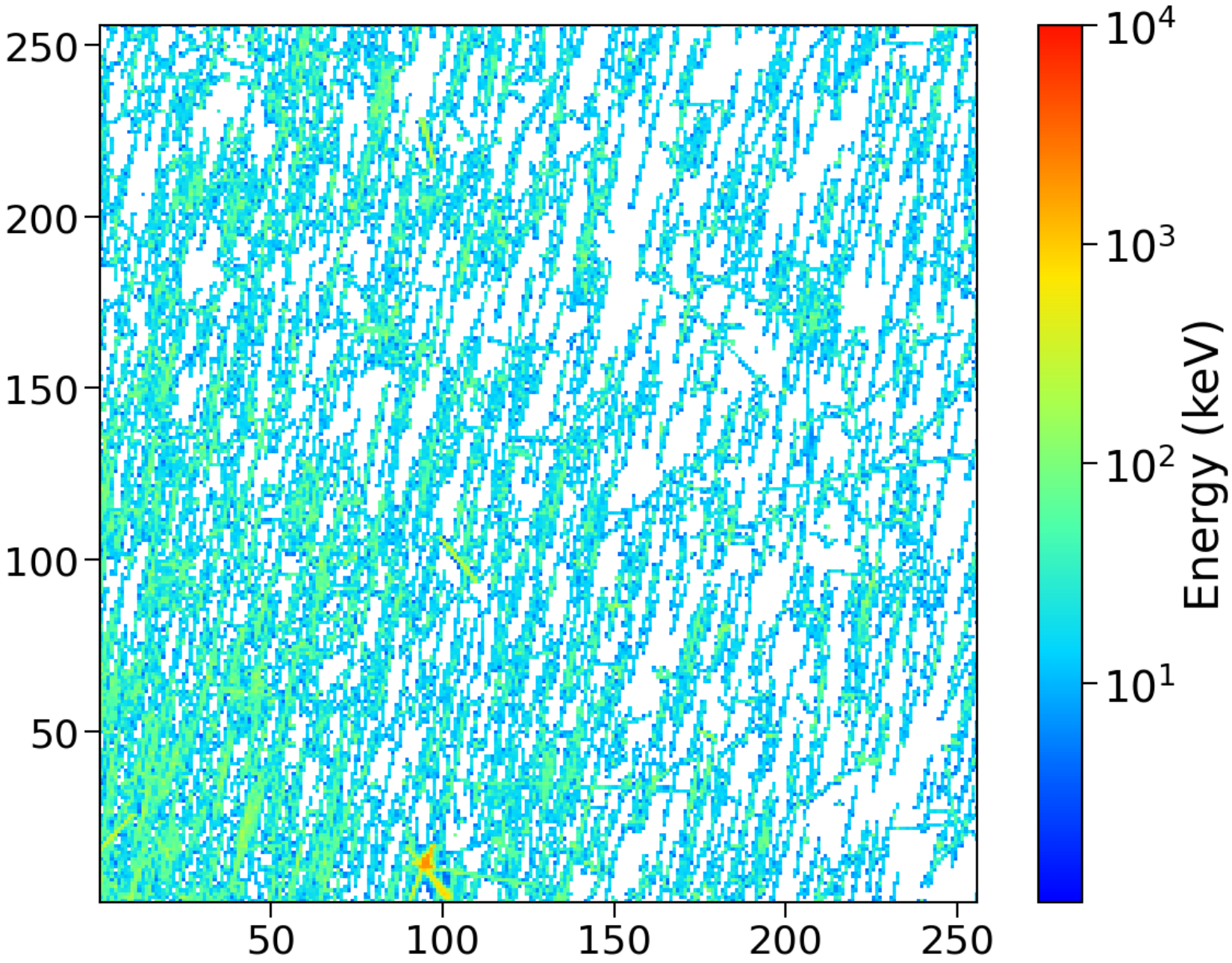

D08-W0246, GCR, 1119 days
10^2
10^1
10^0
10^{-1}
ΔE_1 (MeV)
10^{-1}
10^0
10^1
10^2
ΔE_2 (MeV)
Pions
10^3
10^2
10^1
counts

Hadron Showers

Martin Kroupa et al., Life Sciences in Space Research, “Particle showers detected on ISS in Timepix Pixel Detectors,” https://doi.org/10.1016/j.lssr.2023.02.004

- High density of tracks
- Event localized in time
- Tracks highly aligned
- Track density systematically modulated over image





A particularly busy event:

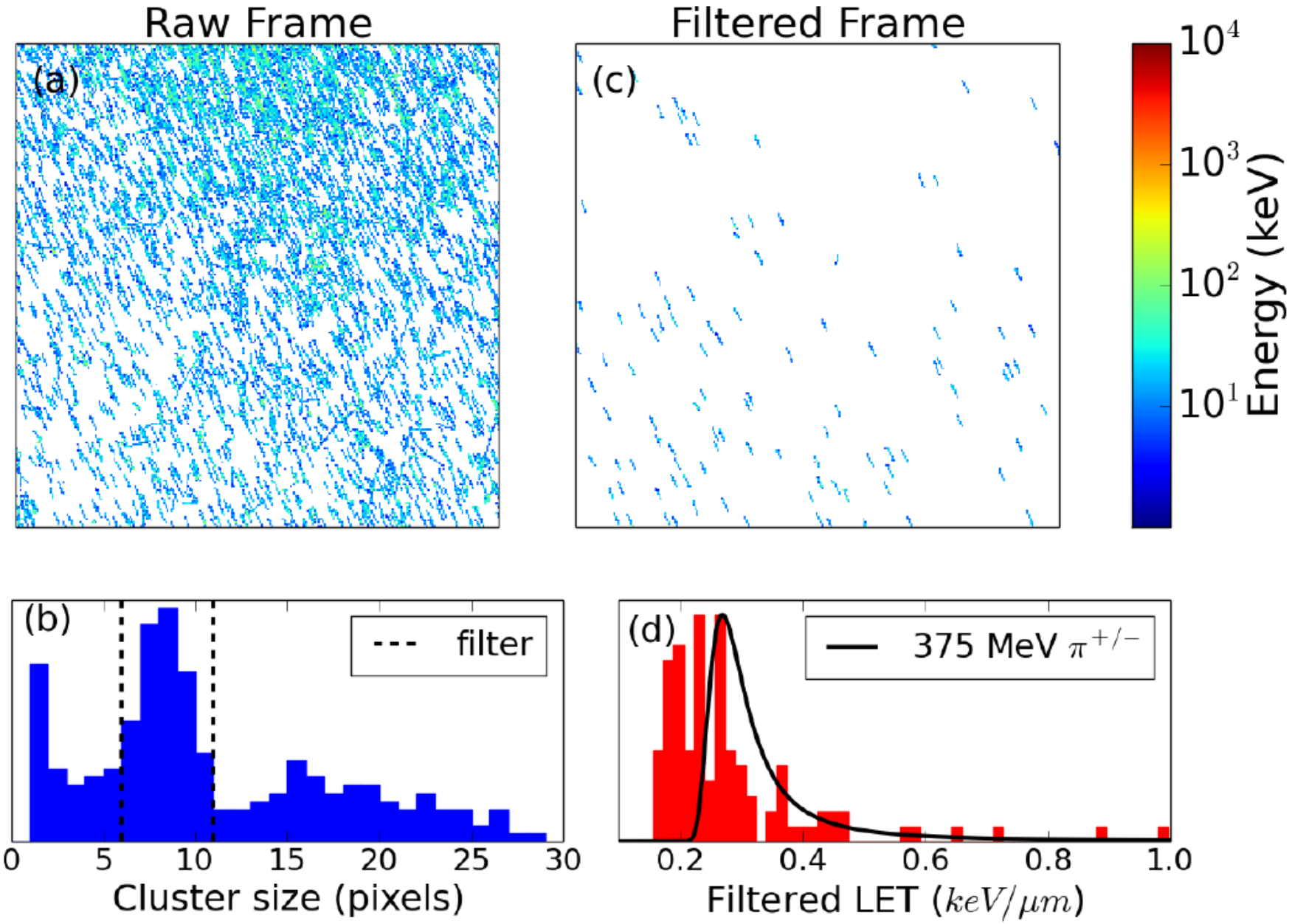
- 1 GeV deposited energy (0.7 μGy)
- 54% pixel occupancy
- Further analysis difficult due to overcrowding of tracks

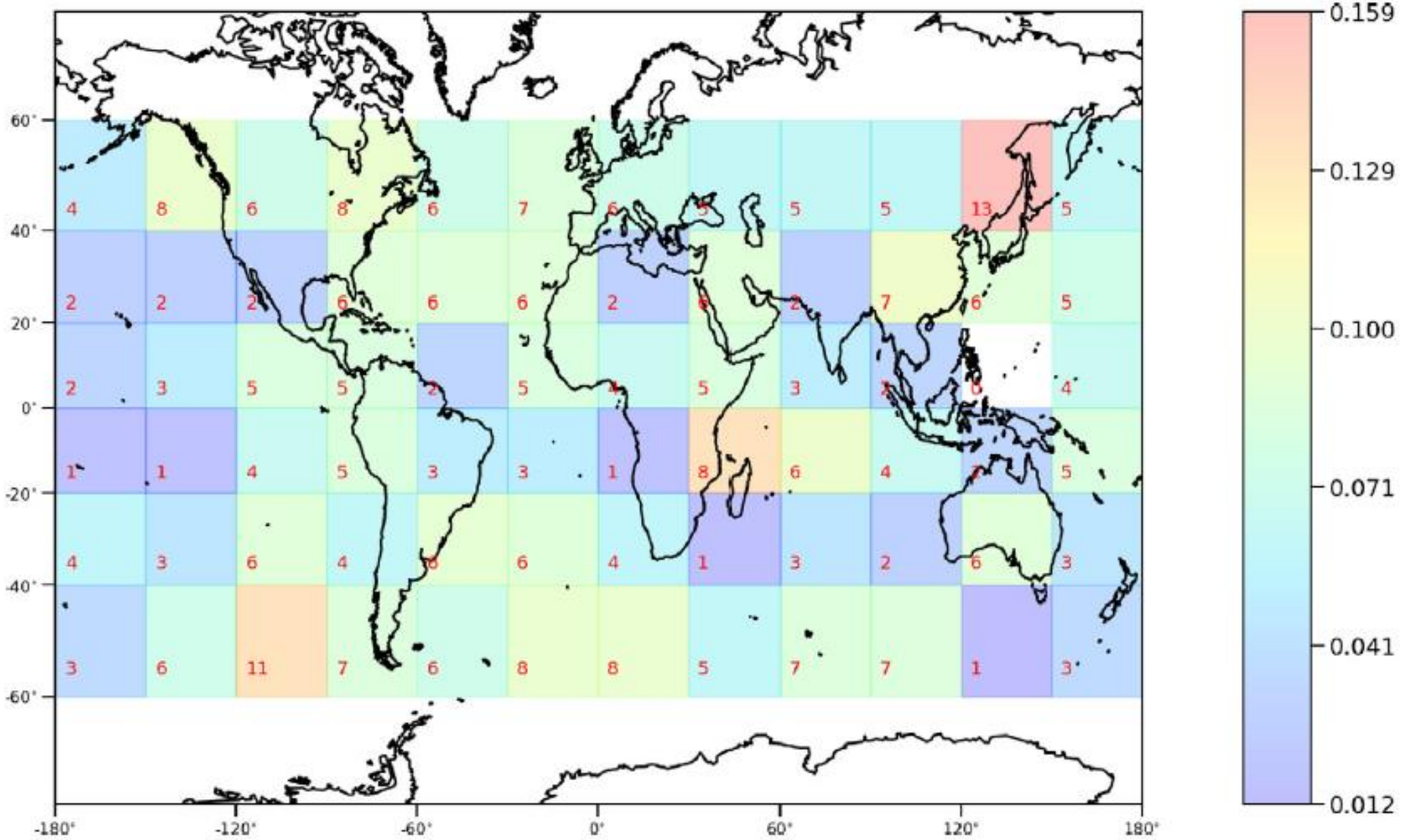
Event analysis:

Estimated particle count of 4124 over detector.

488 MeV deposited in detector (≈ 0.3 µGy)

Primary particle lower bound of 20 TeV




60°
40°
20°
0°
-20°
-40°
-60°
-180°
-120°
-60°
0°
60°
120°
180°
4 8 6 8 6 7 6 5 5 5 13 5
2 2 2 6 6 6 2 6 2 7 6 5
2 3 5 5 2 5 4 5 3 6 4
1 1 4 5 3 3 1 8 6 4 7 5
4 3 6 4 6 6 4 1 3 2 6 3
3 6 11 7 6 8 8 5 7 7 1 3
0.159
0.129
0.100
0.071
0.041
0.012
Events > 10% occupancy per acquisition day

detector ID	location	events	yearly rate	μGy/min, SAA
L05-W0246	NOD1	135	62.7 ± 5.4	2.407
G05-W0246	COLUMBUS	119	63.6 ± 5.8	1.788
D08-W0246	NOD3	155	68.9 ± 5.5	1.650
B08-W0246	LAB1	195	104.9 ± 7.5	0.831
I06-W0246	LAB1	194	109.3 ± 7.8	0.936
E04-W0246	JPM	263	125.4 ± 7.7	1.330
F08-W0246	CUPOLA	279	159.8 ± 9.6	0.898

1,340 in total, over about 2½ years (02/01/2019 to 09/30/2021),
equating to an average of 1 event per detector (mean area = 1.06 cm^2) every 3.75 days

There’s no “I” in “physycs”:

- **NASA JSC** – Martin Kroupa , Nic Stoffle, Stuart George, Martin Leitgab, Ryan Rios, Dan Fry, Ramona Gaza, Mena Abdelmelek, Sergiy Rozhdestvenskyy, Amir Bahadori, Eddie Semones, Catherine McLeod, Michael Ecord, Maddy Vandewalle, Scott Wheeler, Aaron Schram, Diego Laramore, Andy Castro
- **University of Houston** - Larry Pinsky, Son Hoang, John Idarraga, Toni Empl
- **CERN** - Xavier Llopart Cudie, Jerome Alozy, Lukas Tlustos, Rafael Ballabriga, Michael Campbell
- **Advacam** - Jan Jakubek, Martin Jakubek, Pavel Soukup, Carlos Granja, Daniel Turecek
- **IEAP** - Stanislav Pospisil, Zdenek Vykydal
- **HIMAC -** Satoshi Kodaira, Hisashi Kitamura
- **NASA Space Radiation Laboratory** - Mike Sivertz, Adam Rusek,
- **Brookhaven National Laboratory Tandem** - Dannie Steskie, Chuck Carlson