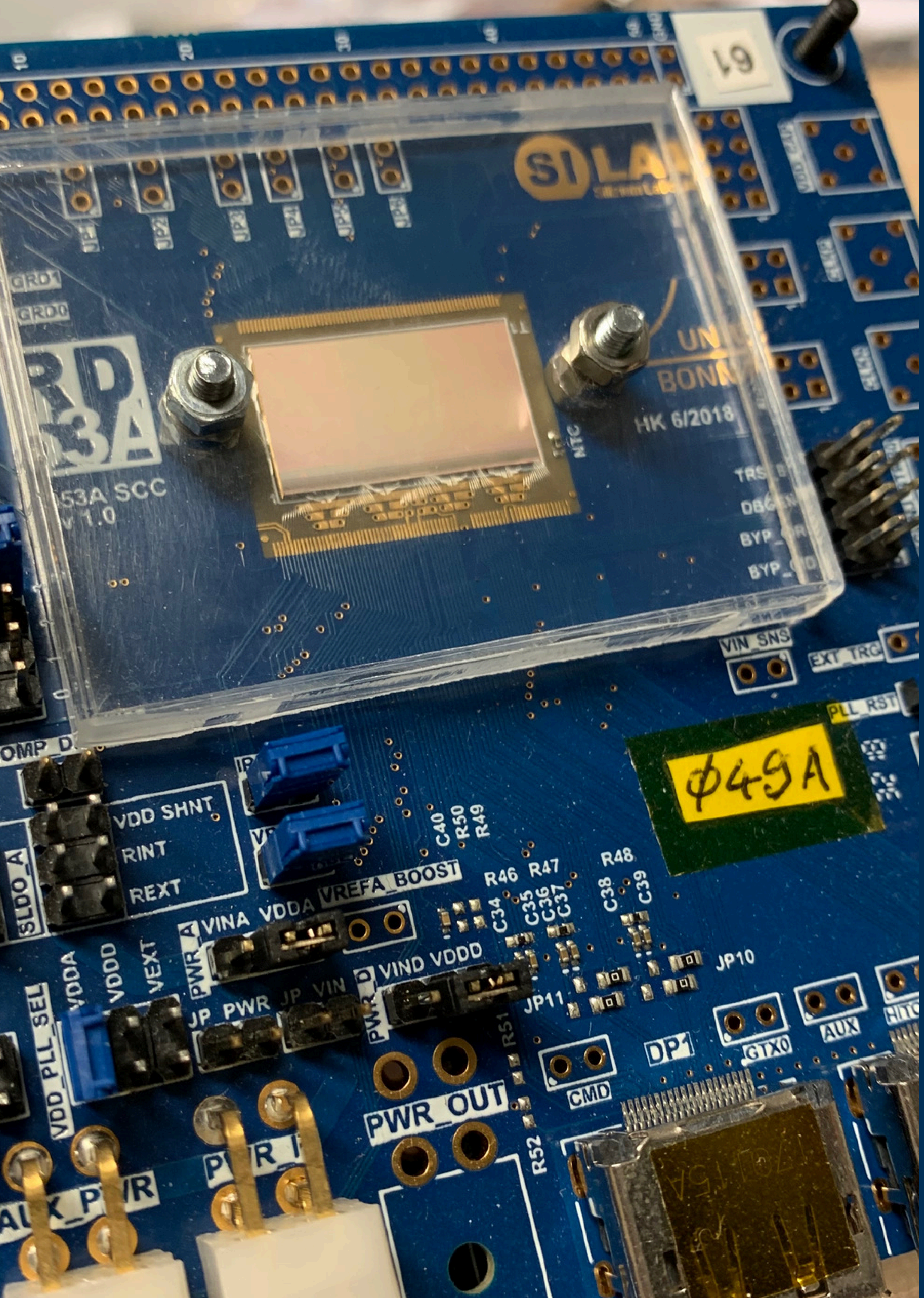


Simulating a cosmic ray detector for physics outreach projects

Stewart Rasmusen
Supervisor: Dr James Howarth

Outline

- Motivation
- Background
  - Cosmic rays
  - Muons
  - Sensor
- Process
- Results
- Conclusion

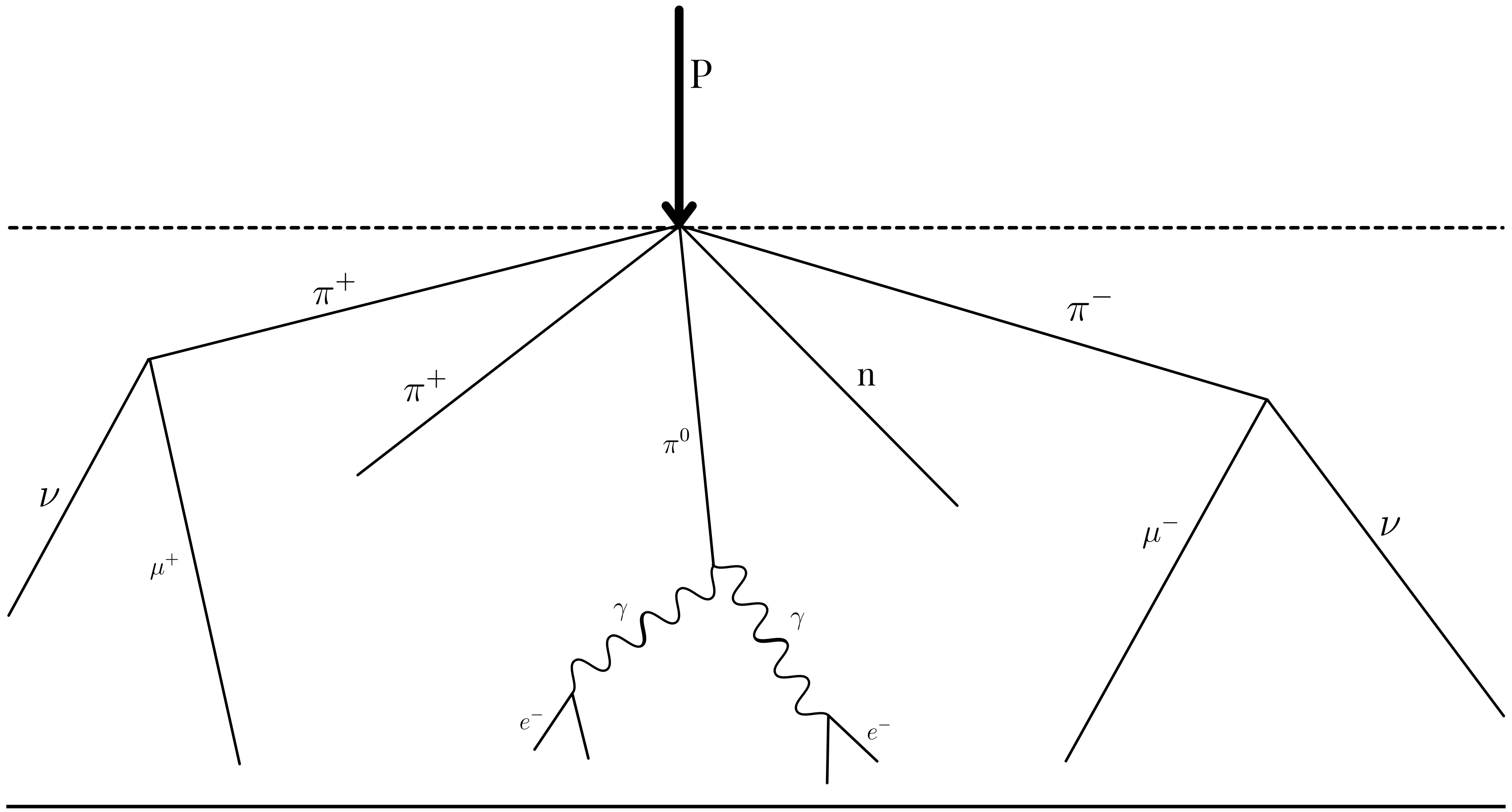
Motivation

- The LHC at CERN will soon undergo an upgrade to increase the luminosity.
- Part of the inner tracker system (ITk) has been constructed at the University of Glasgow and uses silicon sensors.
- Would there be enough cosmic flux to use surplus sensors for an outreach detector?
  - A successful detection rate would be 10-50 detections per minute.

Aim: To develop an accurate simulation of this detector in order to determine the feasibility of the set up for outreach projects

Background - Cosmic Rays

- Discovered in the early 1900's
- High energy jets of particles from stellar events in the Milky Way.
- Primarily made up of protons.
- Impact atmosphere and trigger particle cascade.
- Importantly there is Kaon and Pion production.



Background - Muons

- Produced by the decay of Kaons and Pions, life time of 12 and 26ns respectively.
- Muons decay with lifetime of 2.2µs.
- Muons have time to travel ~15km to surface due to time dilation.
- Are readily available and easy to detect with silicon sensors.
- Charged particles about 200 times the electron rest mass.

$$\kappa^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu})$$

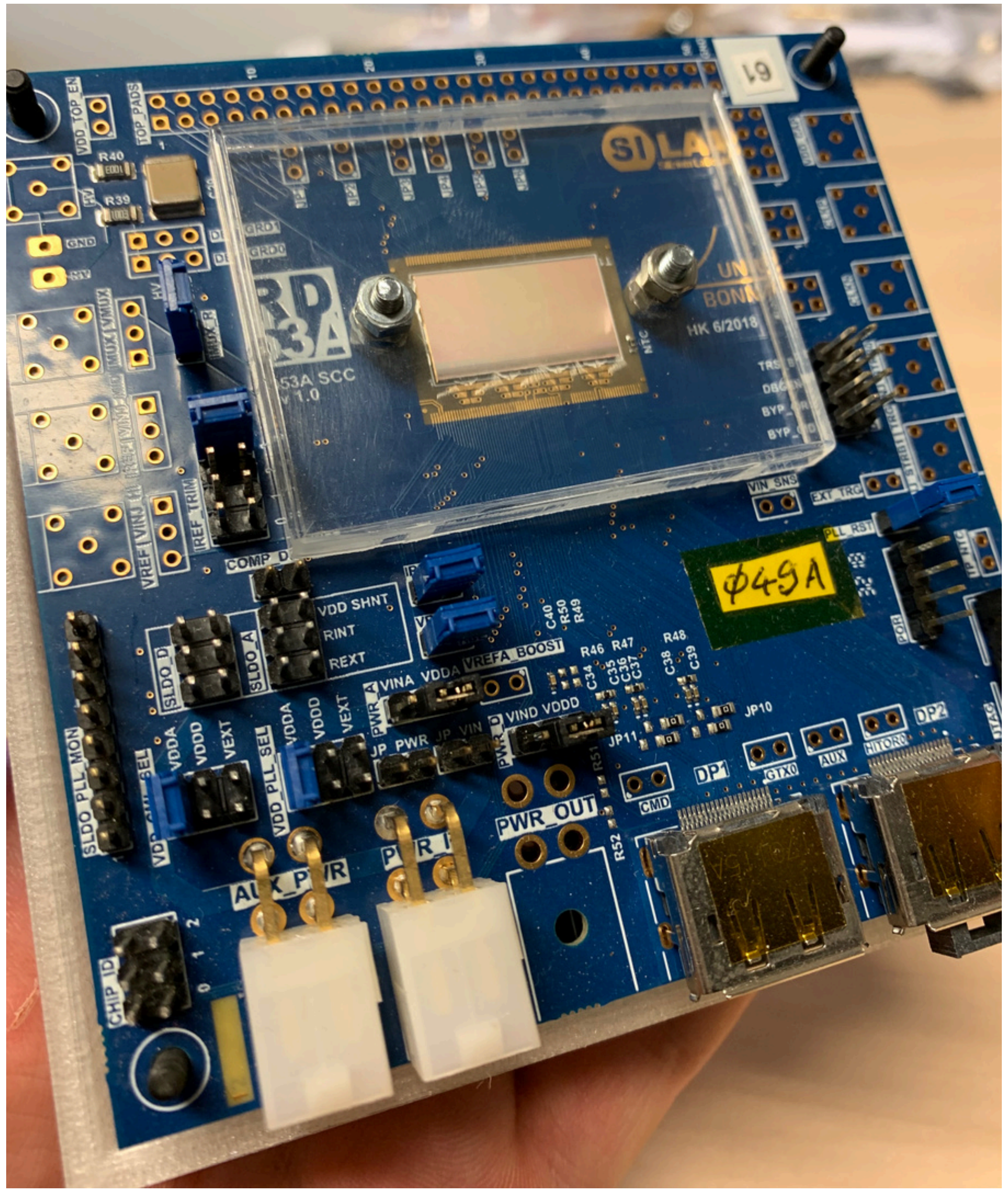
$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu})$$

[1]

[1] - Bindi P 2023 Cosmic Ray Physics:An Introduction to The Cosmic Laboratory (Taylor& Francis) ISBN 978-1-00318138-5

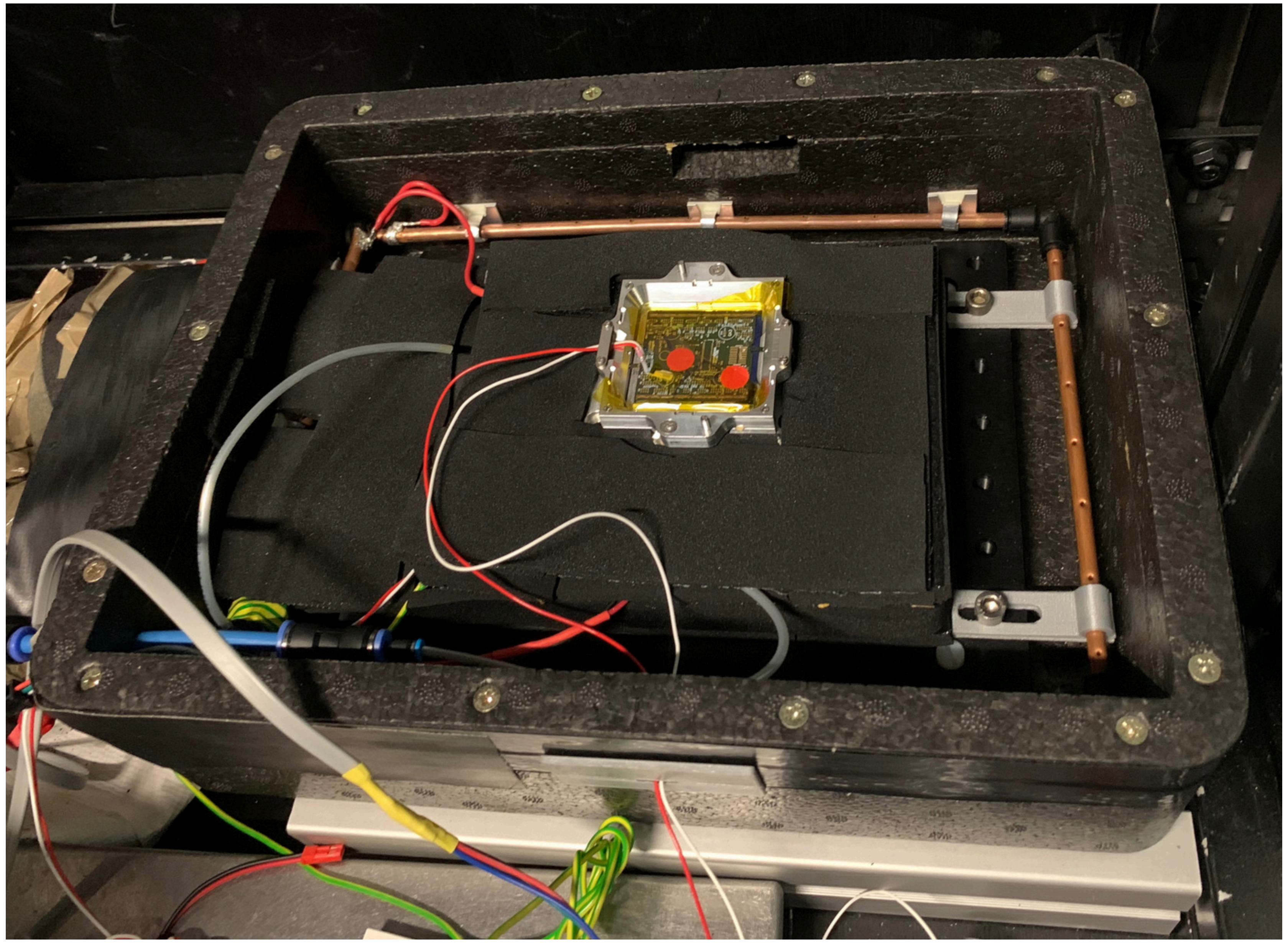
Background - Sensor

- RD53A silicon sensor is prototype for ITkpix which will be used as part of the Inner Tracker upgrade at ATLAS.
- 1cm x 2cm chip
  - 400 x 192 Pixels
- Designed for detection of charged particles.
- Built into simulation environment.



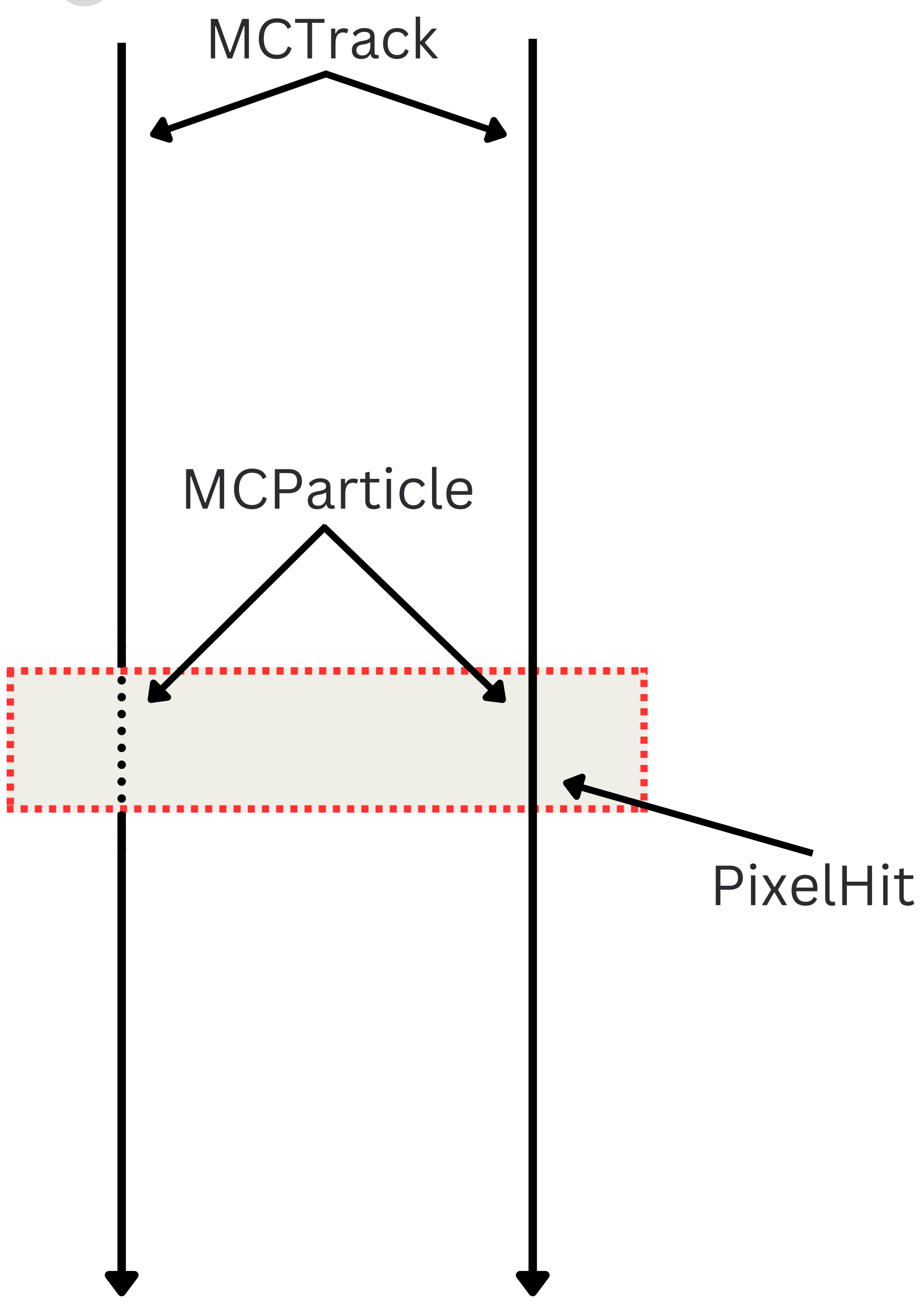
Background - Detector

- 2 x 4 arrangement of chips
- ITkpix sensor is 4cm x 4cm square
  - ‘Quad’
- Quality control including X-ray testing



Process - Allpix Squared

- We chose to use Allpix as it can accurately simulate a variety of particles and sensors.
- We used DepositionCosmics module to set up a natural muon flux through a vacuum.
- Events follow MCTrack one at a time.
- If particle enters sensor volume a MCParticle is created.
- If the particle is detected, we get a PixelHit.
- All data is stored in a ROOT file.



User Workshop

University of Glasgow

Process - Simualtion Development

- Assumed latitude of 56°
- Up to 5,000,000 events generated
- Initially we used a 'large strip' sensor
    - Area of 0.3455 m^2
- This was then replaced with the RD53A sensor
    - Area of 3.84×10^{-4} m^2

```
[ElectricFieldReader]
name ="dut_0","dut_1","dut_2","dut_3","dut_4","dut_5","dut_6","dut_7"
model = "linear"
bias_voltage = -100V
depletion_voltage = -50V #
output_plots = true

[GenericPropagation]
propagate_holes = false
temperature = 293K
charge_per_step = 10
output_plots = true

[SimpleTransfer]
output_plots = true
max_depth_distance = 5um

[DefaultDigitizer]
name = "dut_0","dut_1","dut_2","dut_3","dut_4","dut_5","dut_6","dut_7"
electronics_noise = 50e
threshold = 1500e #
threshold_smearing = 200e
qdc_smearing = 50e
qdc_resolution = 1 # ATLAS strips have only binary hit info
output_plots = 1
```

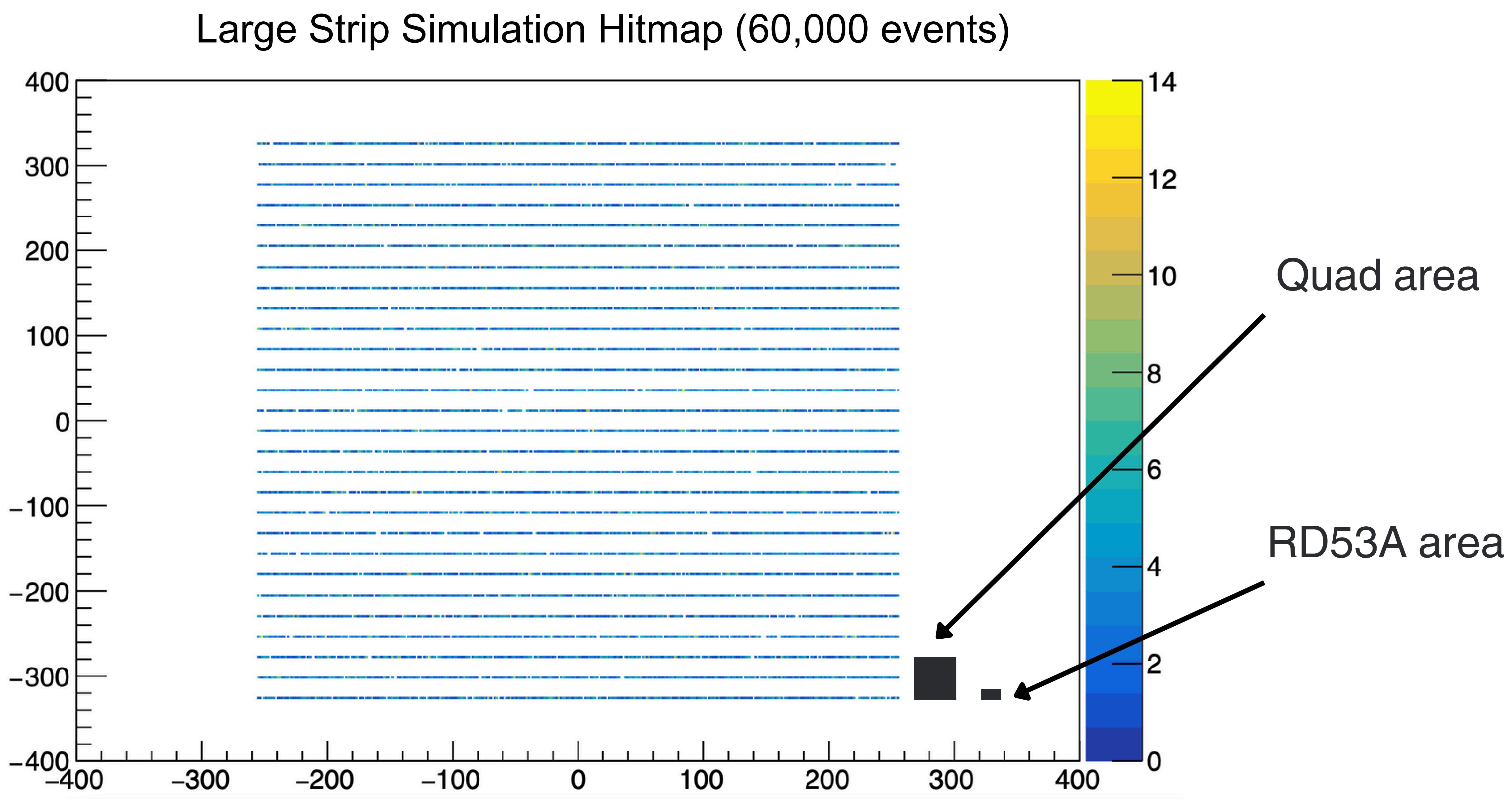
Process - Analysis

- Python scripts were written to calculate the muon flux, detector efficiency, and produce hitmaps.
- Testing was initially conducted with a large strip sensor.
- Simulations with up to 8 RD53A sensors and 5,000,000 events were conducted.

```
p = 0
h = 0
for i in tqdm(range(total_events)):

    tree_particle.GetEntry(i)
    tree_track.GetEntry(i)
    tree_hits.GetEntry(i)
    j = -1

    branch = tree_particle.GetBranch("dut_0")
    branch_part = getattr(tree_particle, branch.GetName())

    if len(branch_part)==0:
        continue

        for particle in tree_particle.dut_0:
            if particle.isPrimary() == True:

                j=0
                startPoint = particle.getLocalStartPoint()
                endPoint = particle.getLocalEndPoint()
                direction = startPoint - endPoint
                direction = direction / direction.z()
                track = (Track([startPoint.x(), startPoint.y(), startPoint.z()],
                    [direction.x(),direction.y(),direction.z()], 0, 0, 0, 0))

                particle_hist.Fill(track._zenithAngle())
                p = p+1
```

Results - Simulated Large Strip hitmap

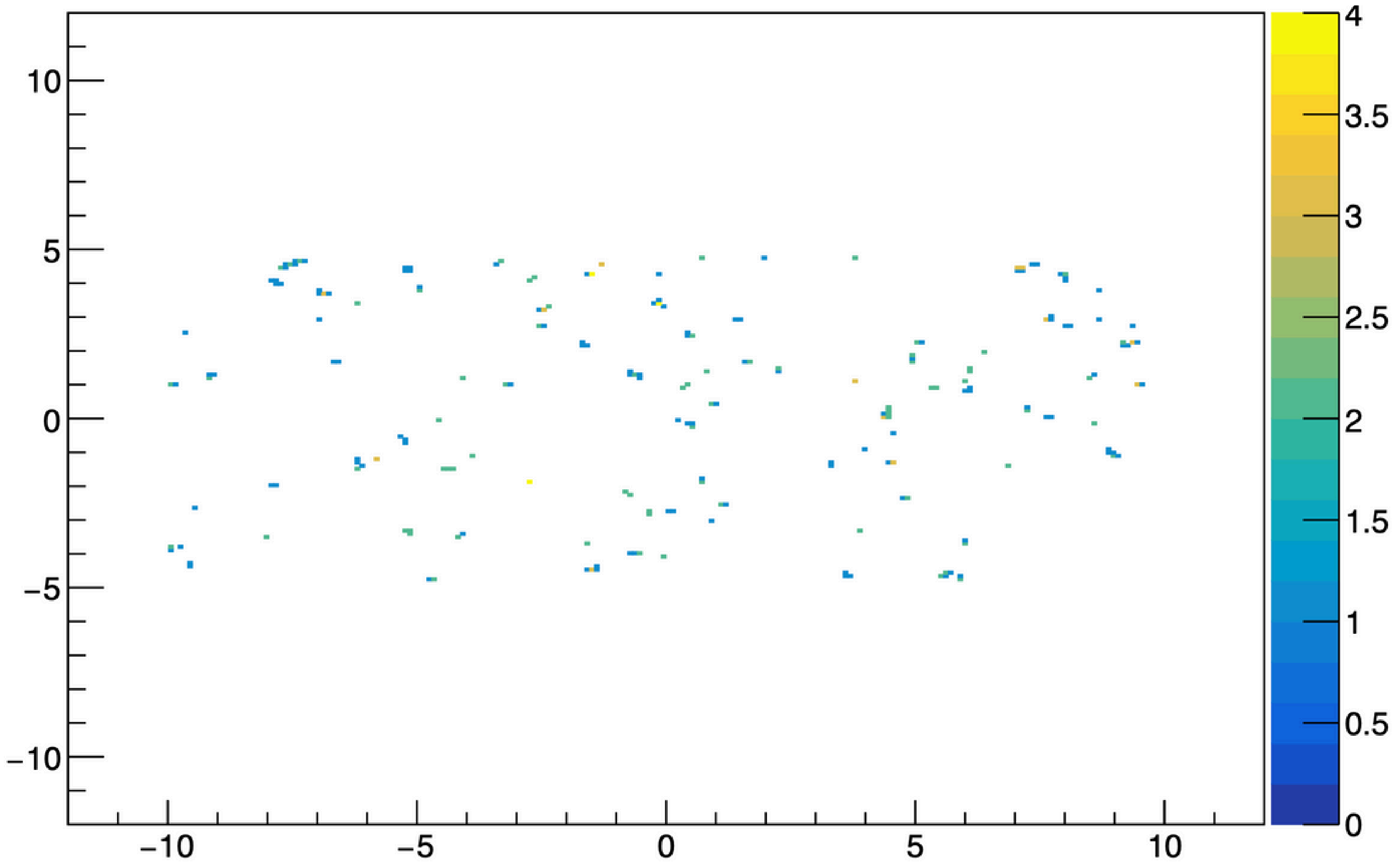
- 60,000 events
- ~506s
- 27,435 hits



Results - Simulated RD53A hitmap

- 500,000 events
- ~4,232s (~70 minutes)
- 318 hits
- ~5 hits per minute

RD53A Simulation Hitmap (500,000 events)



Results - Real Hitmap

Hitmap from real cosmics (3,600s)

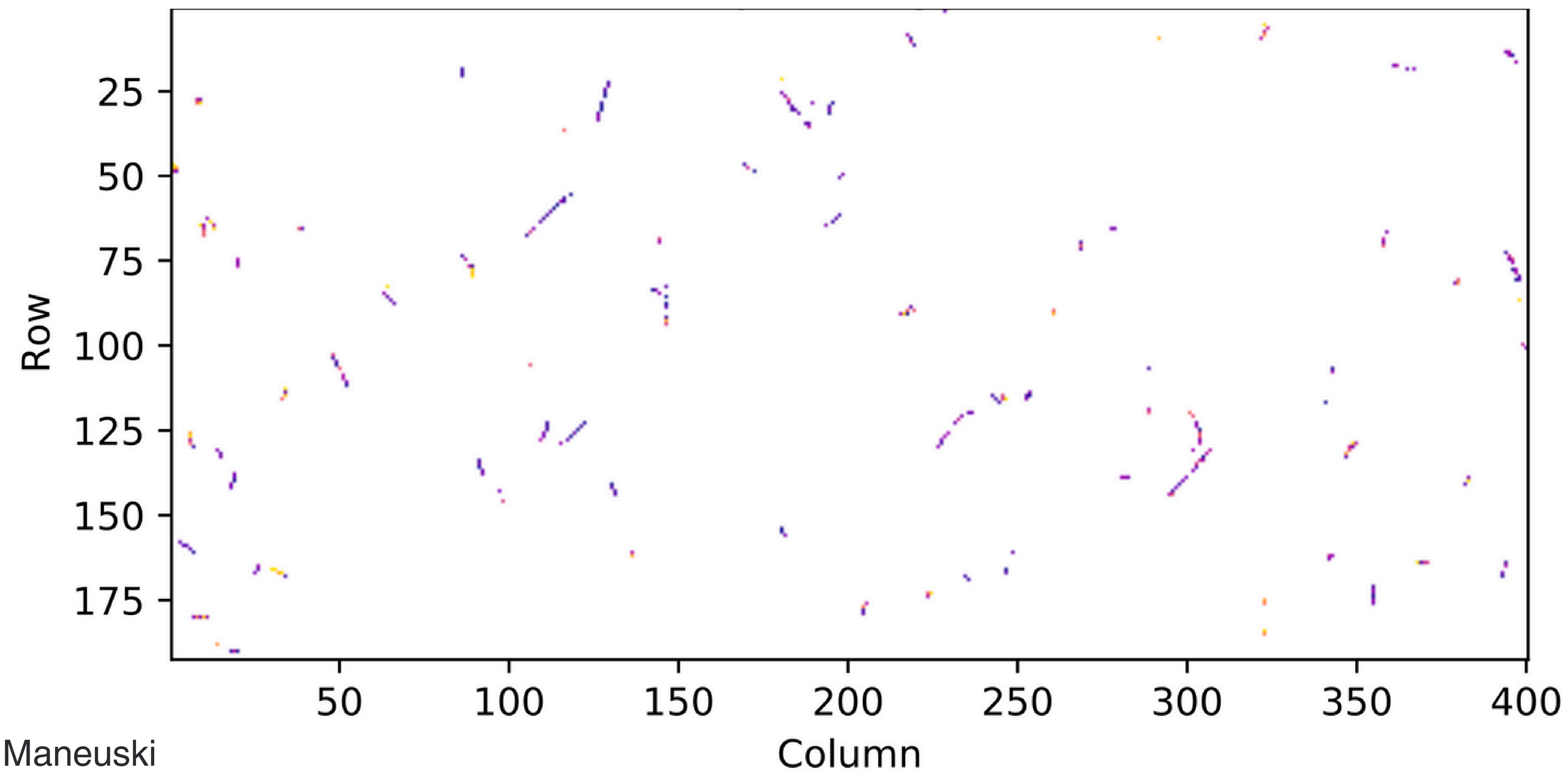


Image sourced by Dr Dima Maneuski

Results - Real data

- 3,600s
- Most Pixels don't get hit
- ~320 hits
- ~6 hits per minute

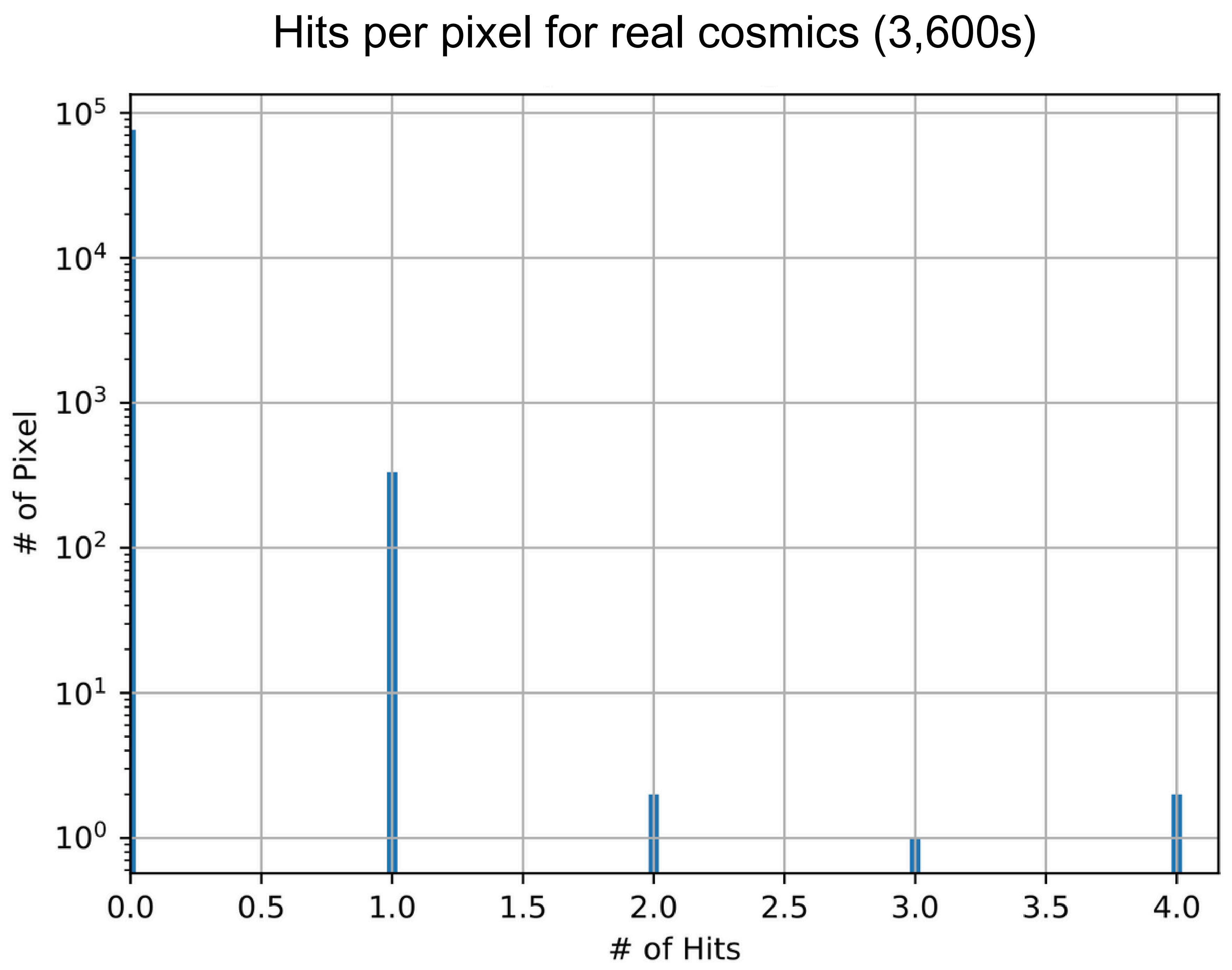
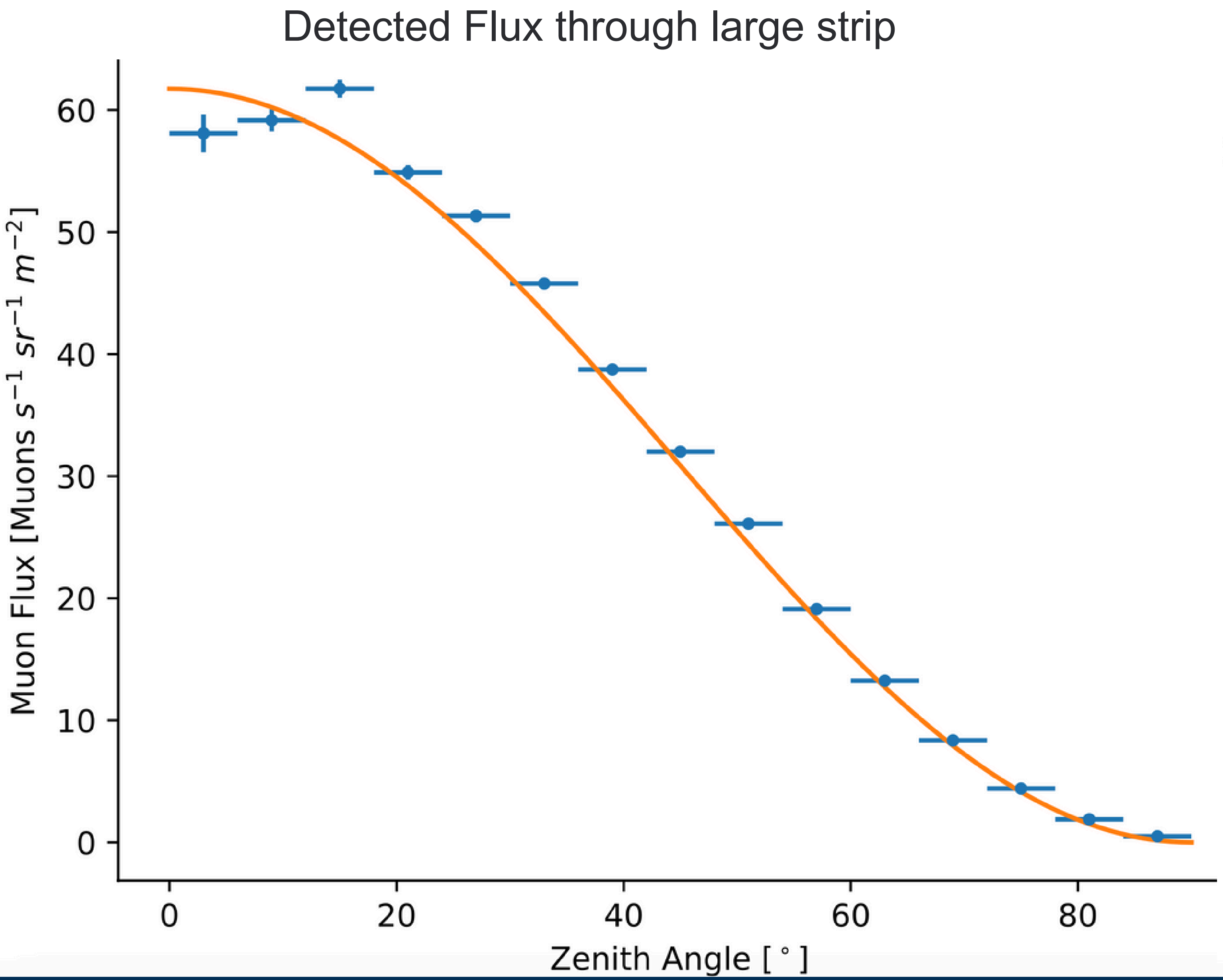
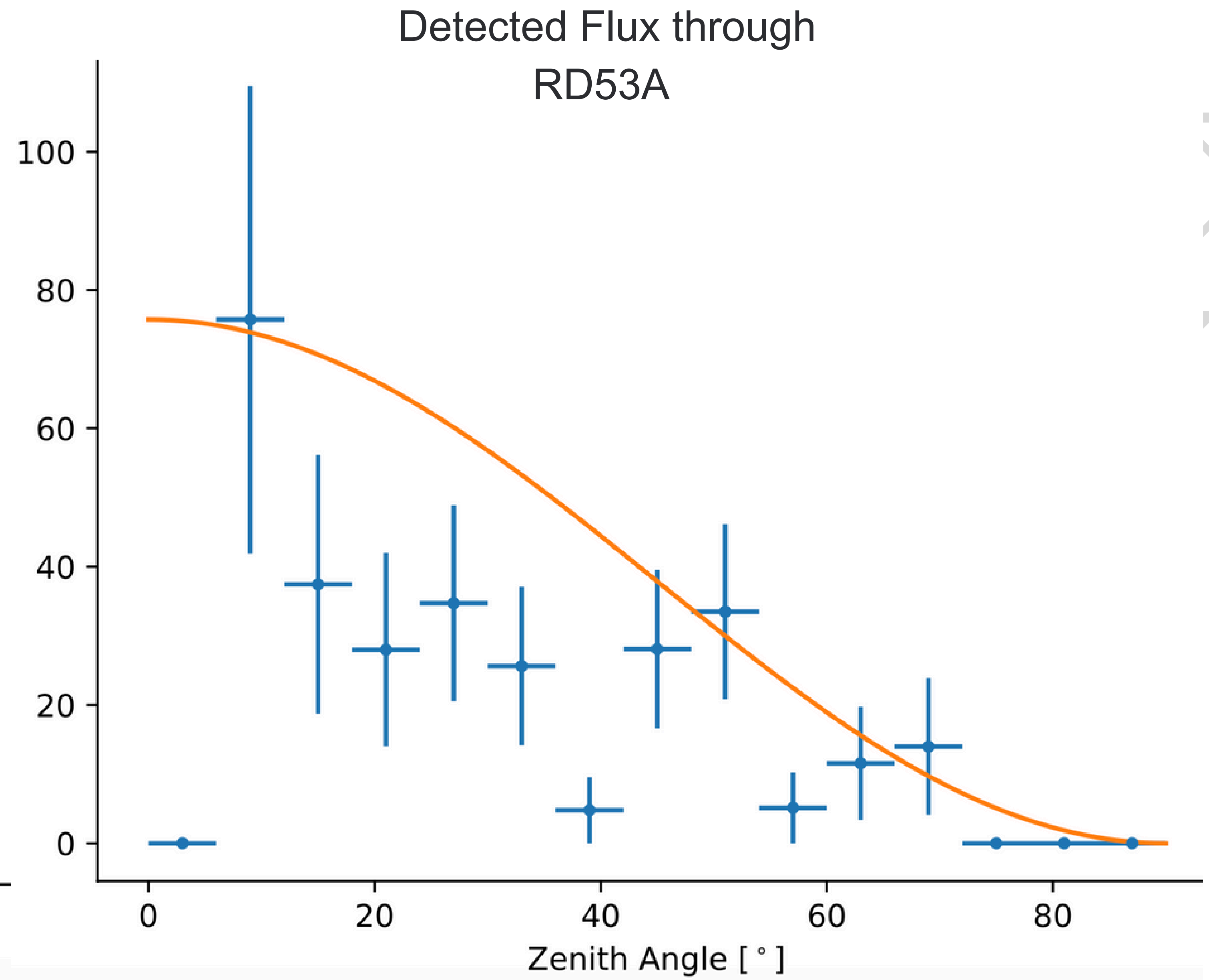


Image sourced by Dr Dima Maneuski

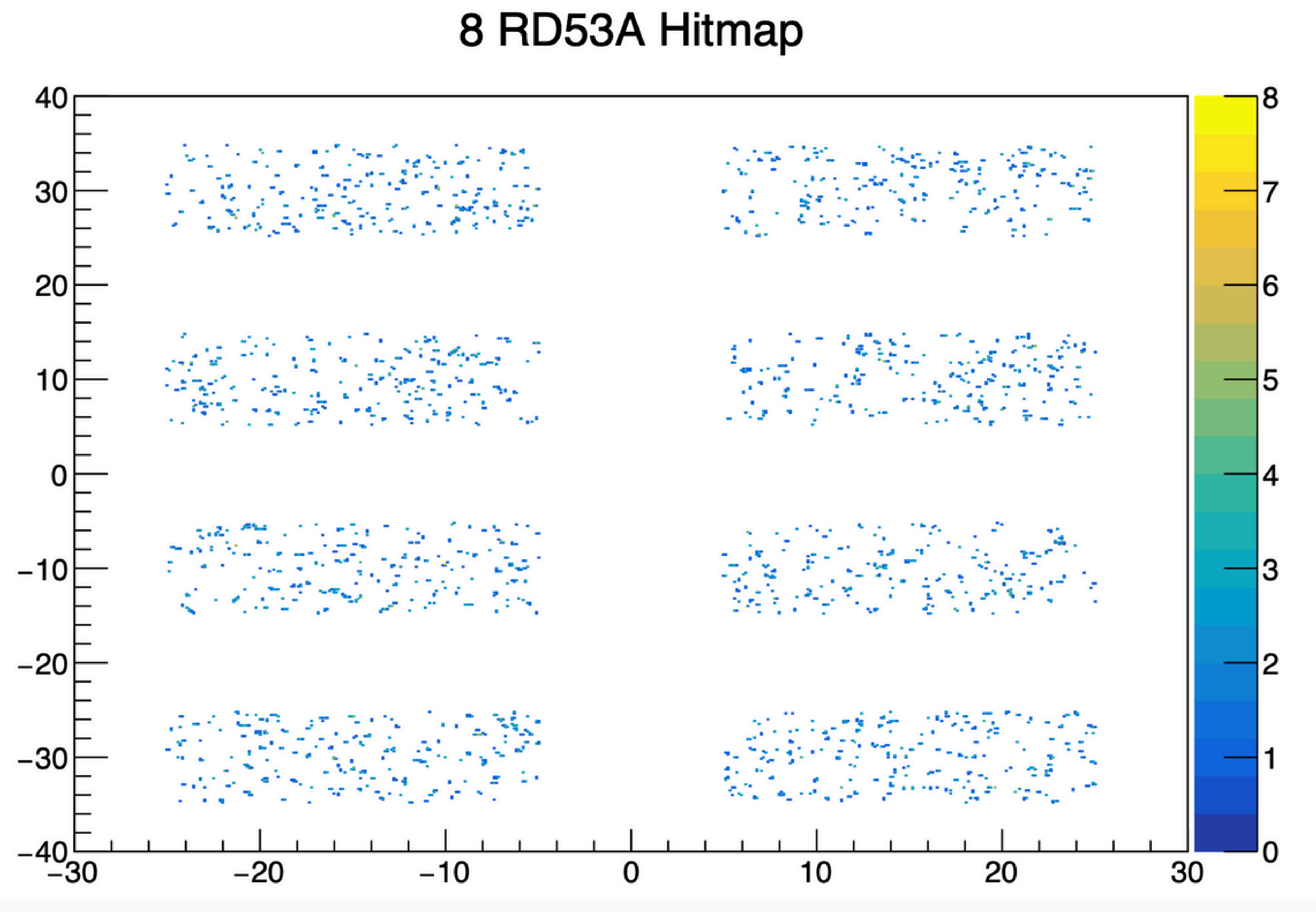
Results - Detected Flux



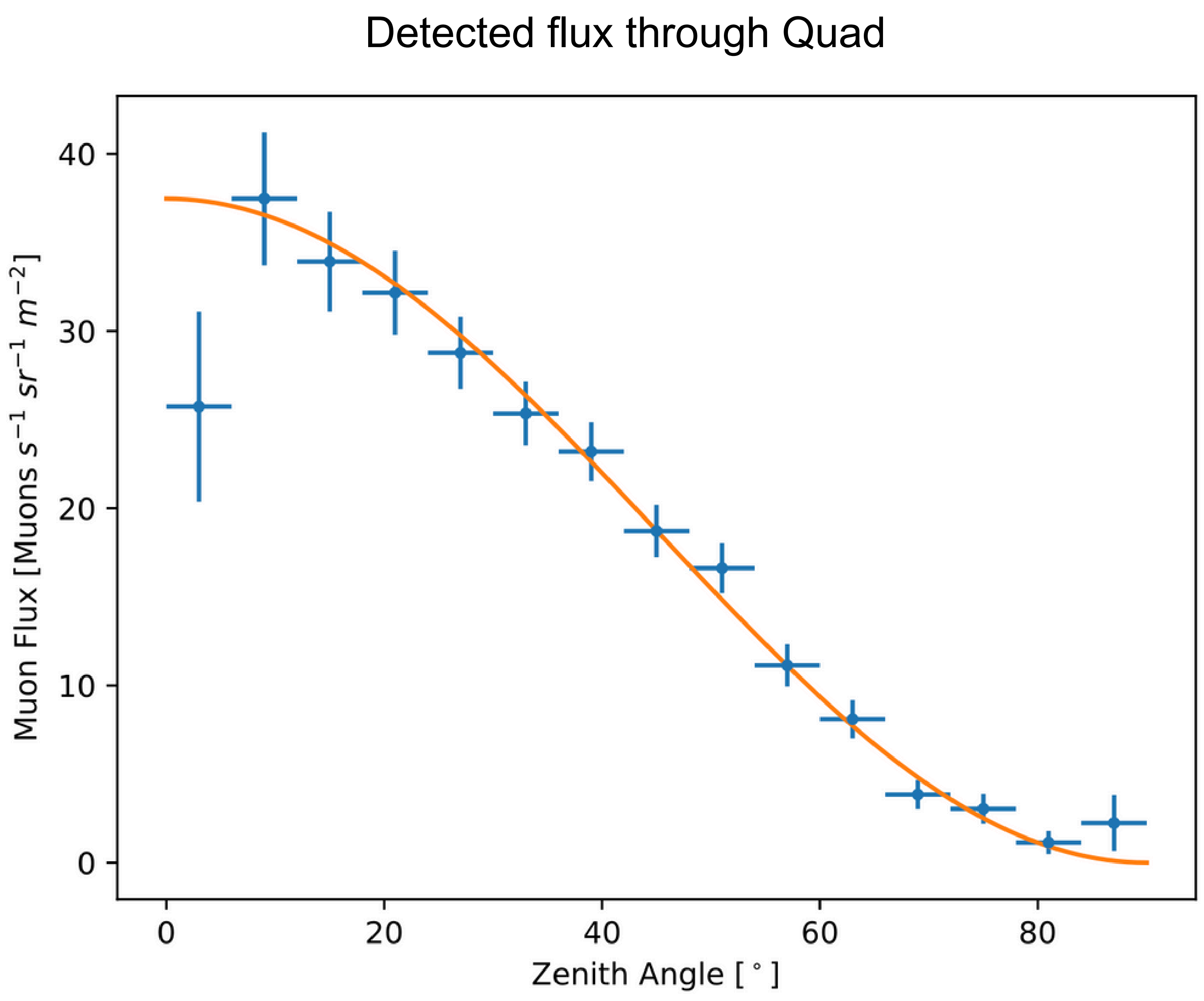


Results - Quad

- 1,000,000 events
- ~8,480s (~141 minutes)
- 5,123 hits
- ~37 hits per minute



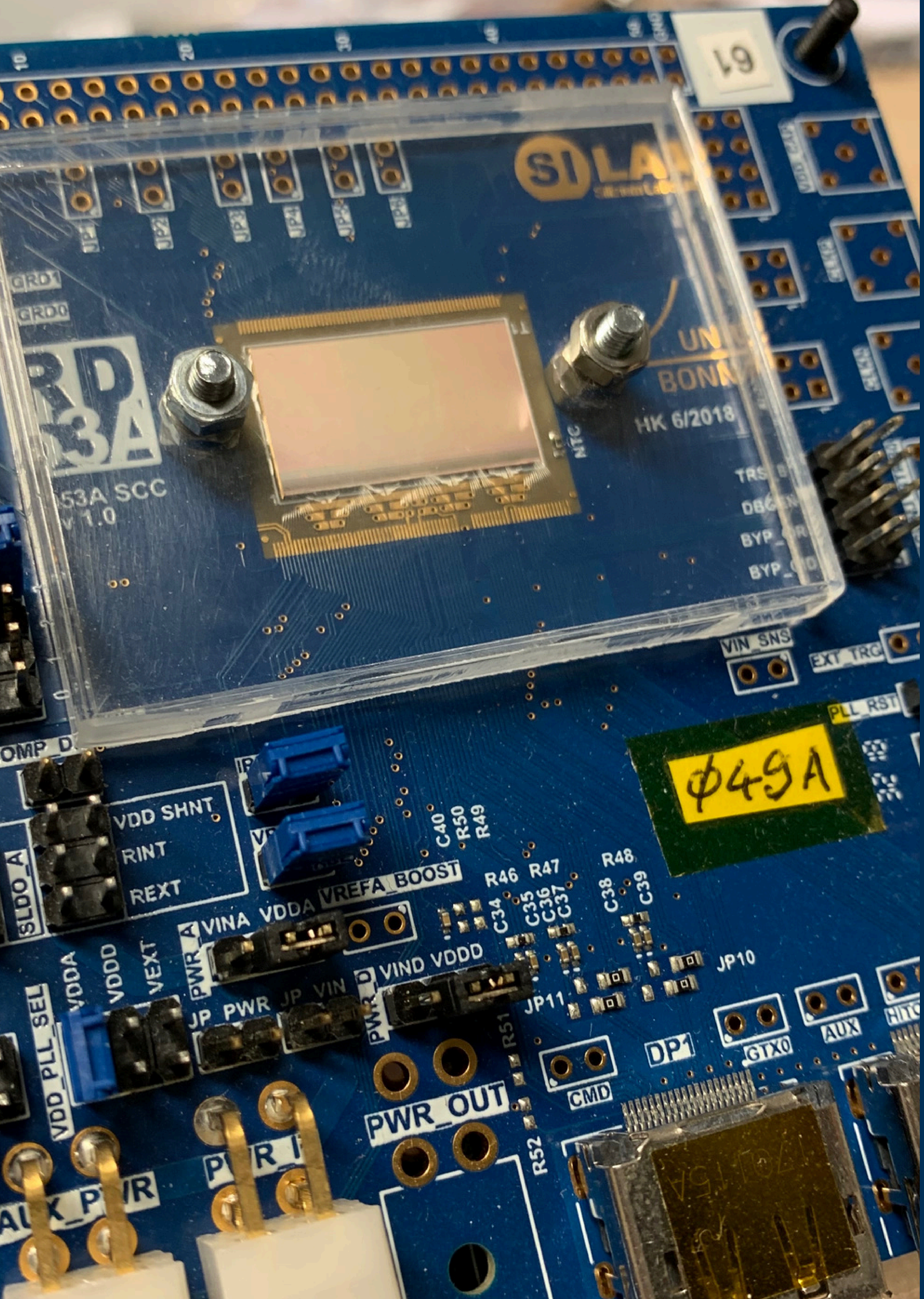
Results - Quad



Conclusions

- The natural muon flux is high enough at ground level to build a successful detector
- The simulation shows similar hitmaps and number of detections to real data
- There is evidence to say that the RD53A could be used for this outreach detector but we need a Quad set up.
- In future we would like to simulate and construct a 2 layer ITk pix detector in order to show tracking

Image sourced by Dr Dima Maneuski



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Thank you

Stewart Rasmusen