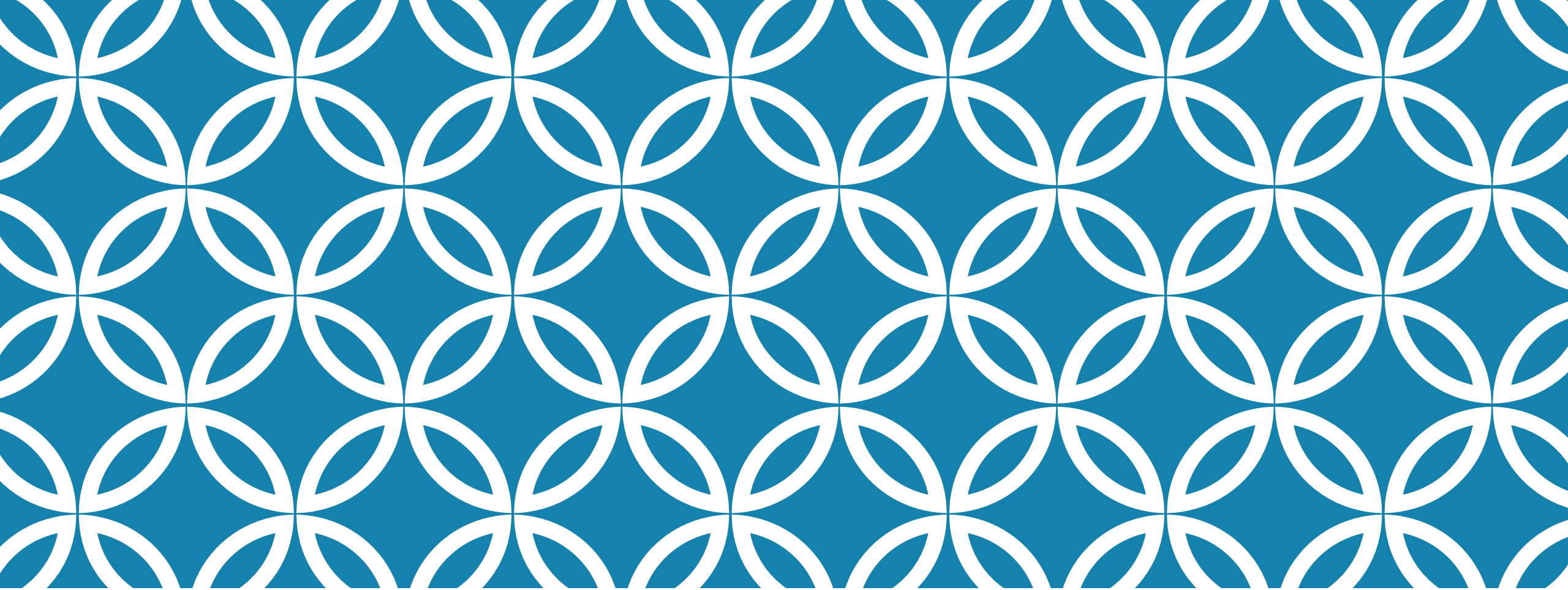


TELESCOPE-SENSOR ALIGNMENT USING HOUGH TRANSFORM

Michal Elad

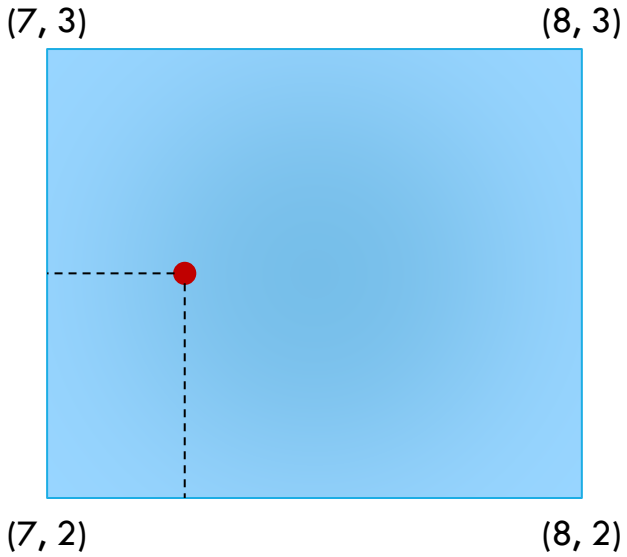
29 / 11 / 23

GOAL

Translate global position given by the telescope to a local position on the sensor.

Local coordinate system agreed – units of pad length

- e.g. (7.25, 2.5) is located as such pad (7, 2):



METHODS

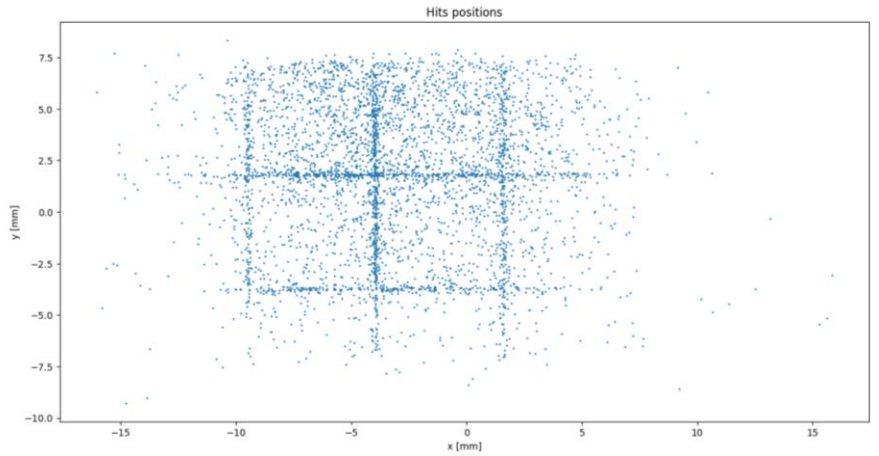
- Hough Transform – in this presentation
- Scan and search max hits in pad – presentation by Kirill

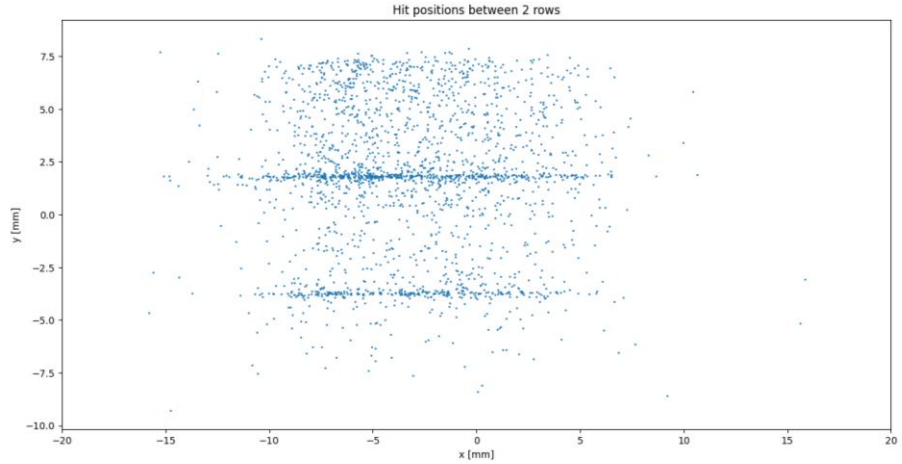
REMINDER

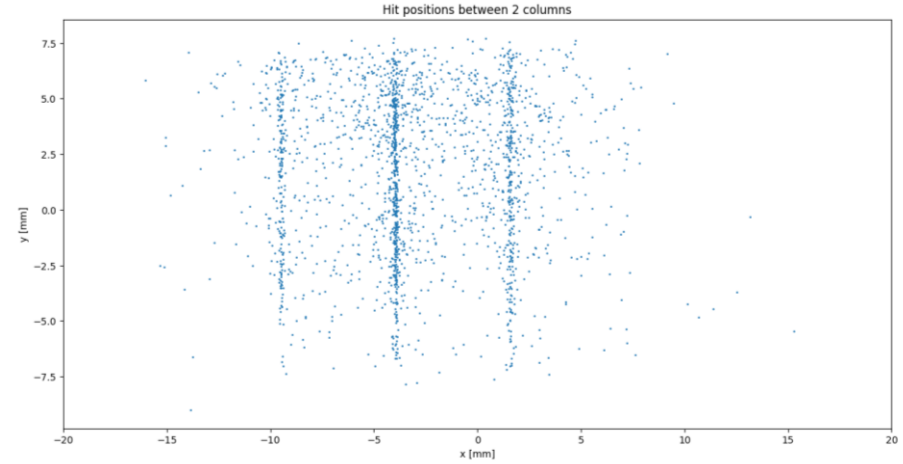
The idea – look at hits in between pads and detect these pad edges.

Given the alignment of a single horizontal edge and a single vertical one, you're done ✓

→ Events chosen – single electron and exactly 2 adjacent pads hits (either same row or same column).





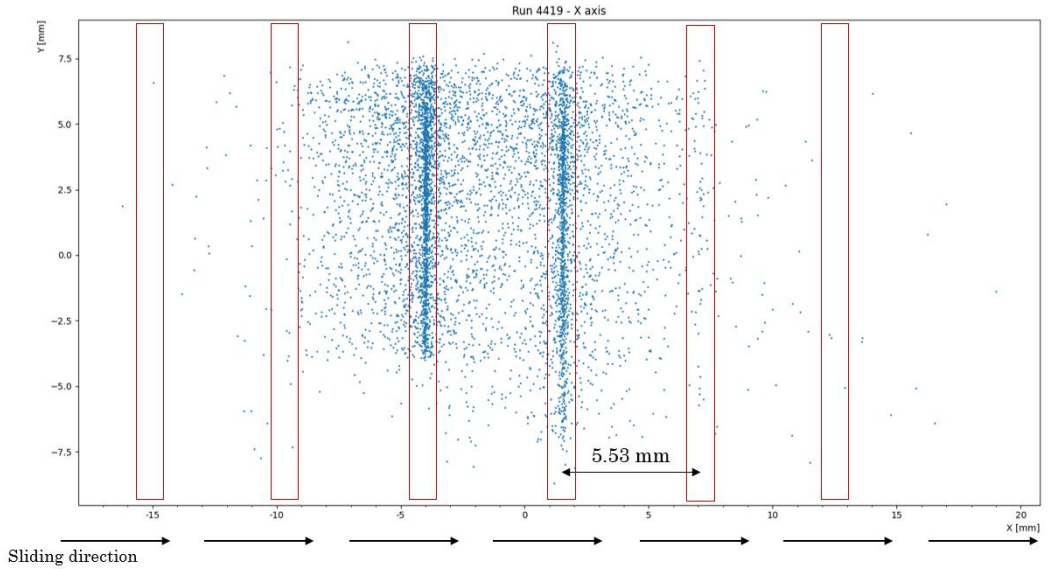


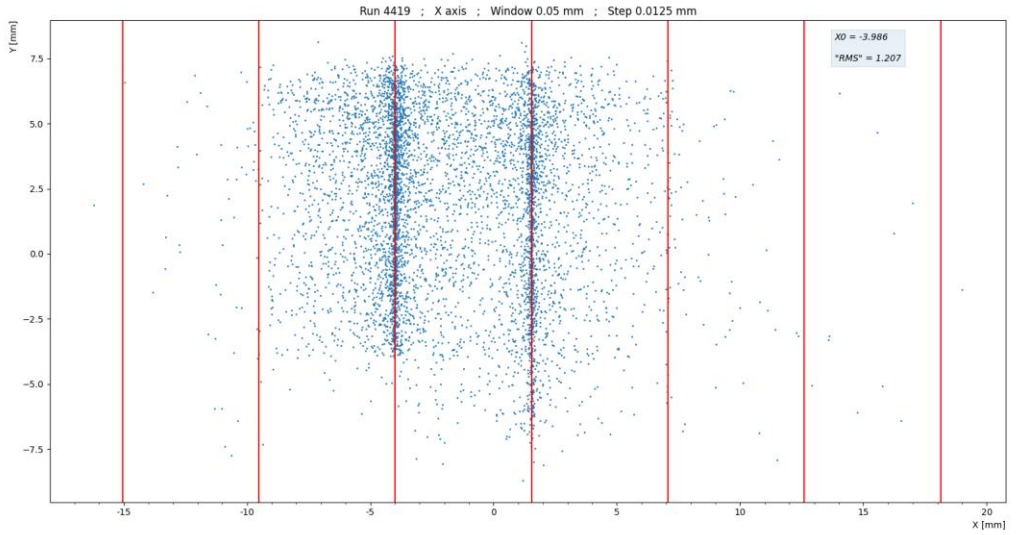
REMINDER

Previously showed an approach using sliding windows.

Seemed successful, but what if there is a rotation in the x-y plane?

Visualization





HOUGH TRANSFORM

- Shape detecting framework
- Used a slight variation of the original

Image and parameter space

variables

$$y = mx + b$$

parameters

variables

$$y - mx = b$$

parameters

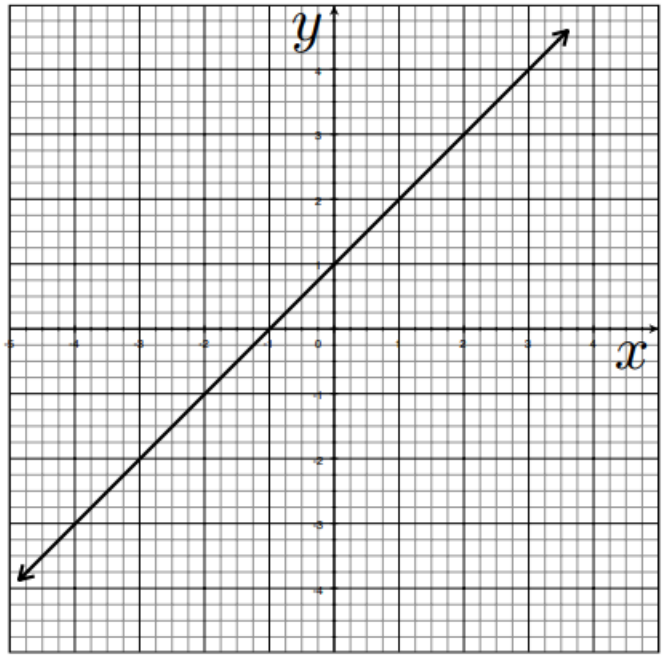
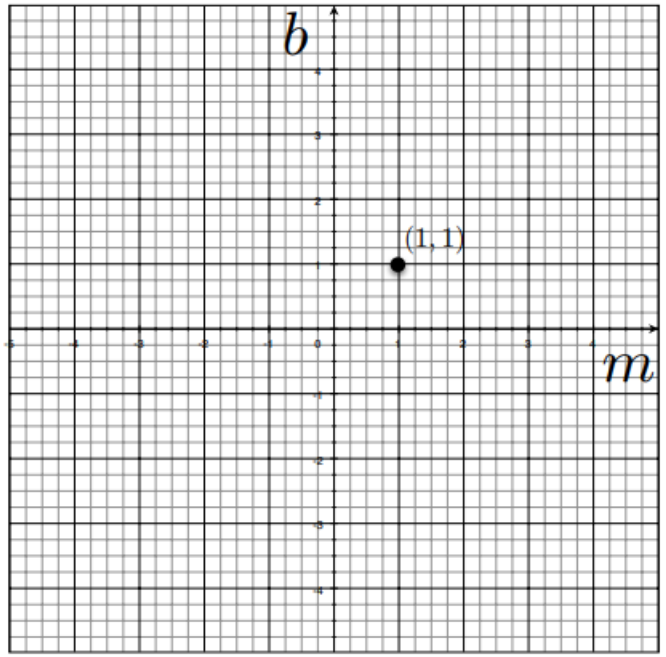


Image space

a line becomes a point



Parameter space

Slide taken from: https://www.cs.cmu.edu/~16385/s17/Slides/5.3_Hough_Transform.pdf

Image and parameter space

variables

$$y = mx + b$$

parameters

variables

$$y - mx = b$$

parameters

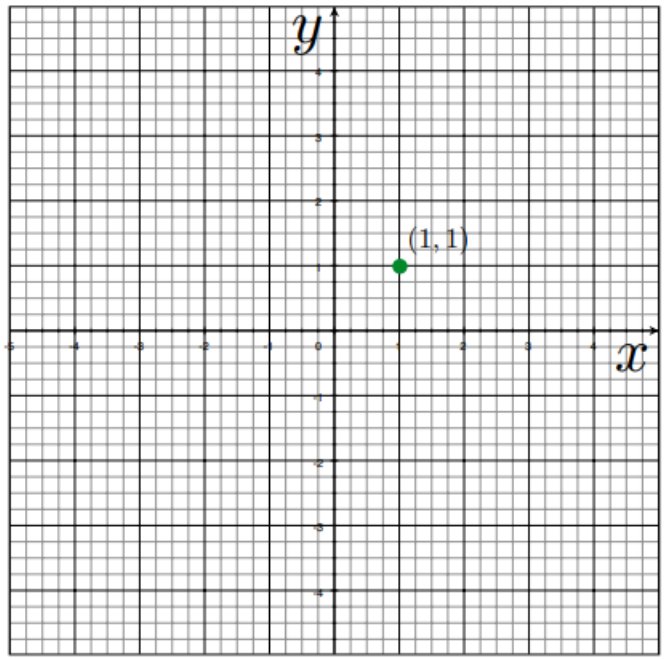
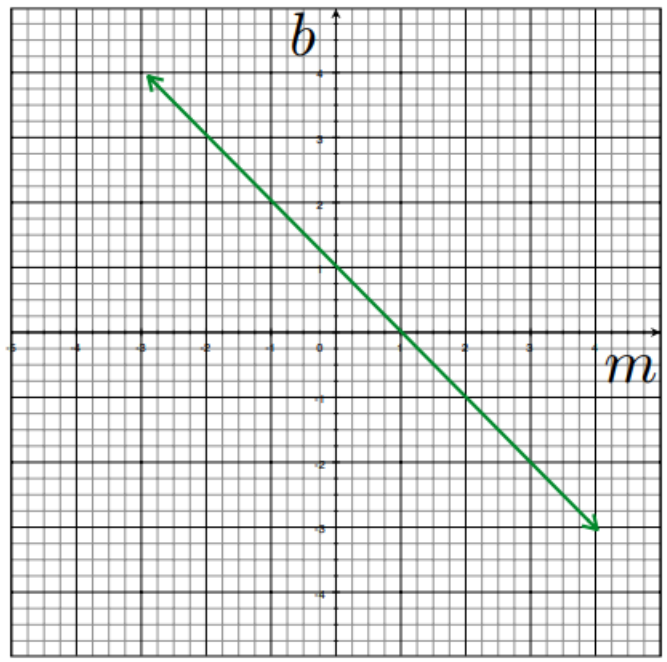


Image space

a point becomes a line



Parameter space

Slide taken from: https://www.cs.cmu.edu/~16385/s17/Slides/5.3_Hough_Transform.pdf

Image and parameter space

variables

$$y = mx + b$$

parameters

variables

$$y - mx = b$$

parameters

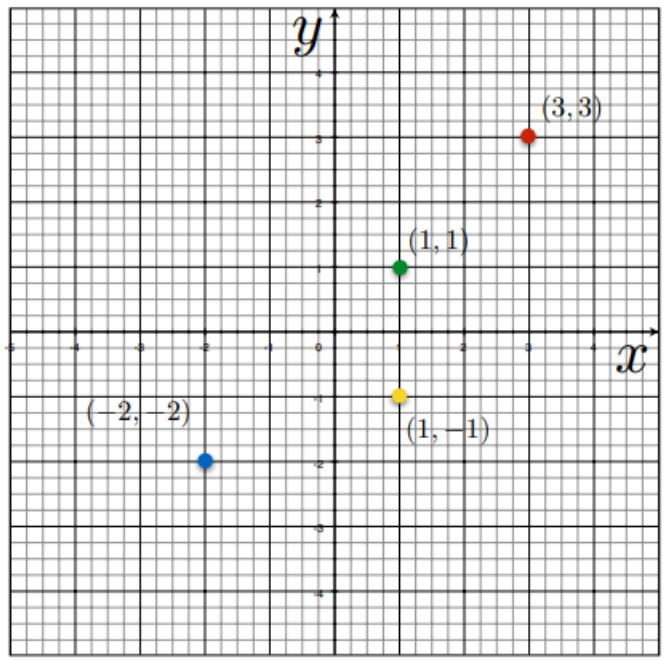
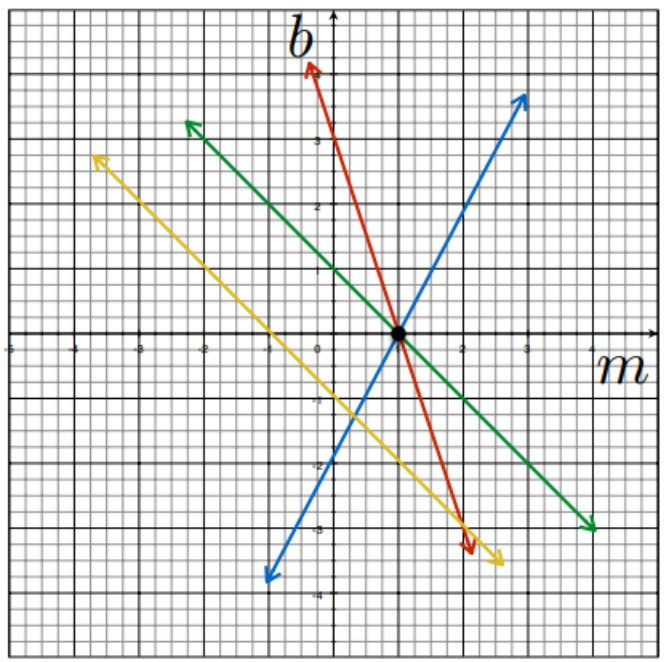


Image space

four points become ?



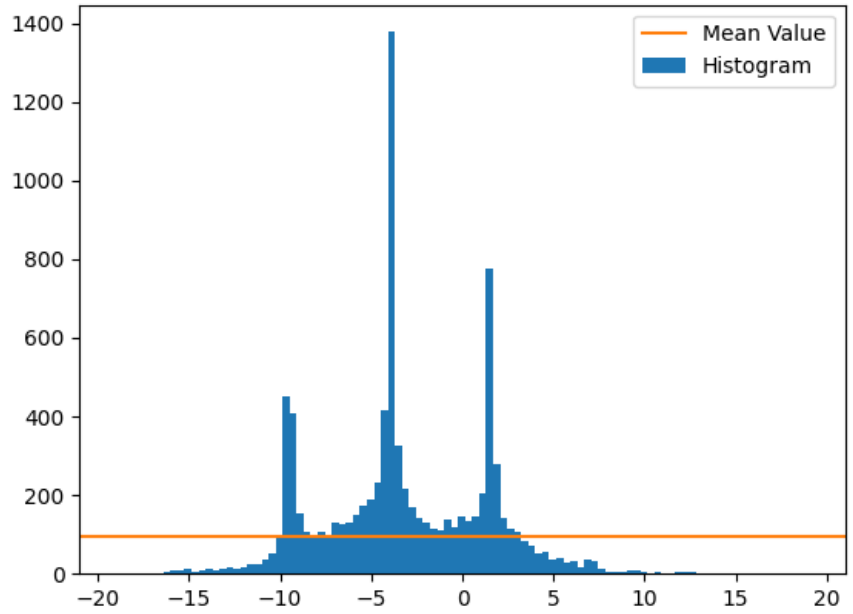
Parameter space

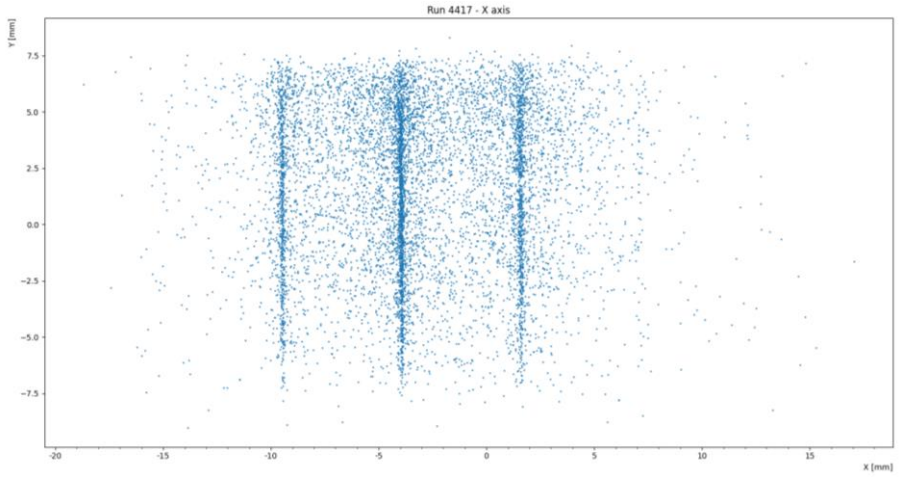
Slide taken from: https://www.cs.cmu.edu/~16385/s17/Slides/5.3_Hough_Transform.pdf

FIND RELEVANT AREA

The data is noisy, and we only want to find a single line.

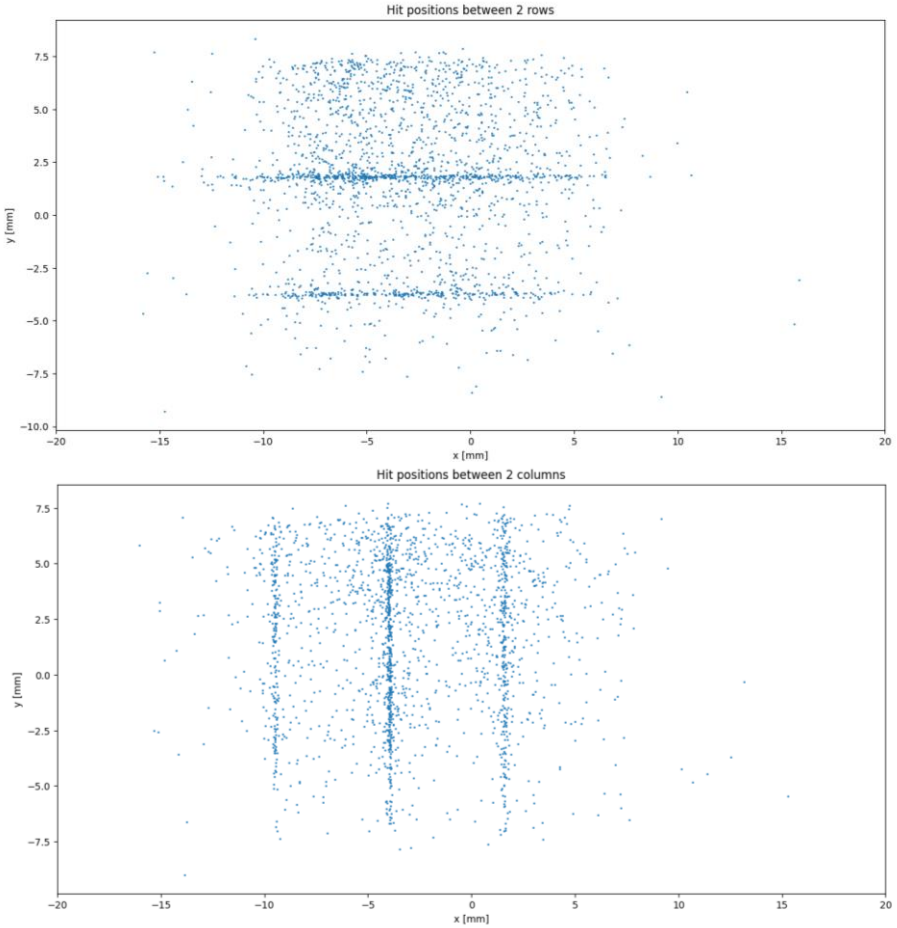
We don't to consider all points, so we first find an estimation for the edge position.





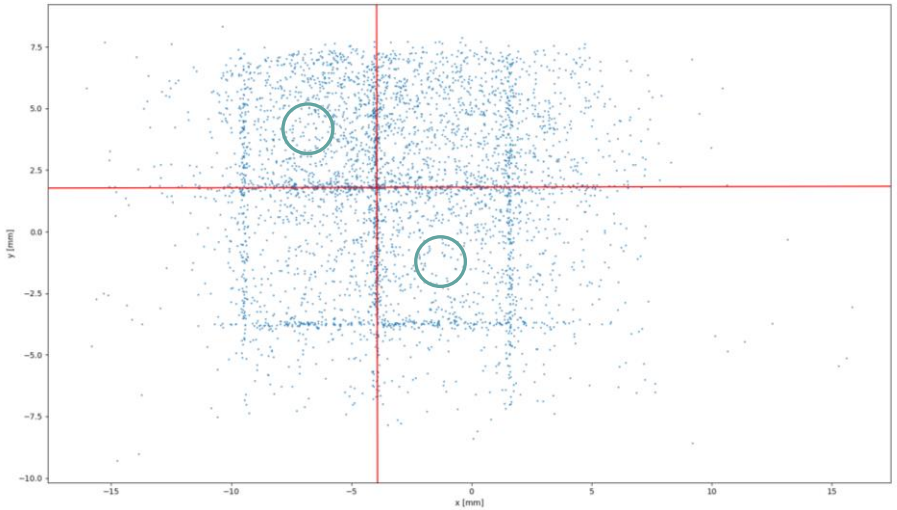
HOUGH TRANSFORM – OUR IMPLEMENTATION

- General idea (part 1):
  - Start with the horizontal edge
  - Consider the area of the edge with most points
  - Find line equation of each 2 far enough points: $y = mx + b$
  - Get a cluster in parameter space around the true values
  - Eliminate outliers and take CM values as the result
  - Repeat for the vertical edge
  - Use polar coordinates (infinite slope)
  - Search for r only since θ is already known (perpendicular)



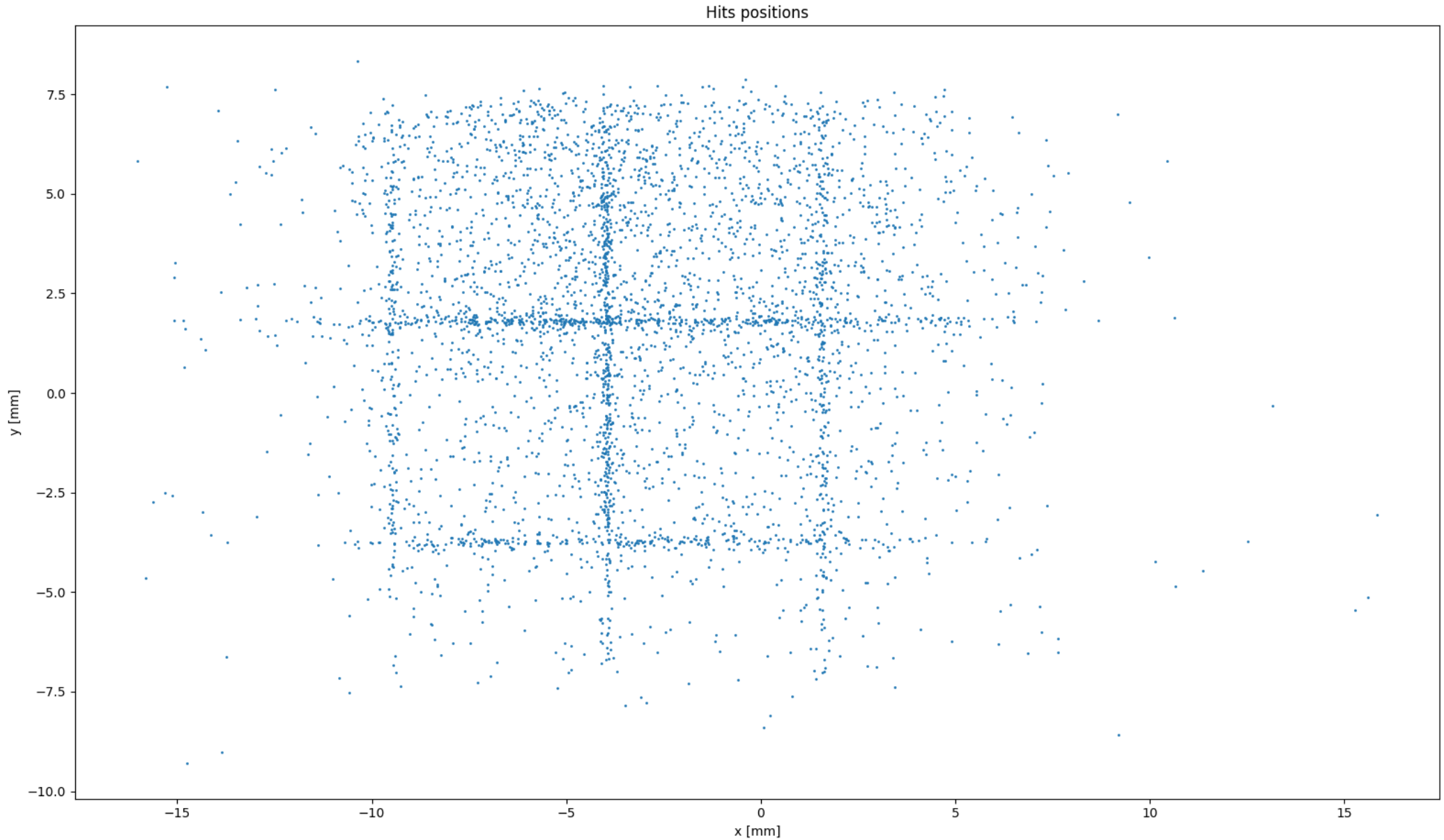
HOUGH TRANSFORM – OUR IMPLEMENTATION

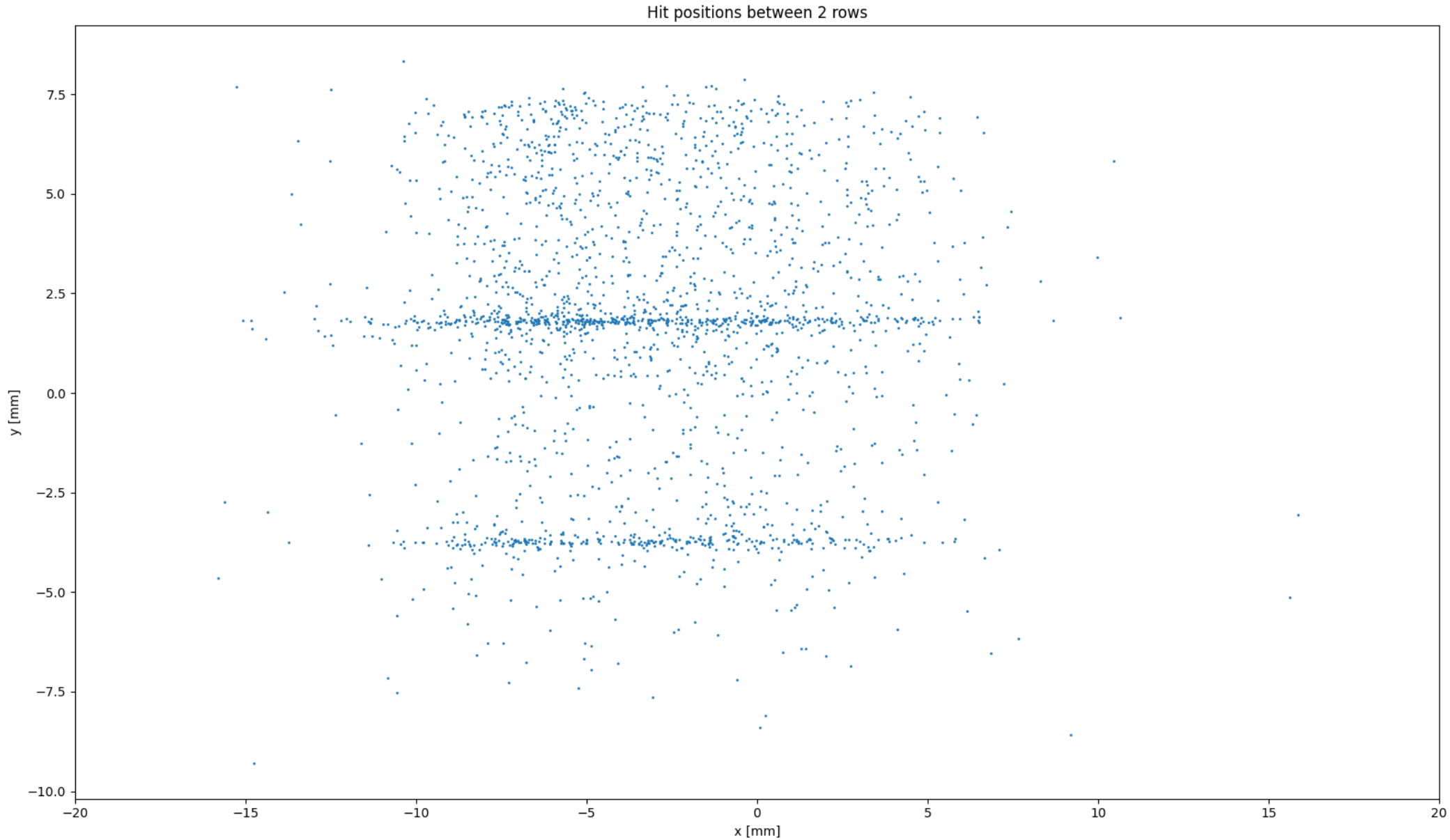
- General idea (cont.):
  - Rotate data if needed
  - Find 2 diagonal channels:
    - Get pad row and column (edge position in local coordinates)
    - Verify sensor is not flipped
  - Flip data if needed
  - Convert coordinates

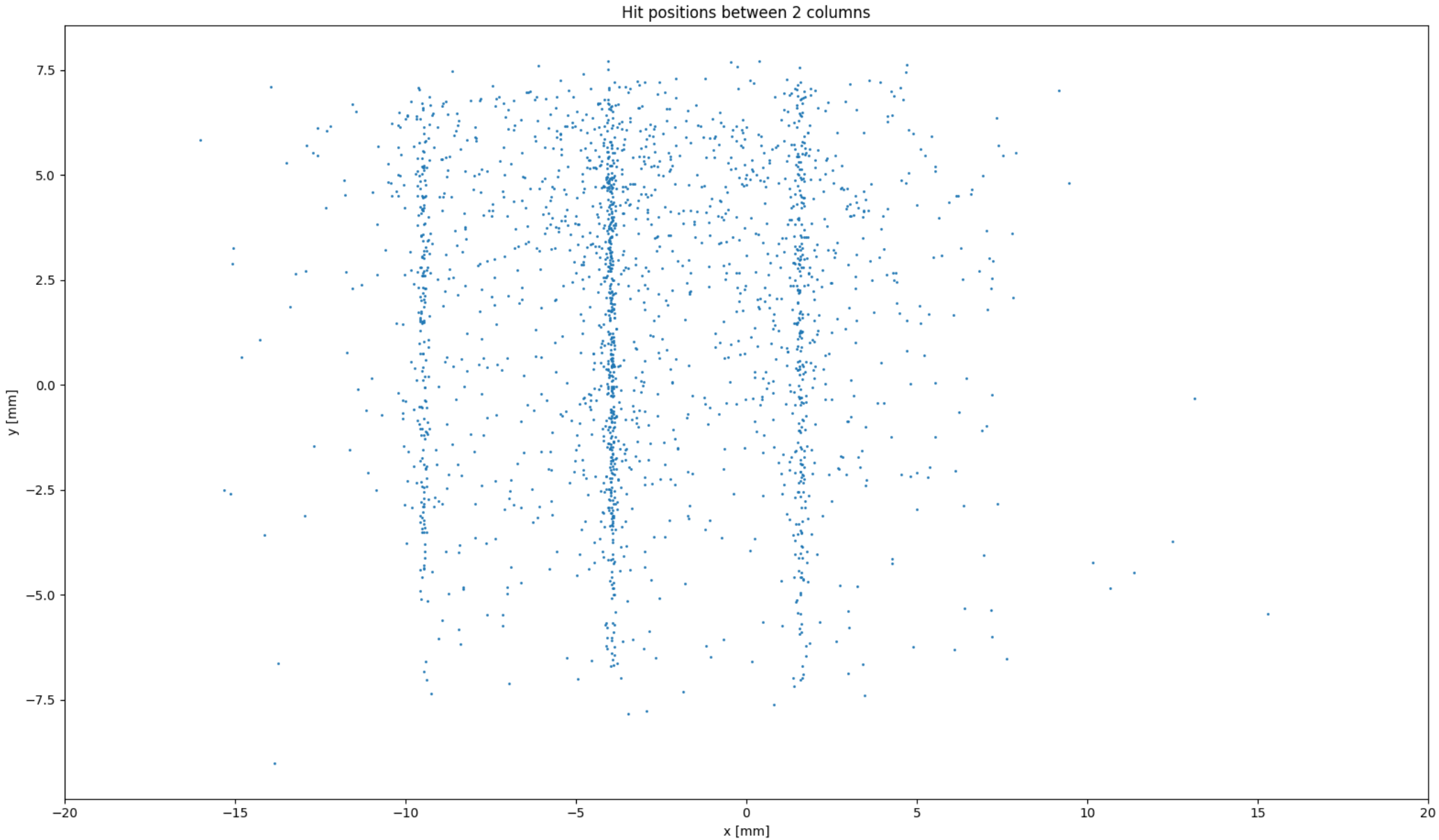


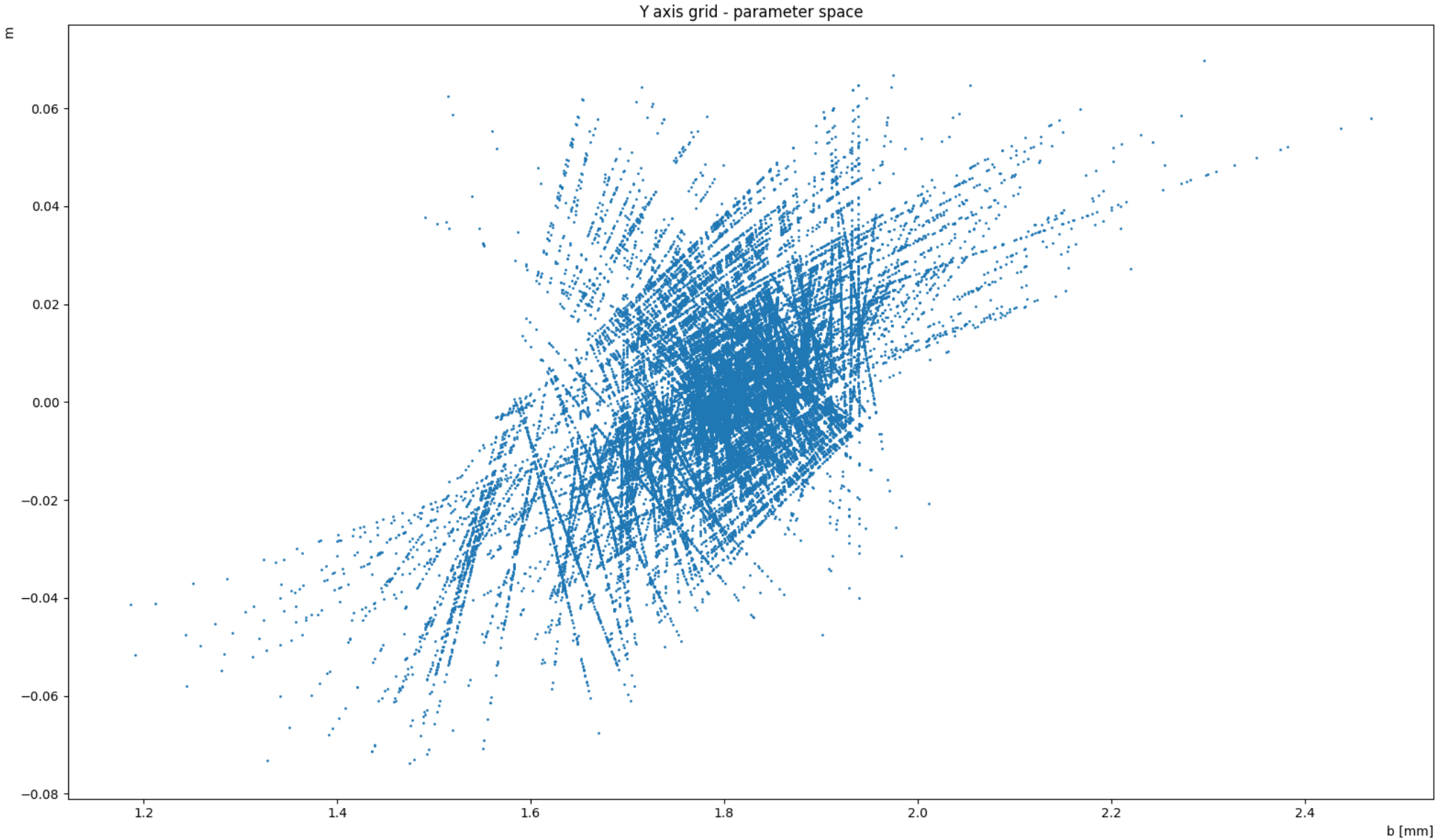
The green circles are the search area to get the channel number

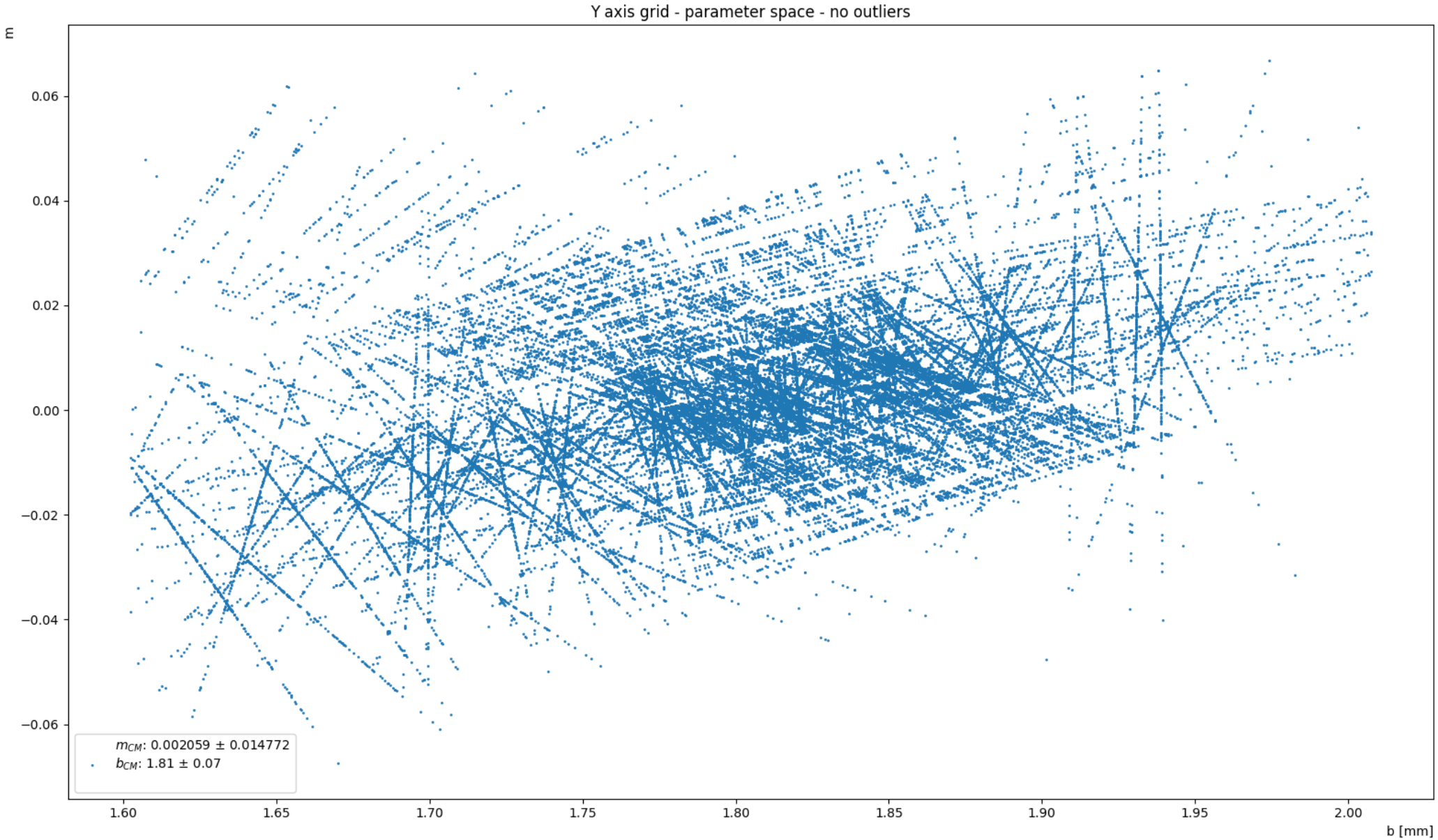
RUN 4417 – CALICE

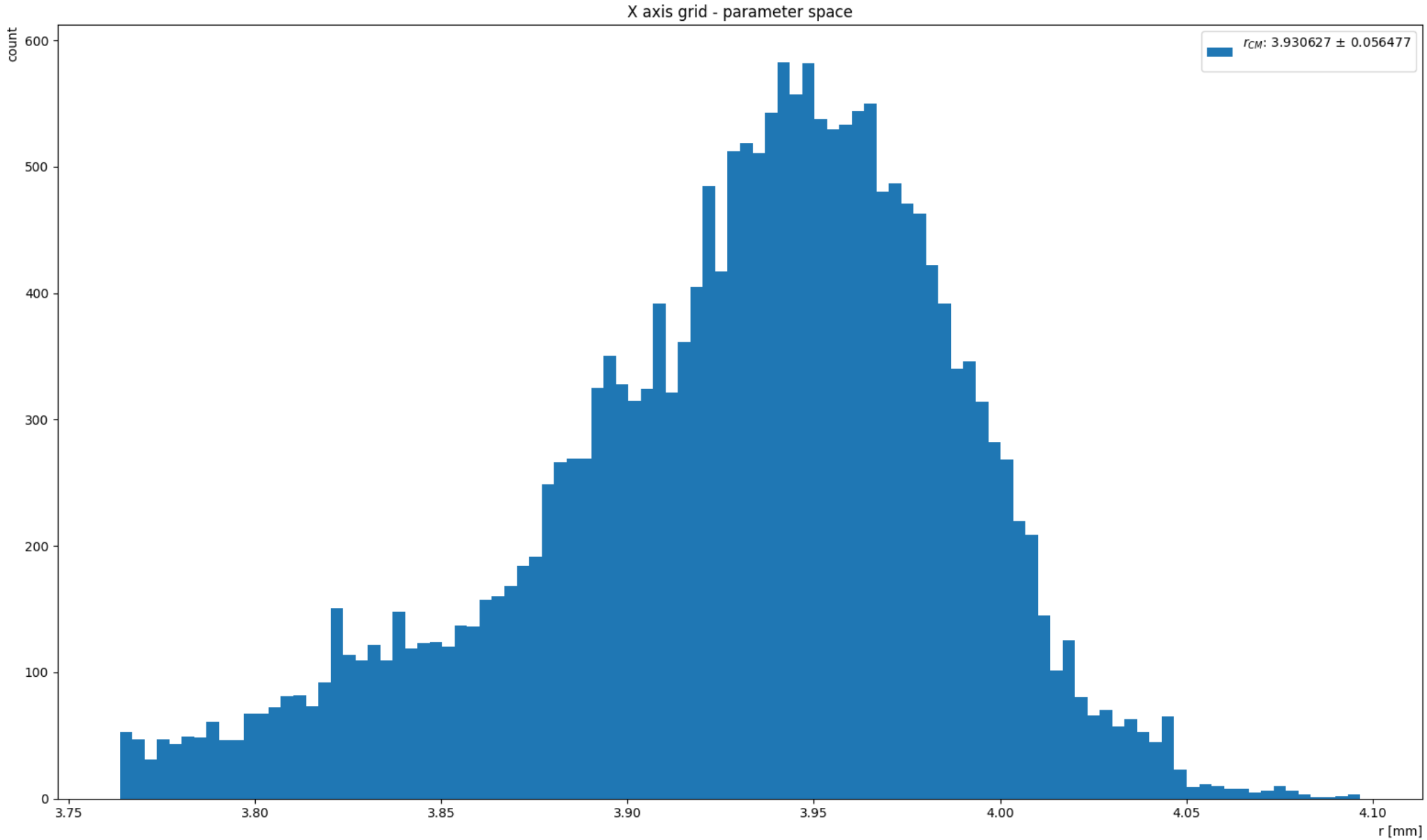

Hits positions
y [mm]
x [mm]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−15
−10
−5
0
5
10
15

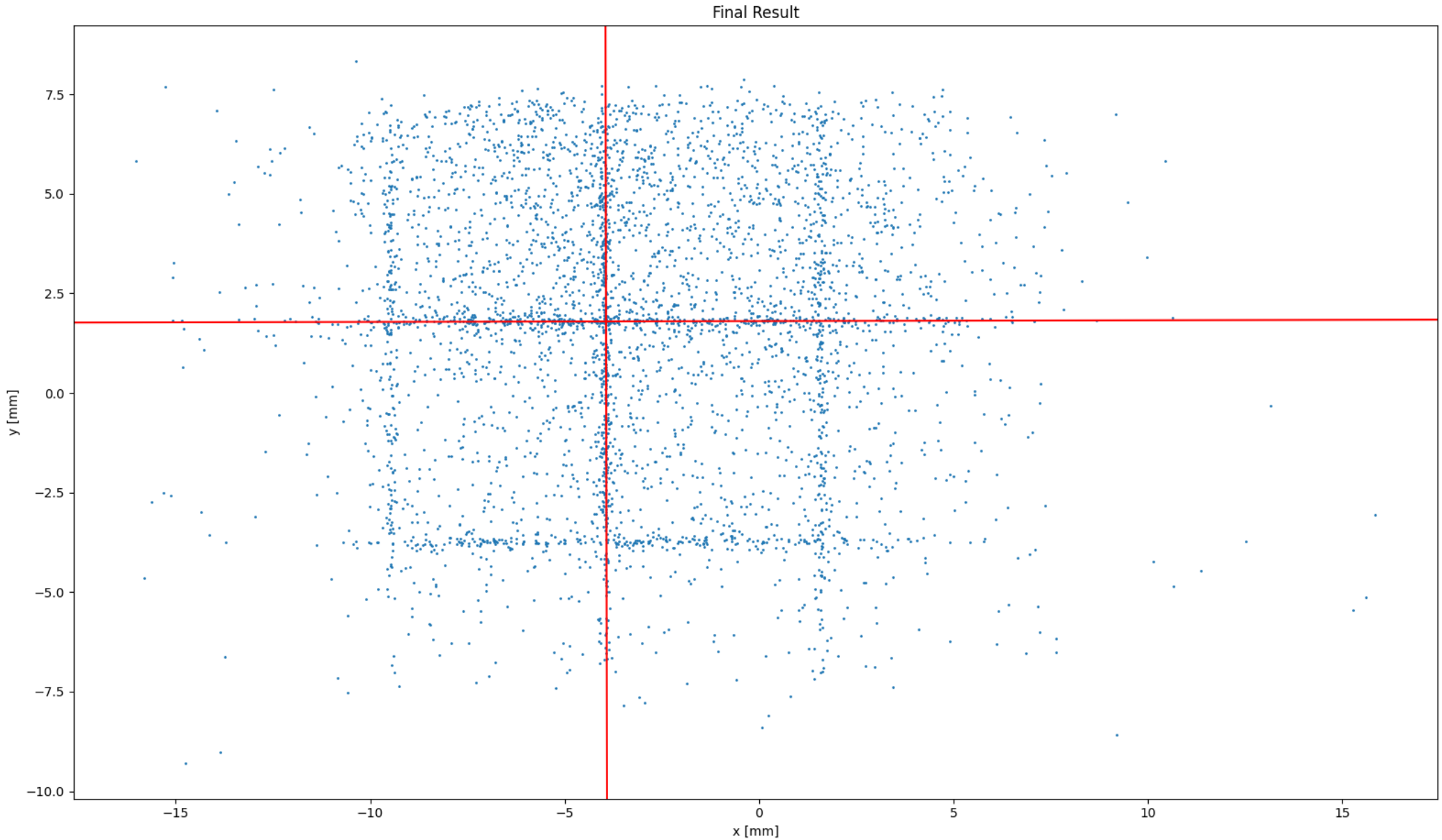

Hit positions between 2 rows
y [mm]
x [mm]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−20
−15
−10
−5
0
5
10
15
20

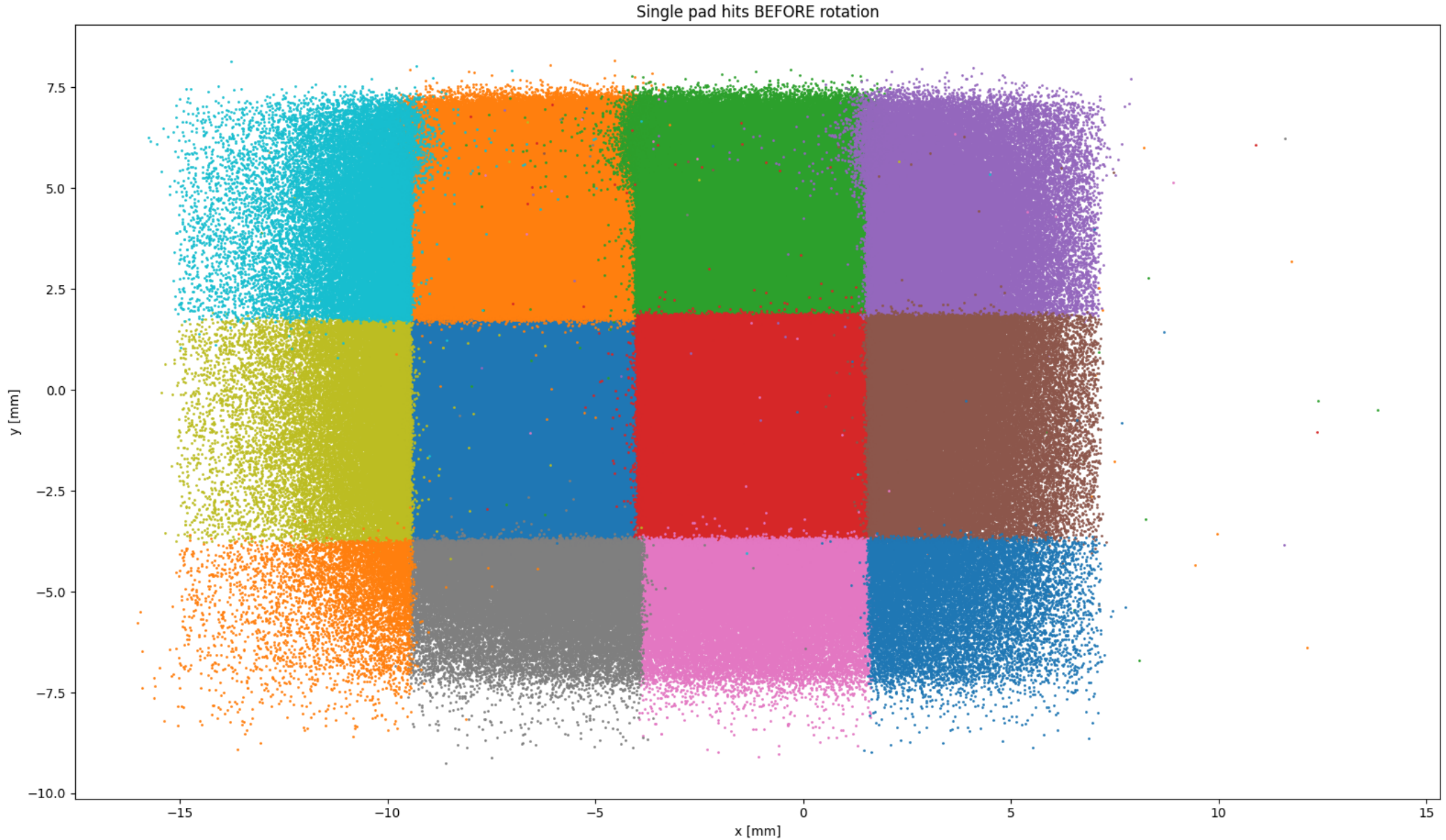

Hit positions between 2 columns
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
y [mm]
−20
−15
−10
−5
0
5
10
15
20
x [mm]

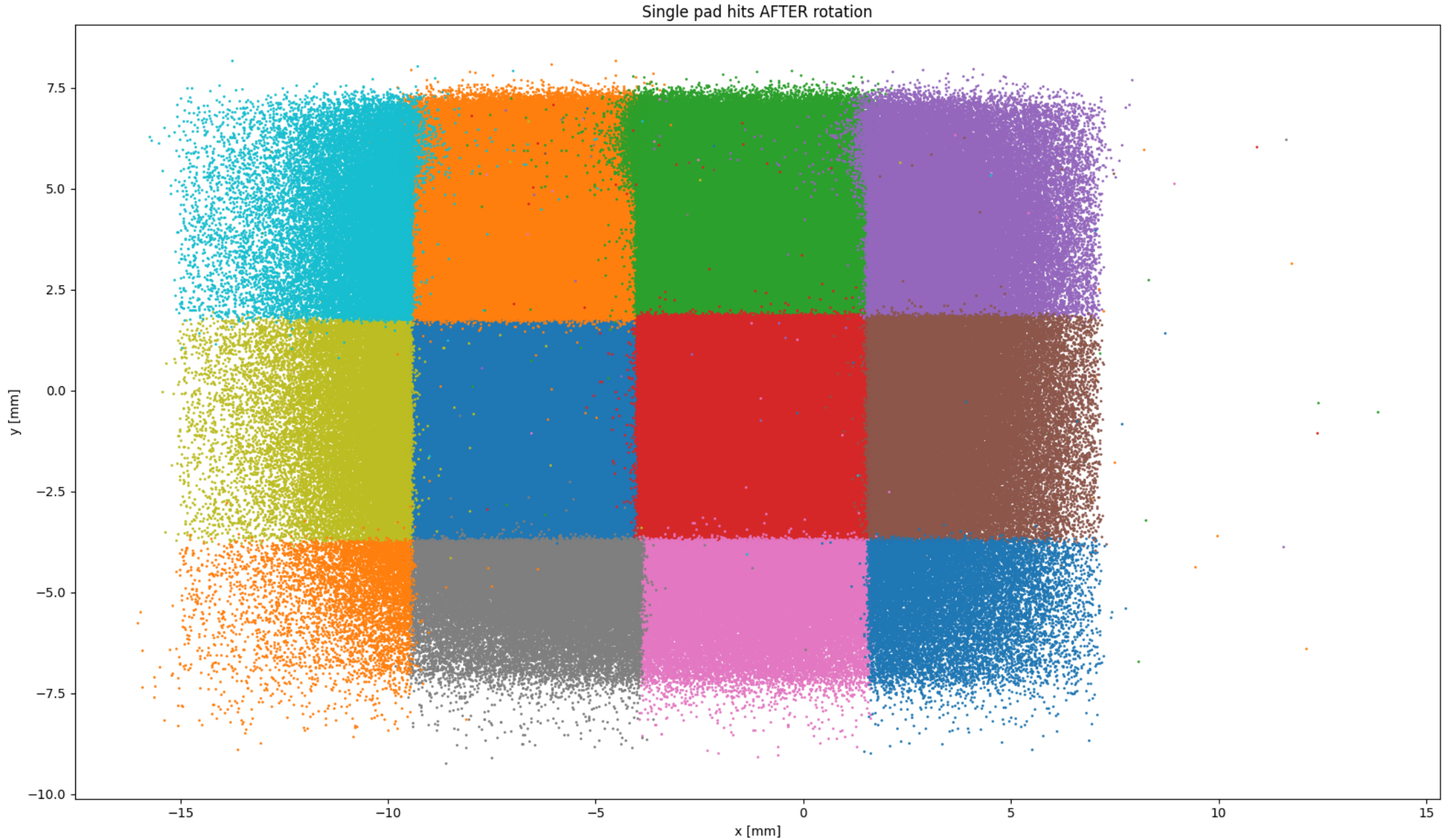

Y axis grid - parameter space
m
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
−0.08
1.2
1.4
1.6
1.8
2.0
2.2
2.4
b [mm]

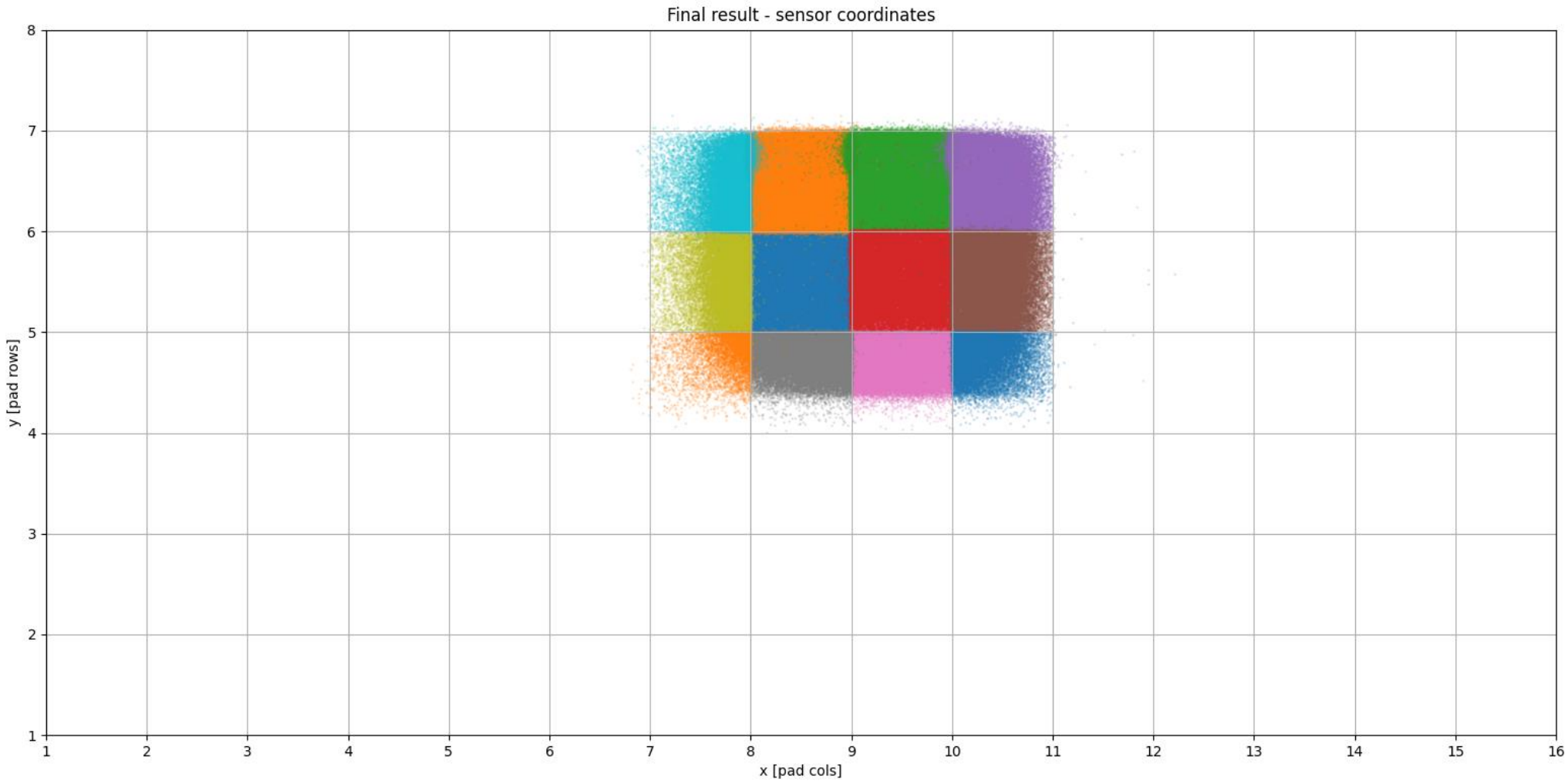

Y axis grid - parameter space - no outliers
m
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
1.60
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00
b [mm]
m_{CM}: 0.002059 ± 0.014772
b_{CM}: 1.81 ± 0.07


X axis grid - parameter space
count
600
500
400
300
200
100
0
3.75
3.80
3.85
3.90
3.95
4.00
4.05
4.10
r [mm]
r_{CM}: 3.930627 ± 0.056477


Final Result
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
y [mm]
−15
−10
−5
0
5
10
15
x [mm]


Single pad hits BEFORE rotation
y [mm]
x [mm]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−15
−10
−5
0
5
10
15

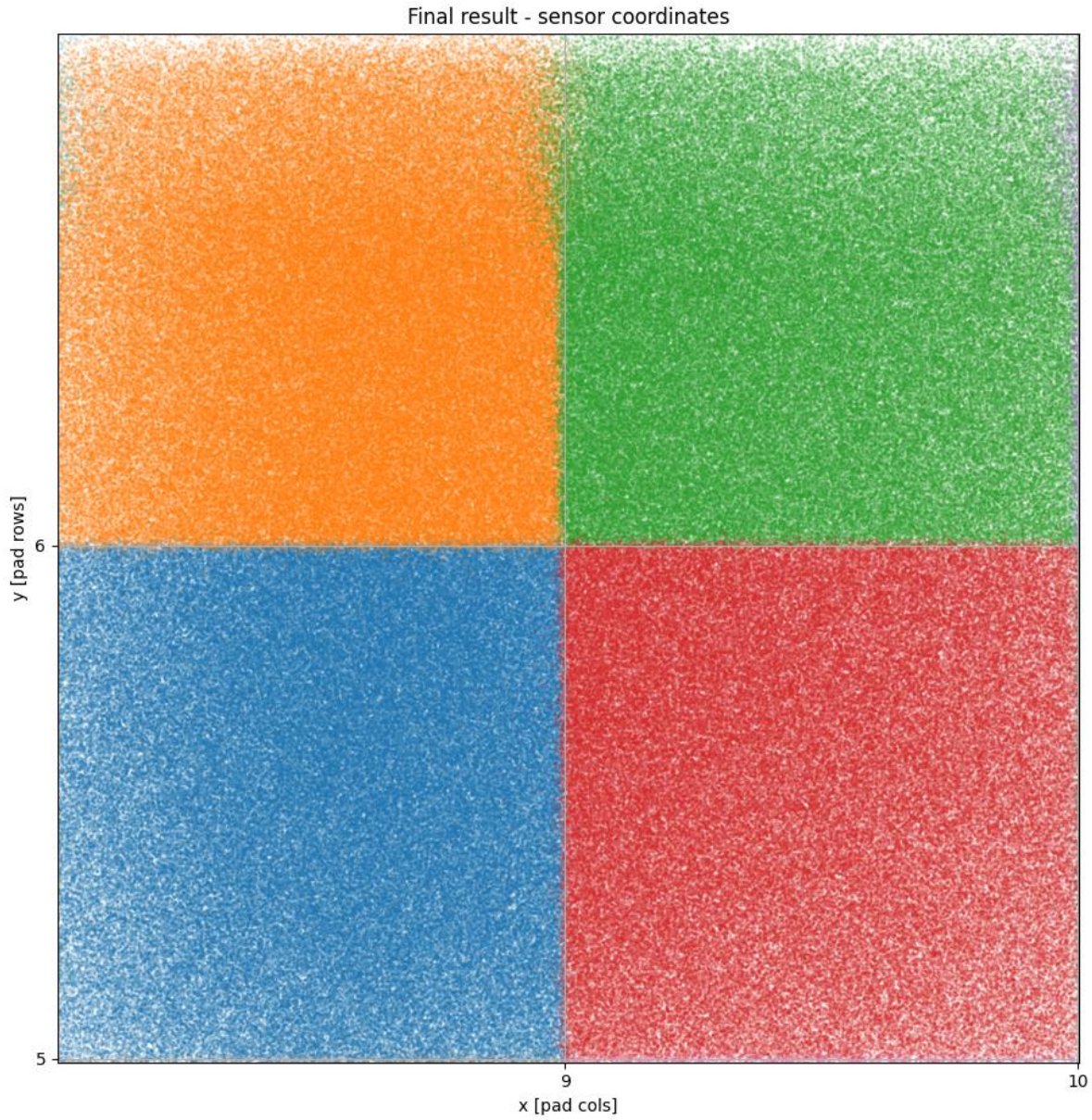

Single pad hits AFTER rotation
y [mm]
x [mm]
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−15
−10
−5
0
5
10
15


Final result - sensor coordinates
y [pad rows]
x [pad cols]
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

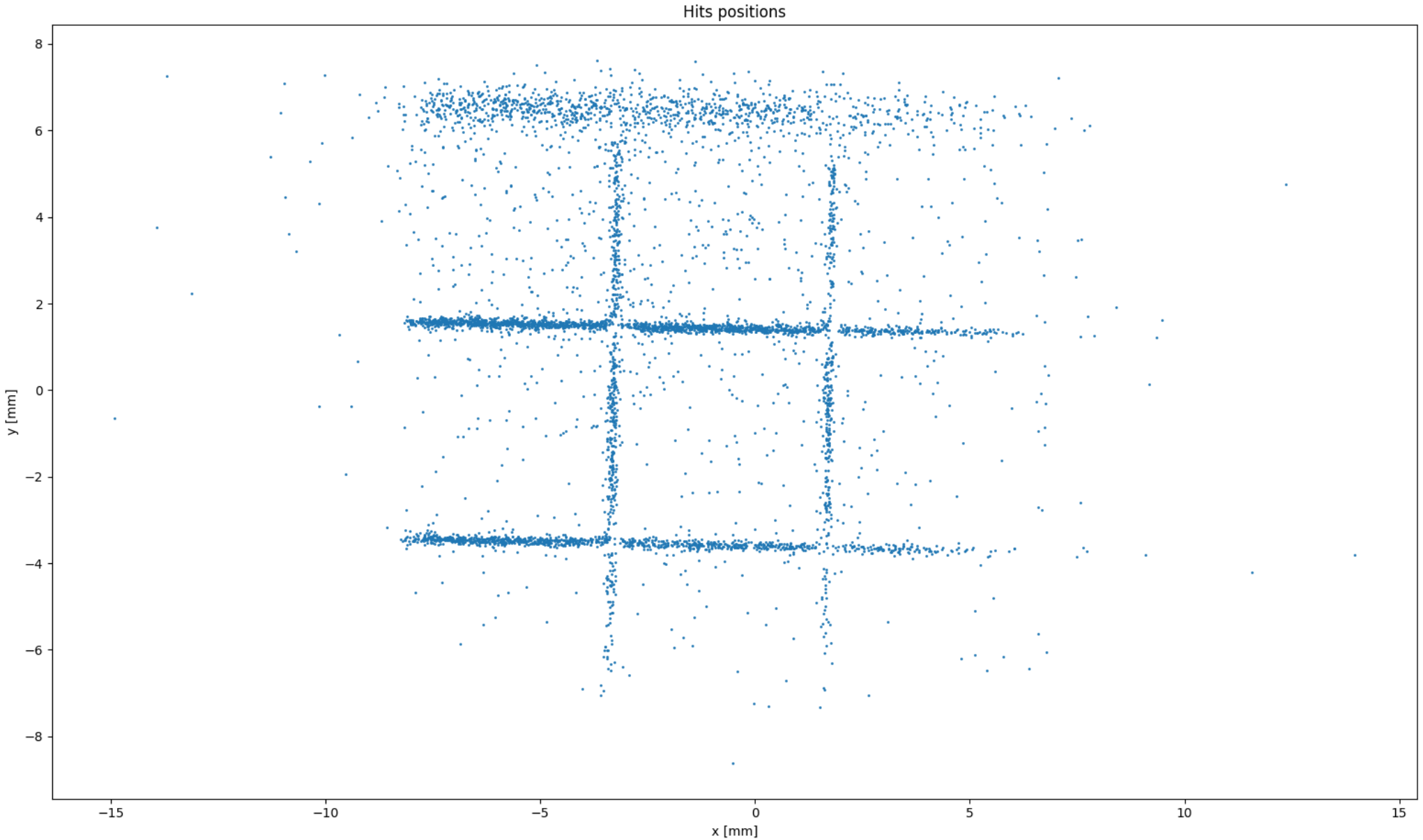
Percentage inside pad:

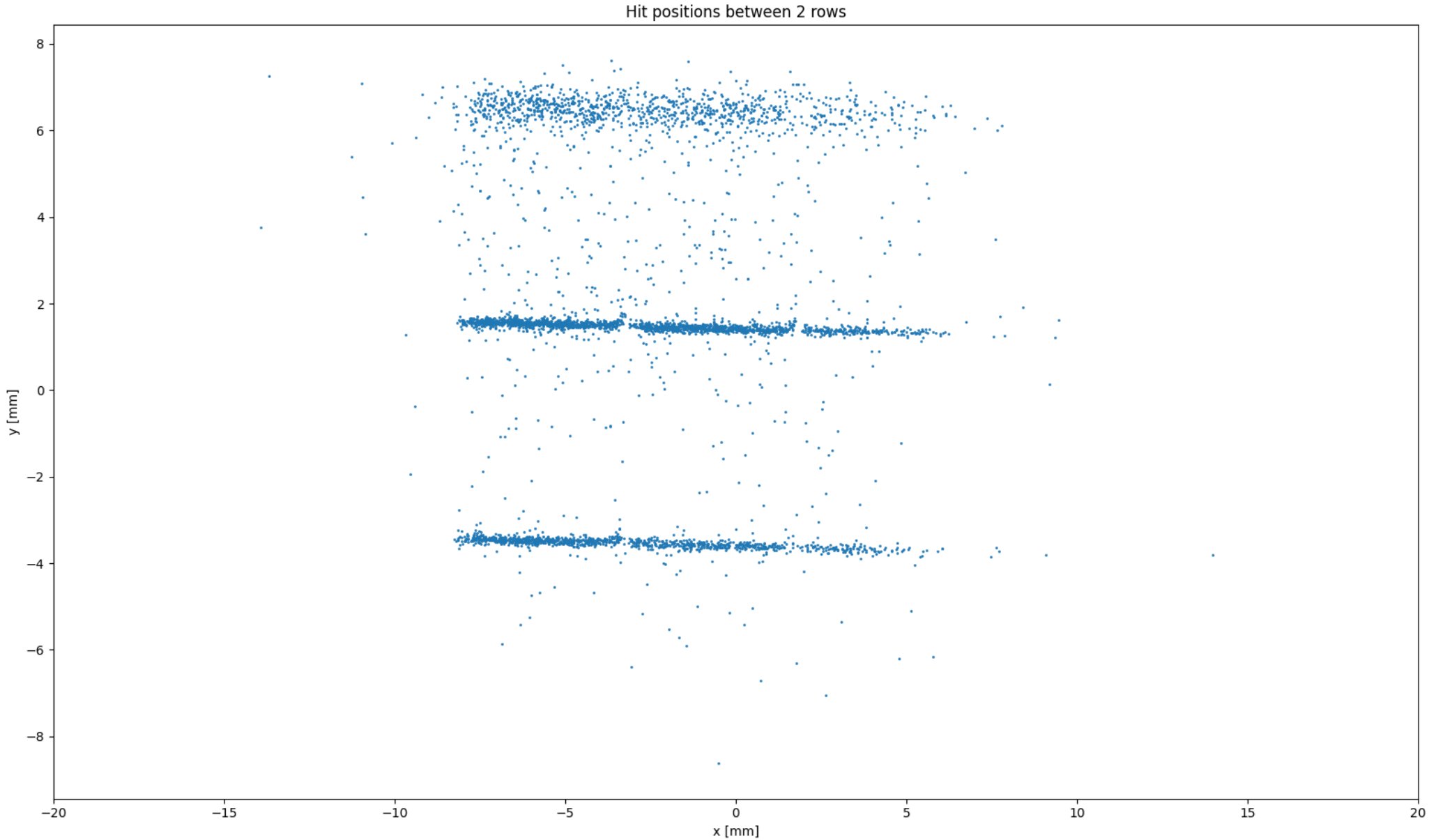
- (8, 5) – 98.62 %
- (8, 6) – 98.65 %
- (9, 6) – 97.55 %
- (9, 5) – 98.40 %

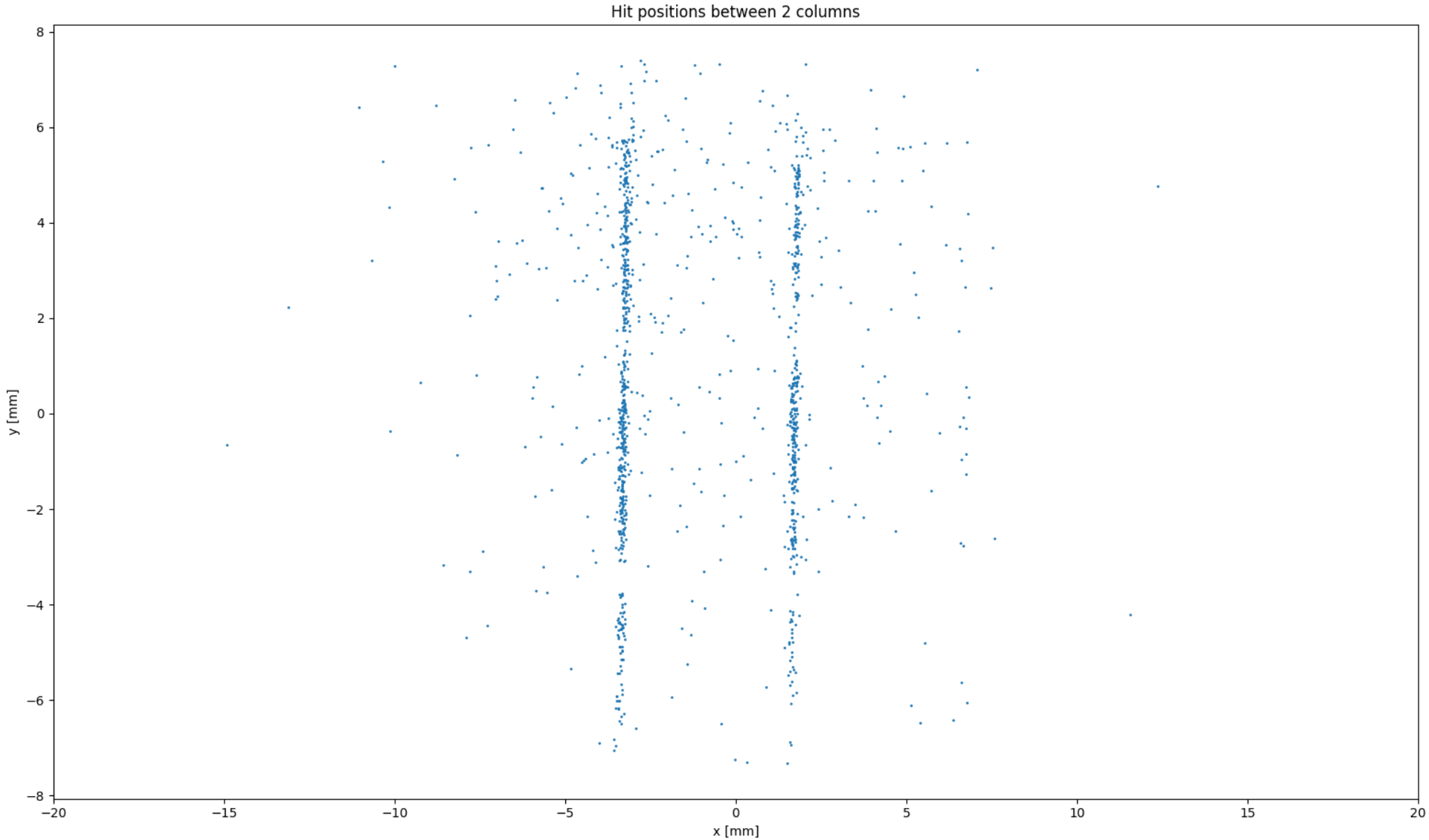
Number of events: ~1.5M
Run time: ~ 3 minutes
(not optimized)

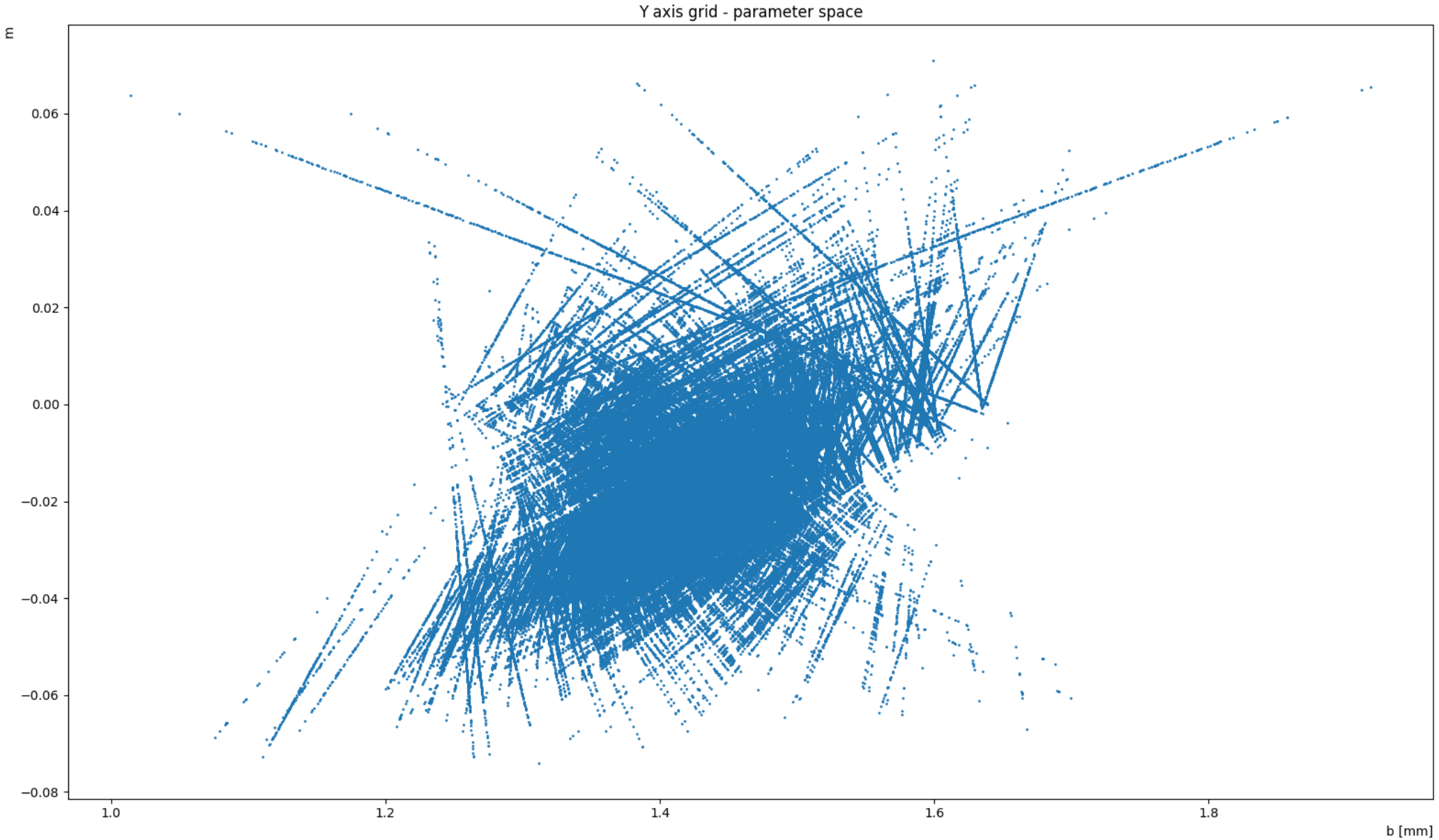


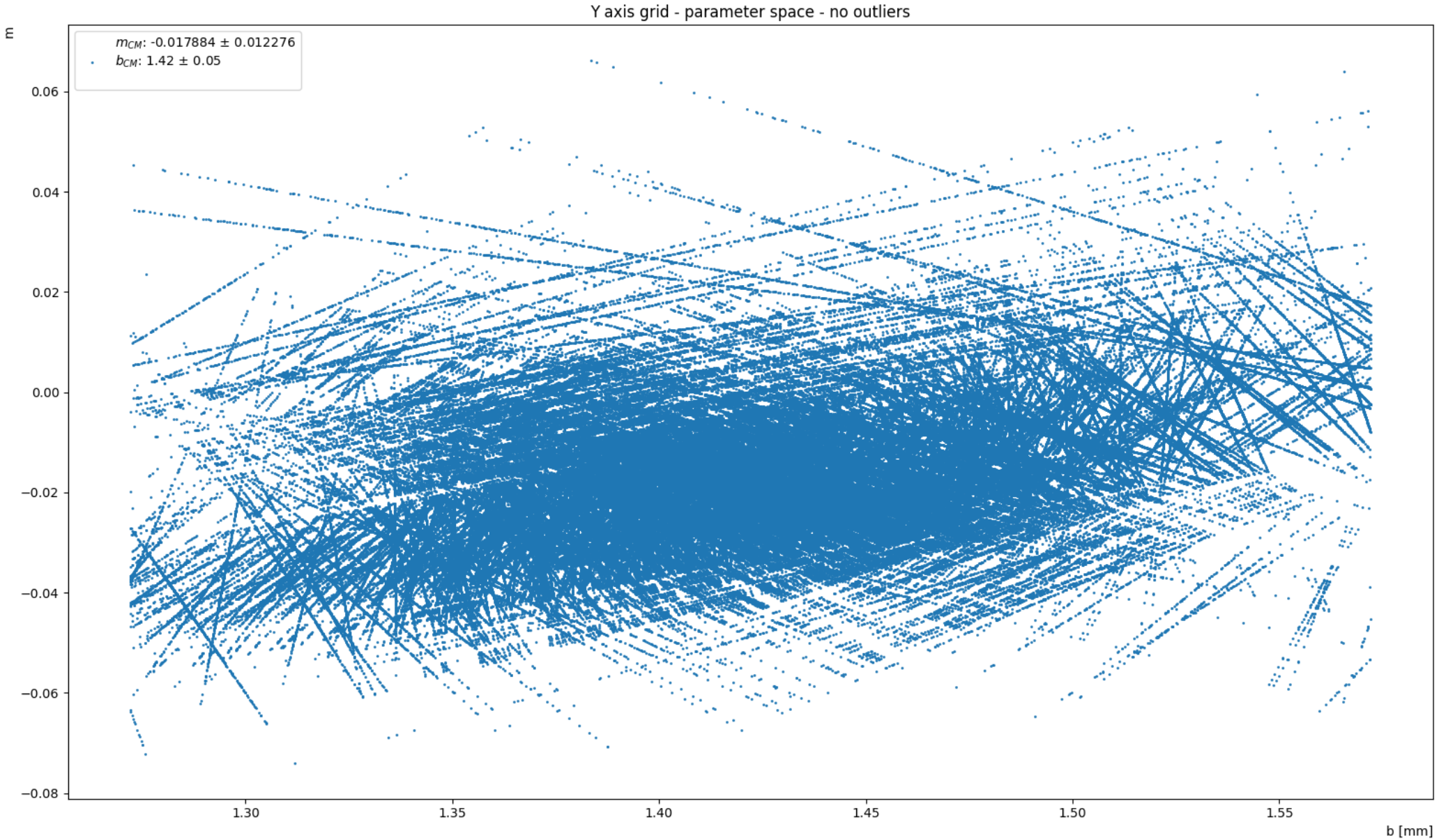
RUN 4475 – GAAS

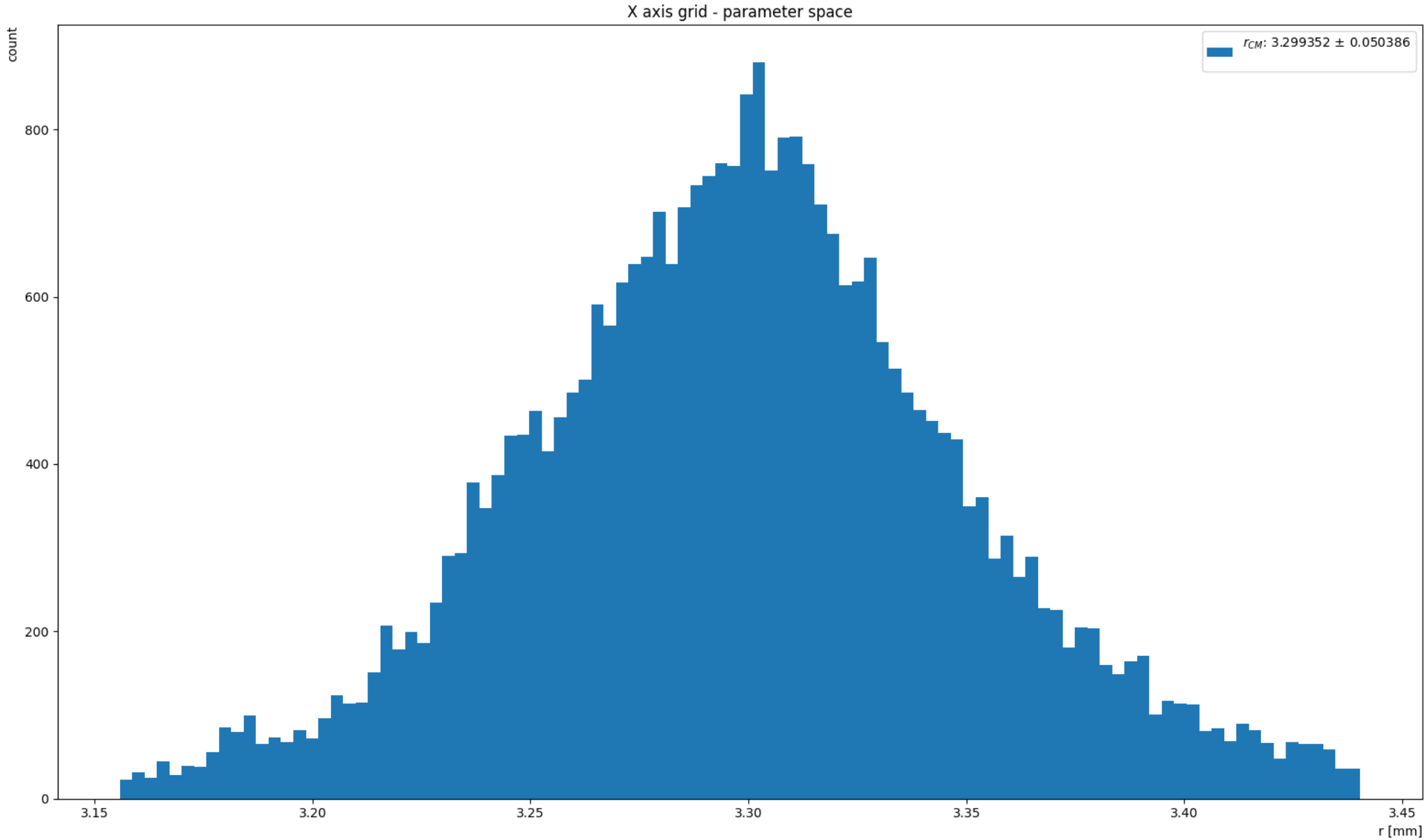

Hits positions
y [mm]
x [mm]
8
6
4
2
0
−2
−4
−6
−8
−15
−10
−5
0
5
10
15

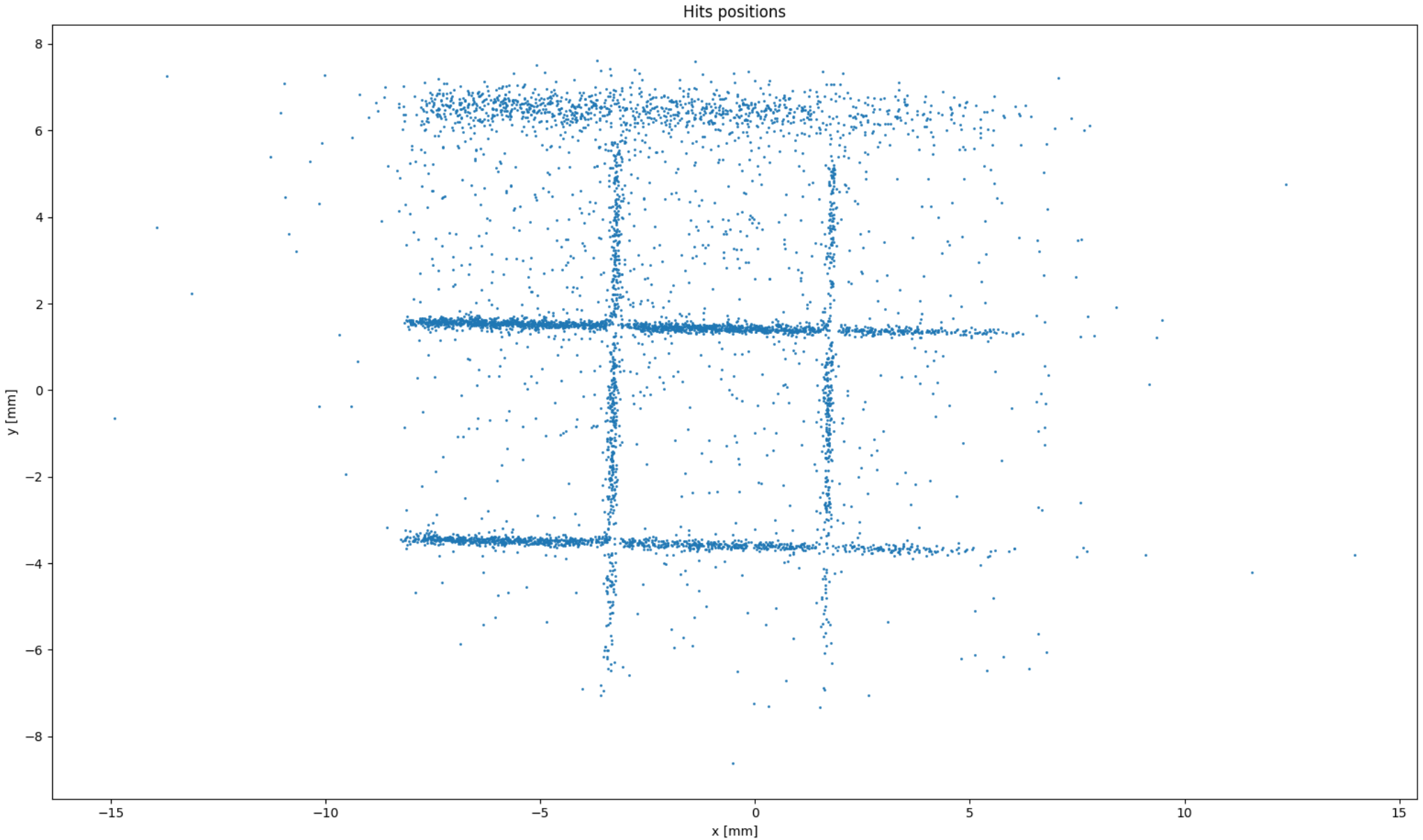

Hit positions between 2 rows
y [mm]
x [mm]
8
6
4
2
0
−2
−4
−6
−8
−20
−15
−10
−5
0
5
10
15
20

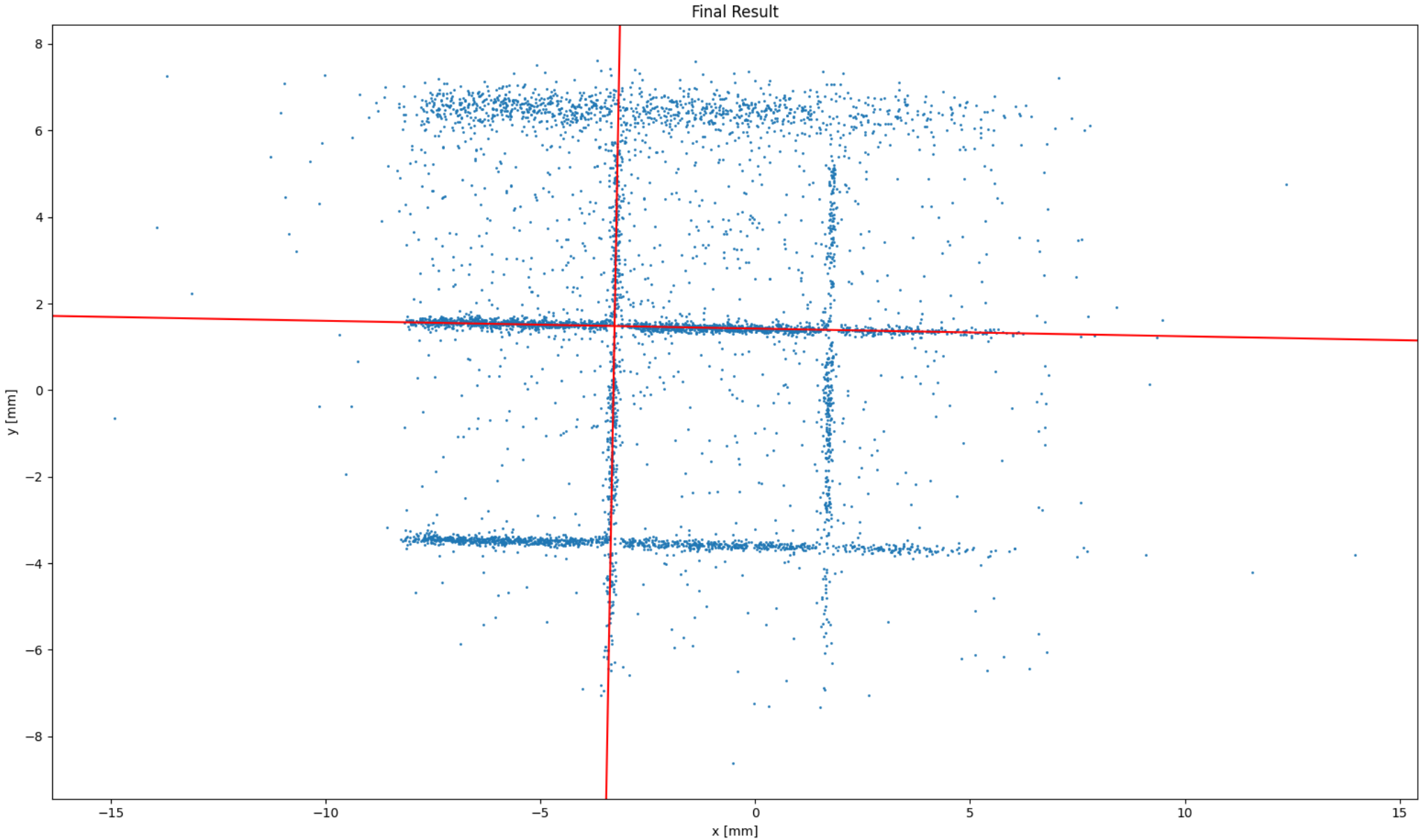

Hit positions between 2 columns
y [mm]
x [mm]
8
6
4
2
0
−2
−4
−6
−8
−20
−15
−10
−5
0
5
10
15
20

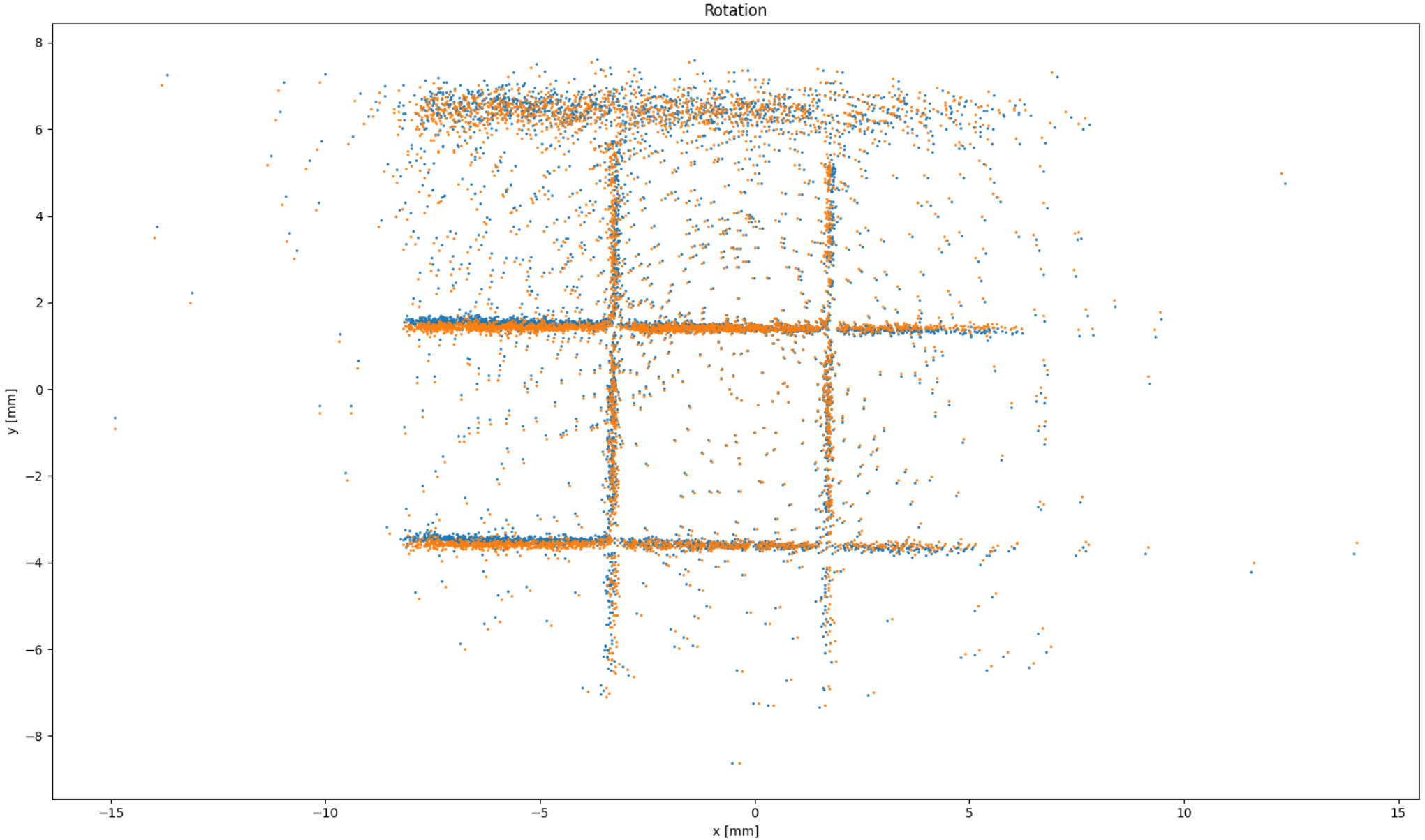

Y axis grid - parameter space
m
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
−0.08
1.0
1.2
1.4
1.6
1.8
b [mm]

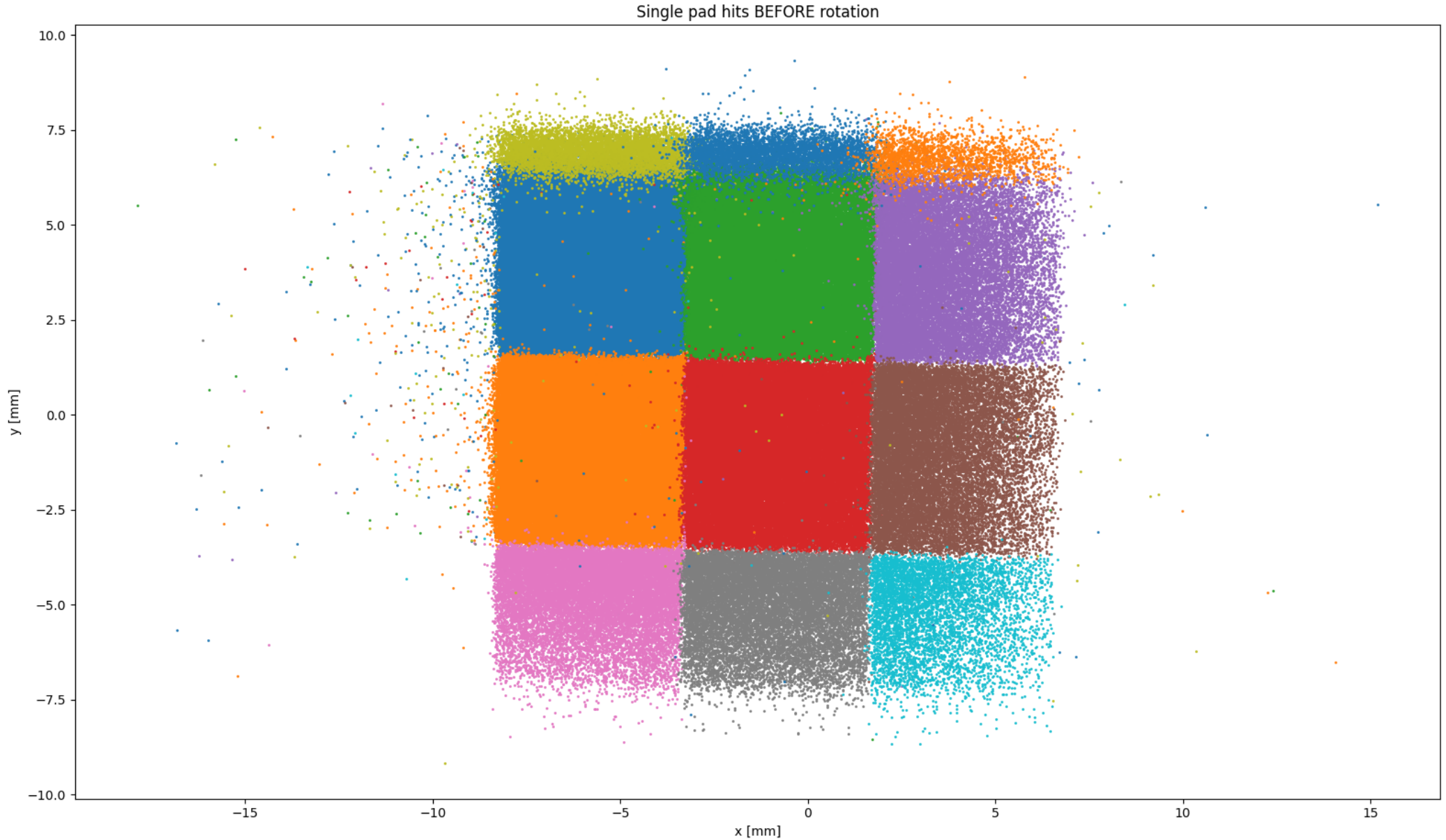

Y axis grid - parameter space - no outliers
m_{CM}: -0.017884 ± 0.012276
b_{CM}: 1.42 ± 0.05
m
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
−0.08
1.30
1.35
1.40
1.45
1.50
1.55
b [mm]

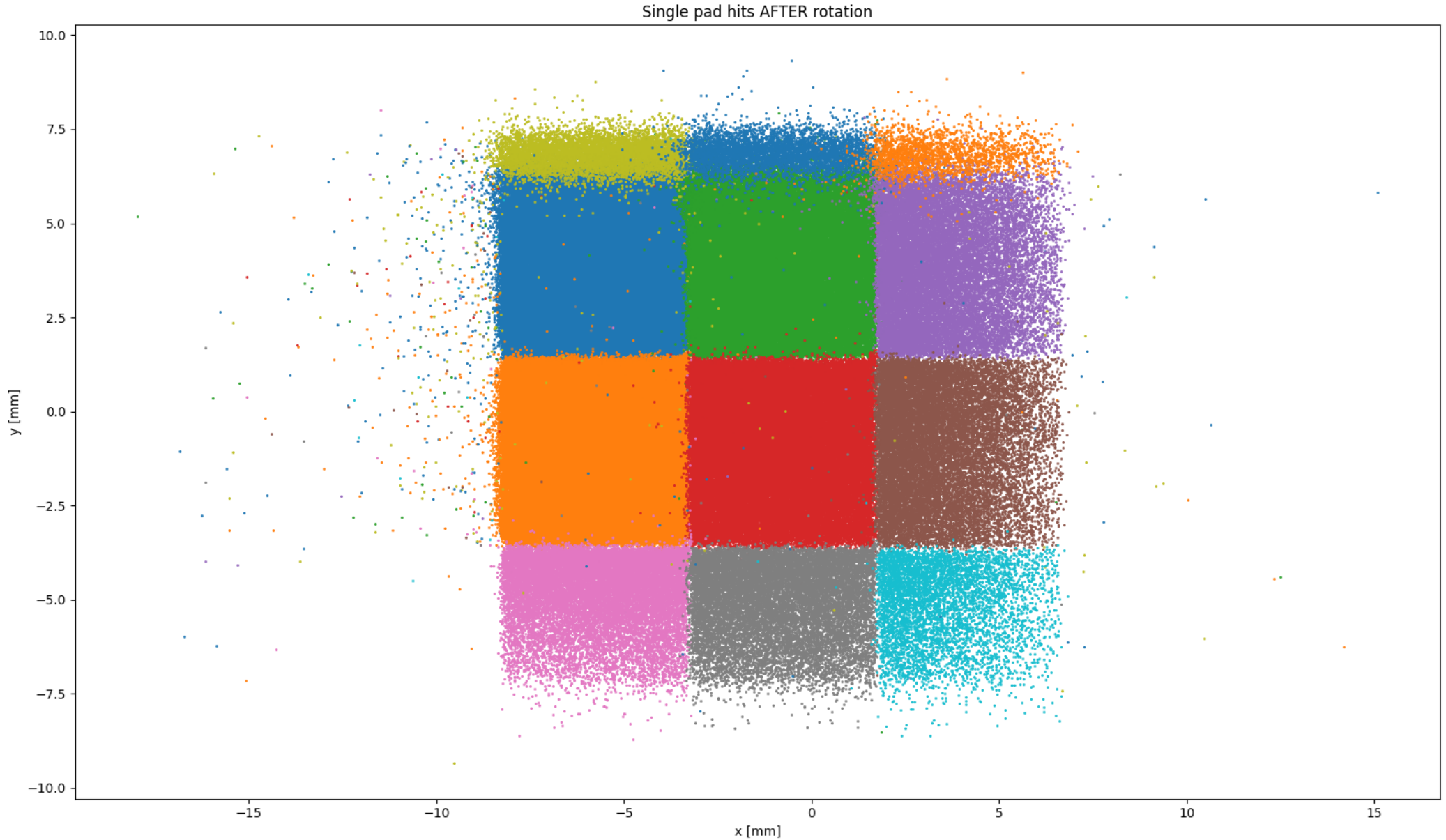

X axis grid - parameter space
count
r_{CM}: 3.299352 ± 0.050386
0
200
400
600
800
3.15
3.20
3.25
3.30
3.35
3.40
3.45
r [mm]

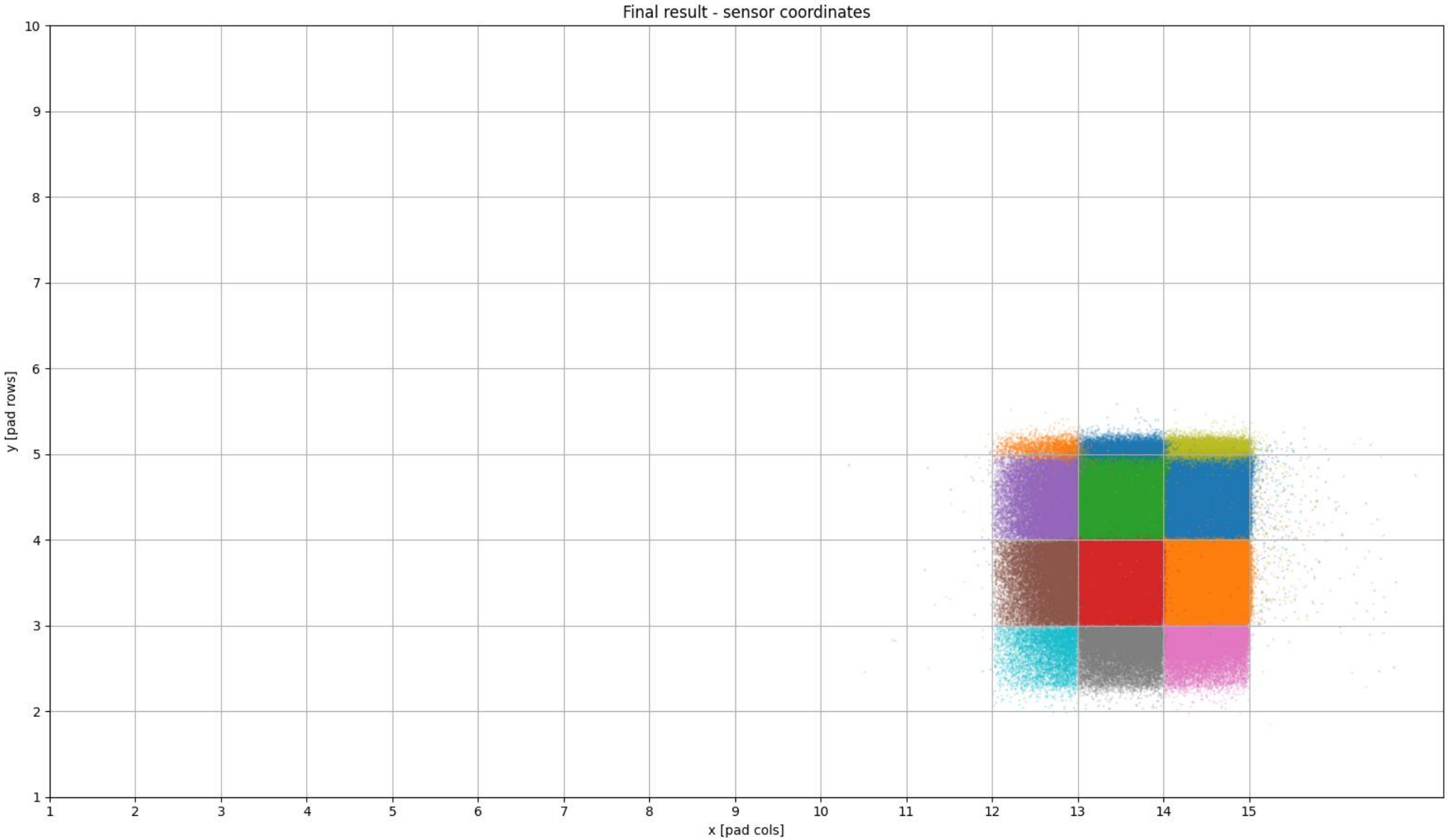

Hits positions
y [mm]
x [mm]
8
6
4
2
0
−2
−4
−6
−8
−15
−10
−5
0
5
10
15


Final Result
y [mm]
x [mm]
8
6
4
2
0
−2
−4
−6
−8
−15
−10
−5
0
5
10
15


Rotation
y [mm]
x [mm]
8
6
4
2
0
−2
−4
−6
−8
−15
−10
−5
0
5
10
15


Single pad hits BEFORE rotation
y [mm]
x [mm]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−15
−10
−5
0
5
10
15

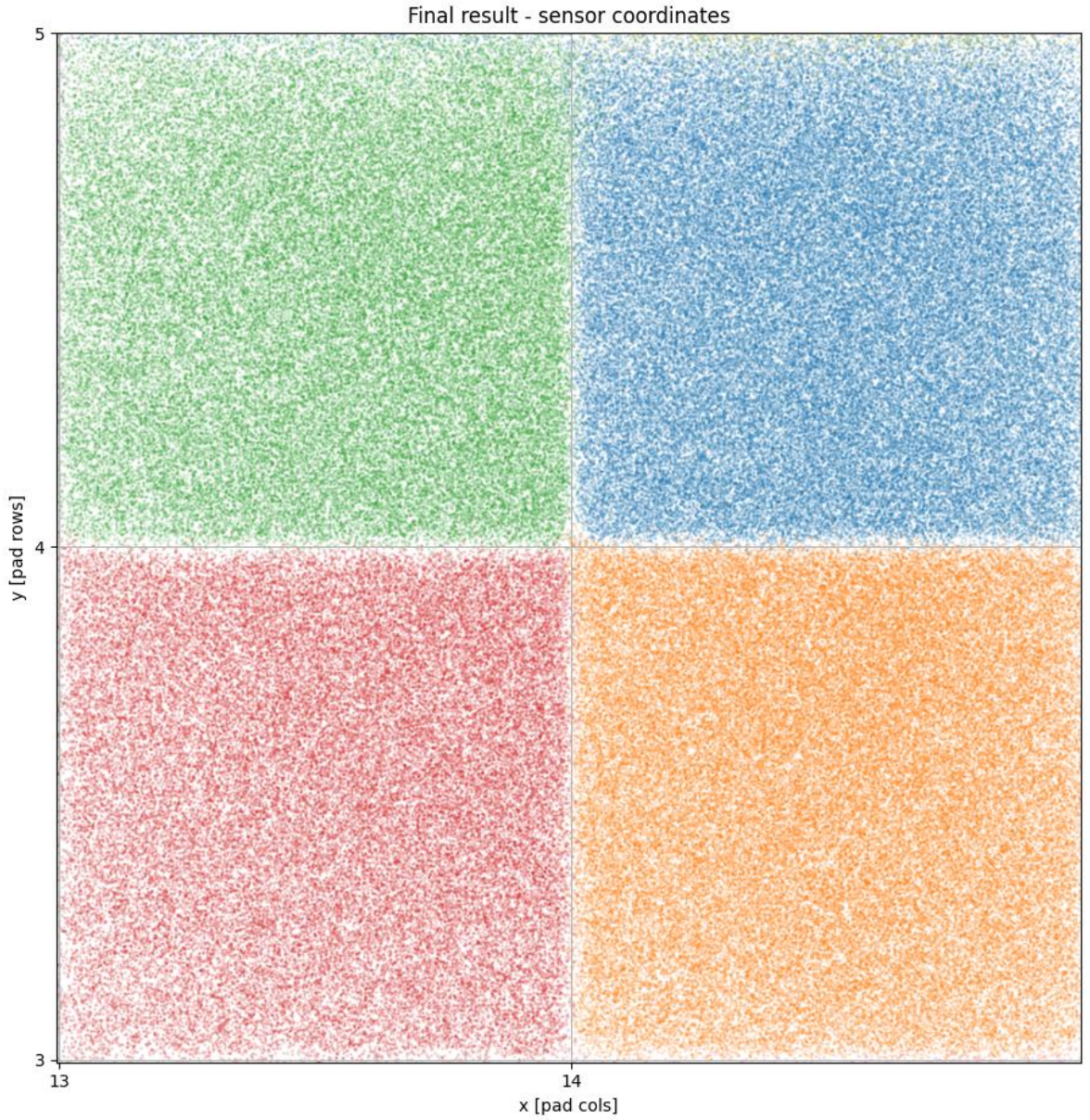

Single pad hits AFTER rotation
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
y [mm]
−15
−10
−5
0
5
10
15
x [mm]


Final result - sensor coordinates
y [pad rows]
x [pad cols]
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Percentage inside pad:

- (14, 4) – 97.74 %
- (14, 3) – 98.66 %
- (13, 4) – 97.60 %
- (13, 3) – 99.09 %

Number of events: ~0.5M
Run time: ~ 1 minute
(not optimized)



THANK YOU!