# Bubble Velocity Analysis

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PICO

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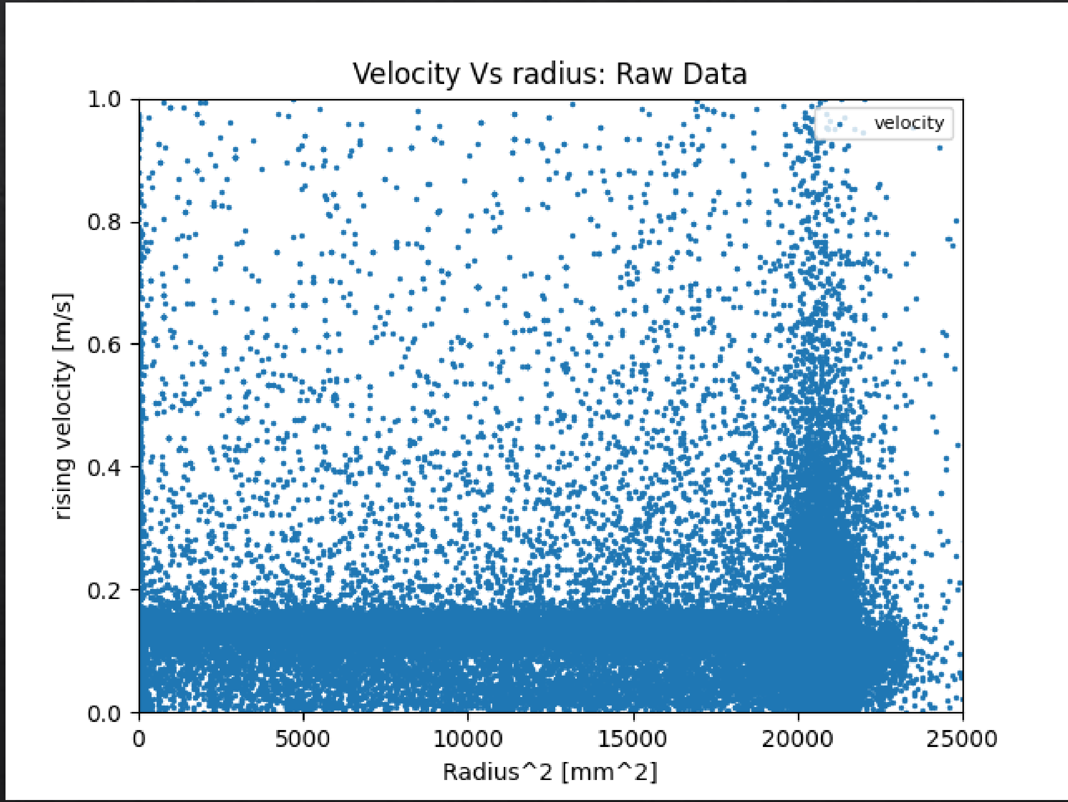
# Velocity Calculation

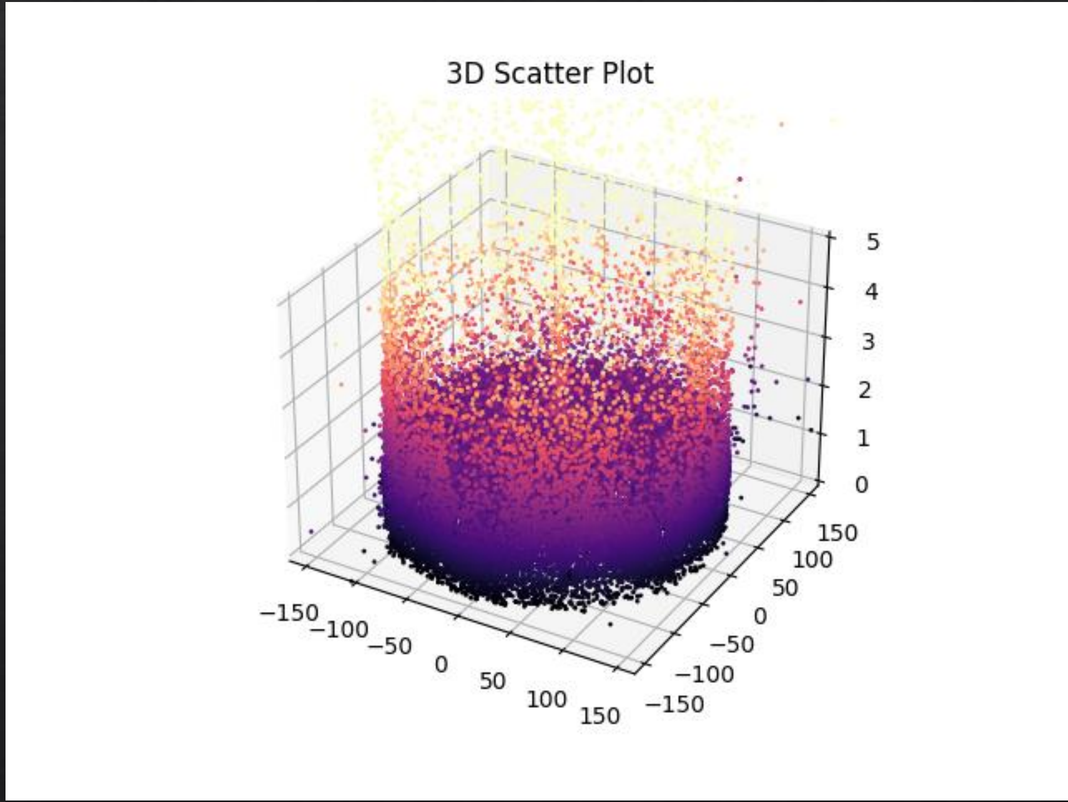
- Used TrkCZ data in merged_all.txt file
  - Take difference in positions of the bubble

- Created module by Pitam for tracking the bubble as it rises
  - Finds and tracks the center of the bubble over 10 frames from genesis

- Cameras are 100hz, or frame every 10ms

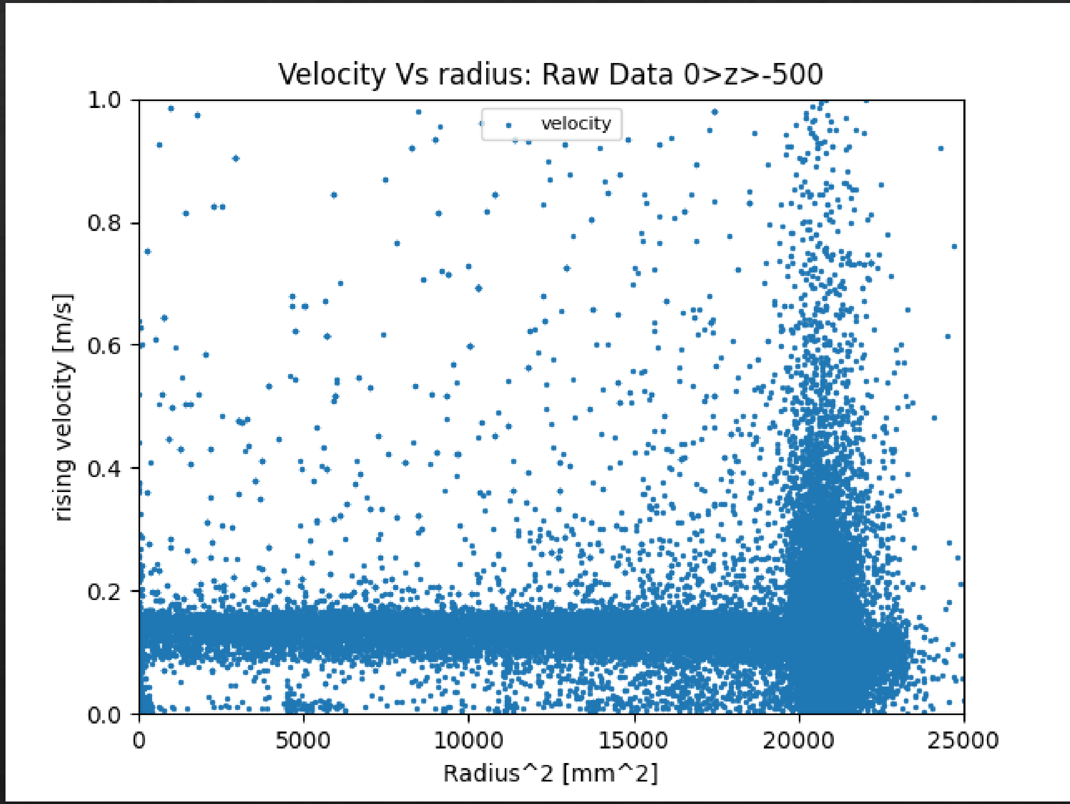
# Raw Data


Velocity Vs radius: Raw Data
velocity
rising velocity [m/s]
Radius^2 [mm^2]
0.0
0.2
0.4
0.6
0.8
1.0
0
5000
10000
15000
20000
25000


3D Scatter Plot
0
1
2
3
4
5
−150
−100
−50
0
50
100
150
−150
−100
−50
0
50
100
150

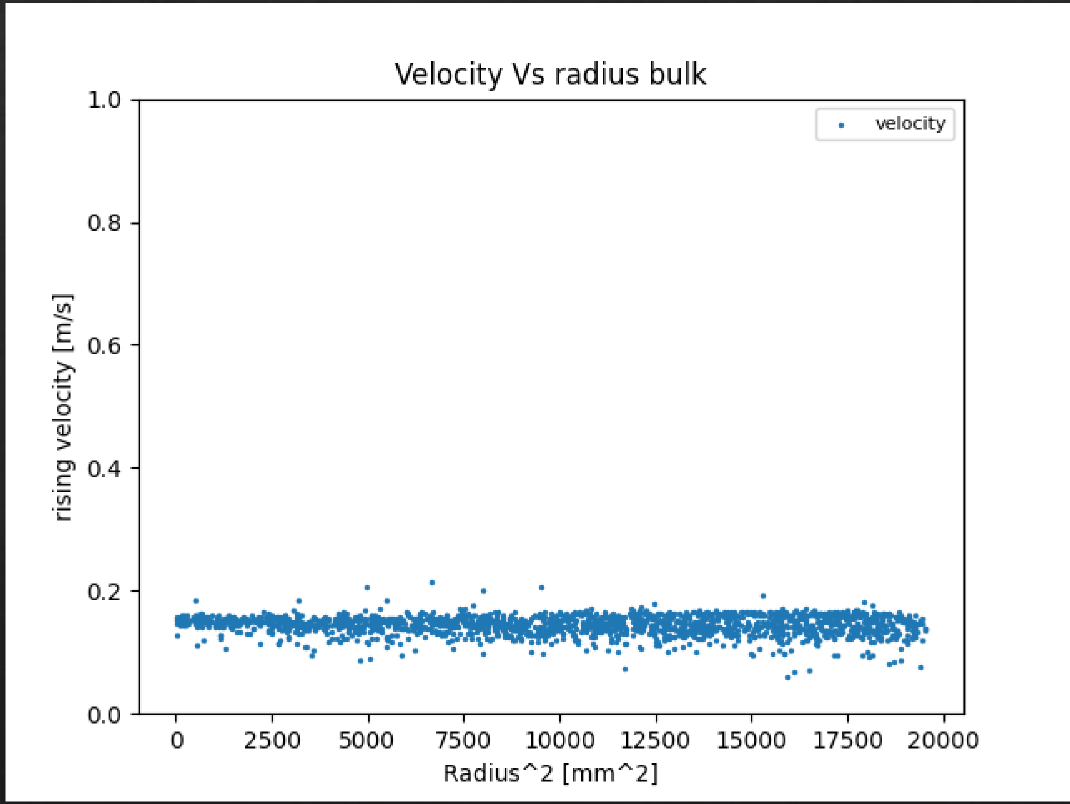
# Cuts

- Cutting Z-coordinate 0<z<-500
  - Removes Dome and IJ events
  - Removes values that cross this range
  - Reconstruction is not great in this region
- Band between 0.1 and 0.2 [m/s] forming
- Wall Events with higher velocities?



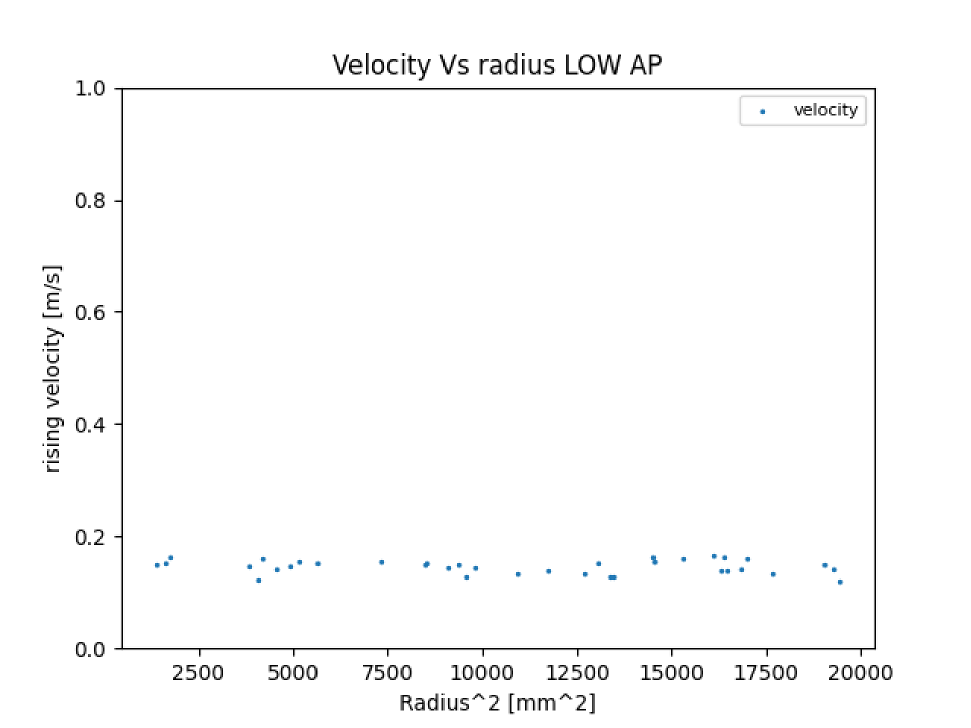
# Bulk events

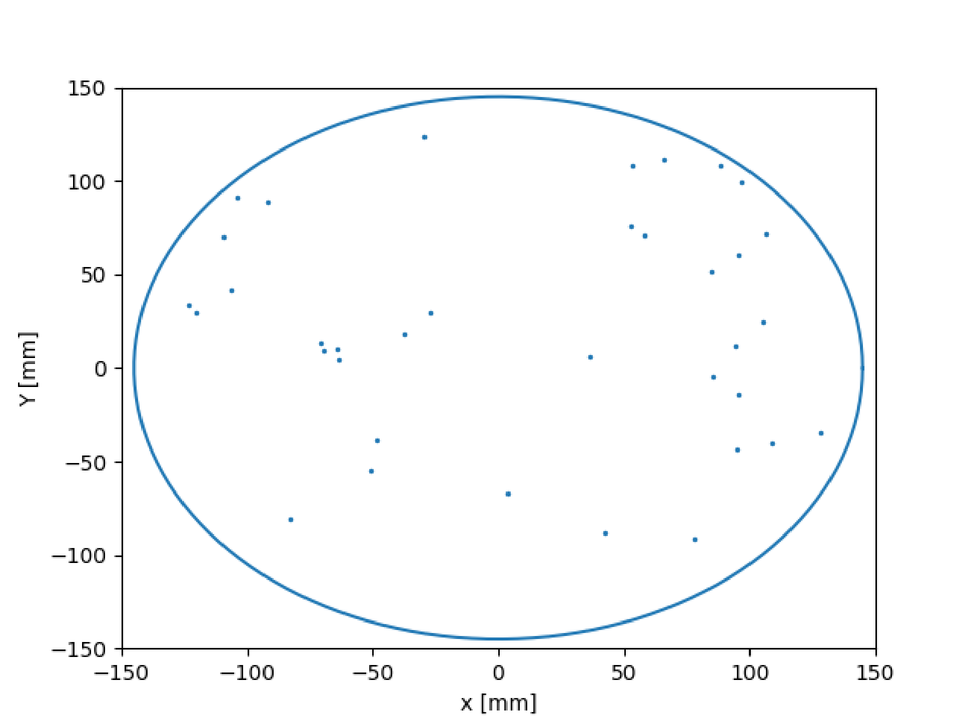
- Cut using “get_bulk_events”
- Includes DytranT cut between 1.1 and 1.8
  - This removes multiples and walls, and any events with higher velocities than 0.2 [m/s]
- Average velocity of 0.1446 +/- 0.0004 m/s



# Low AP

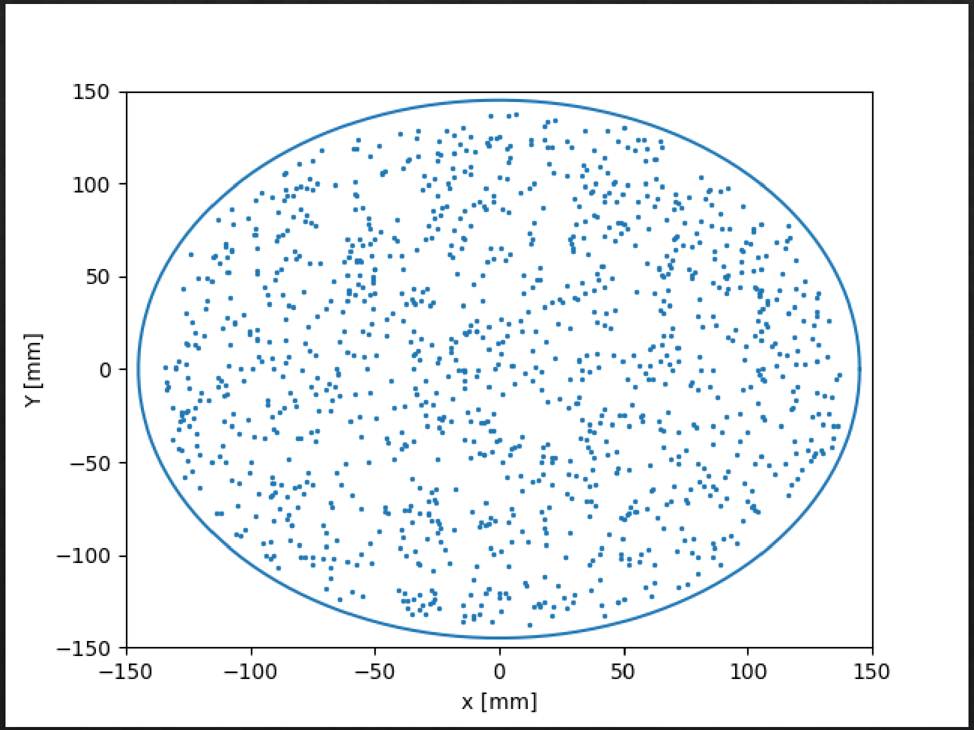
- Low AP events: recon.AP < 2
- Nothing too interesting about these events
- Average velocity: 0.146 +/- 0.002

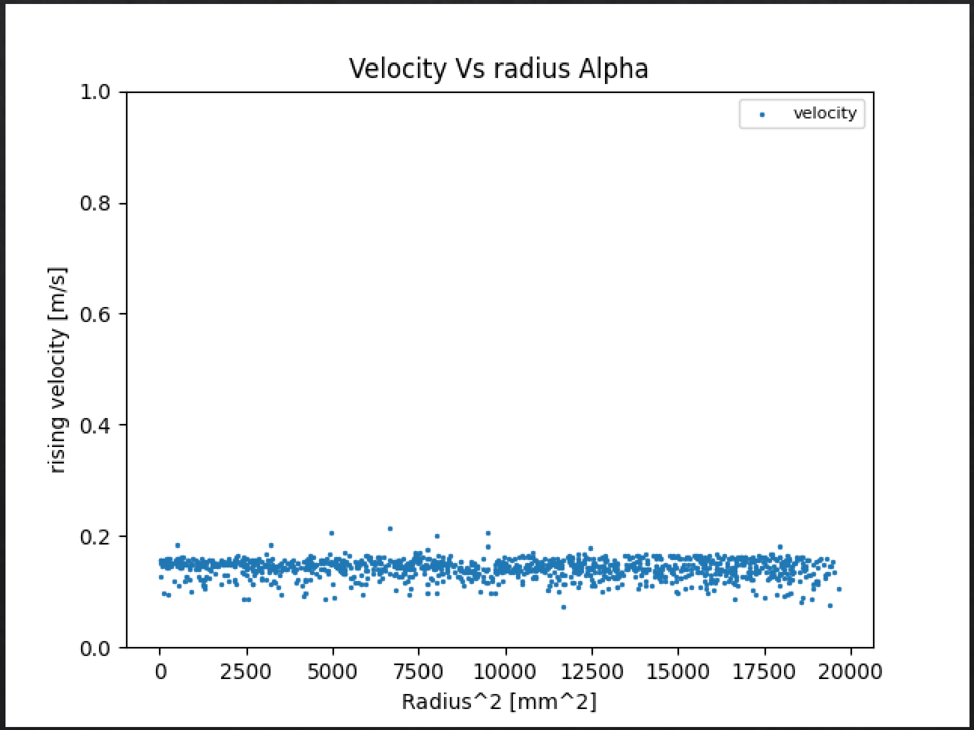


# Alphas

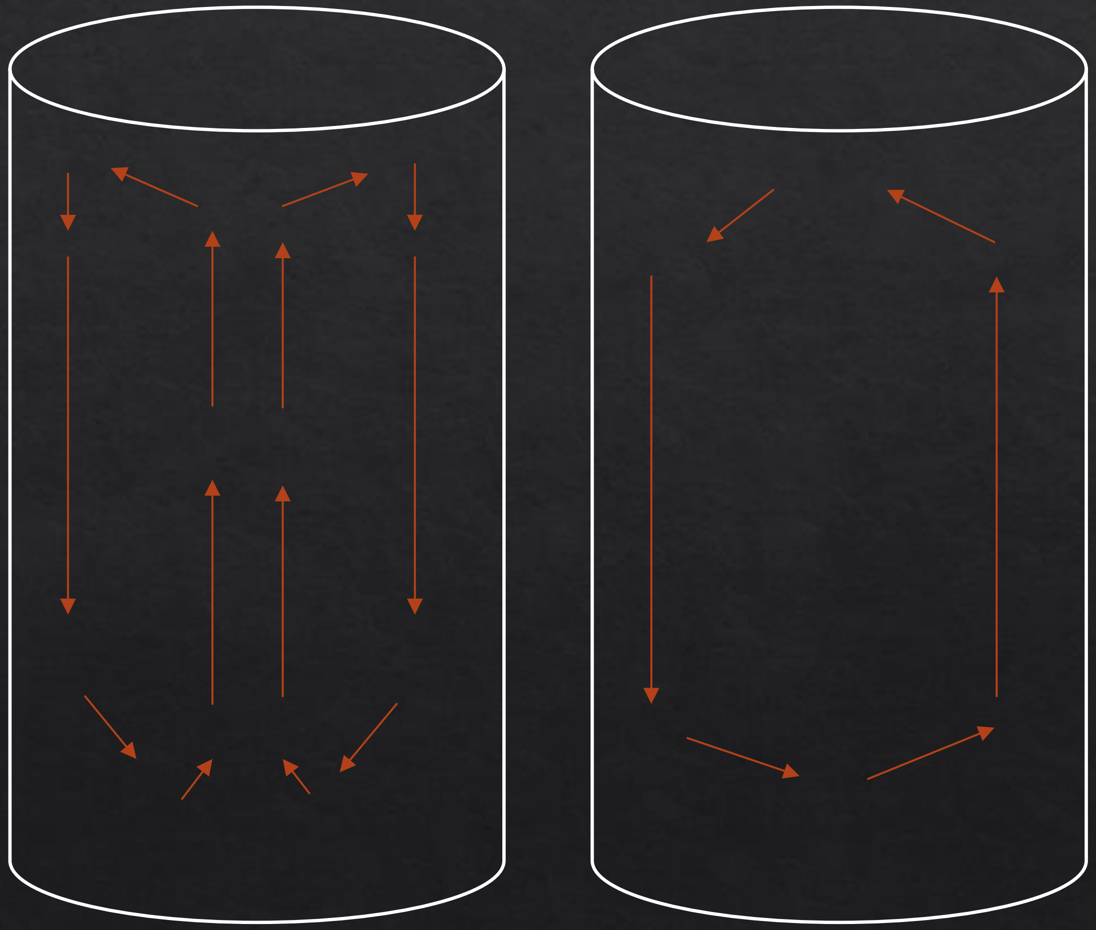
- Single Alphas: recon.AP between 2 and 4.7
- Similar data set to the bulk
- Average Velocity: 0.1424 +/- 0.0005



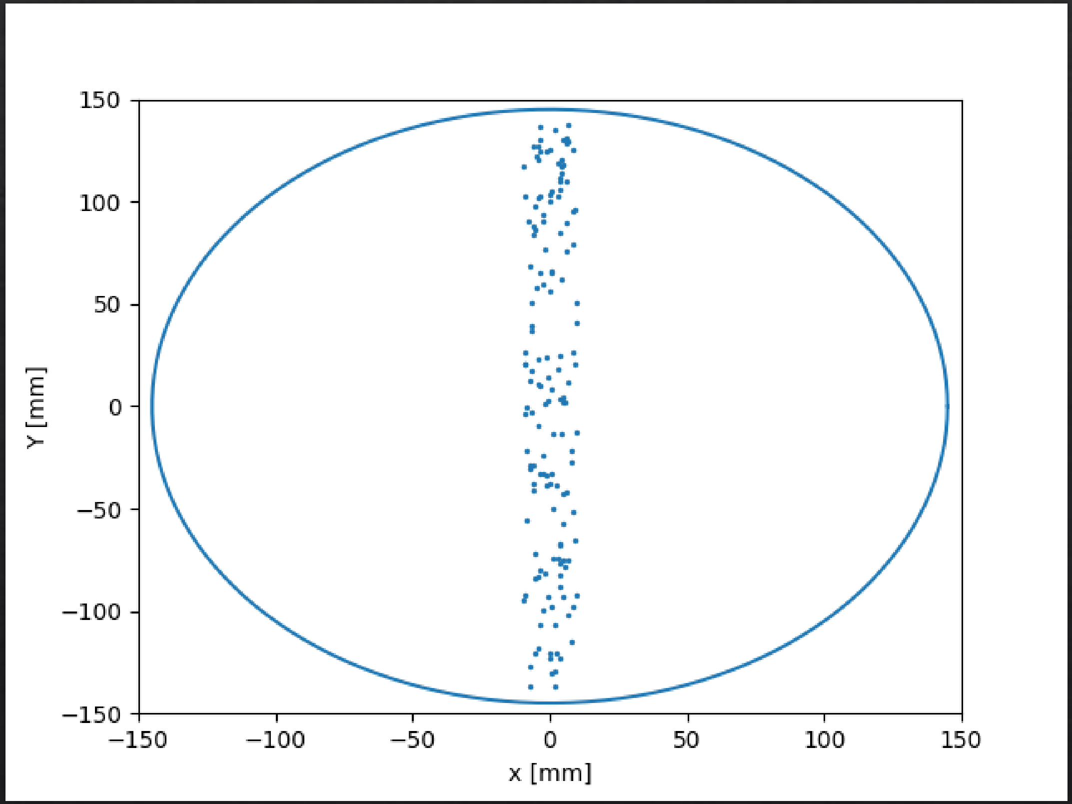



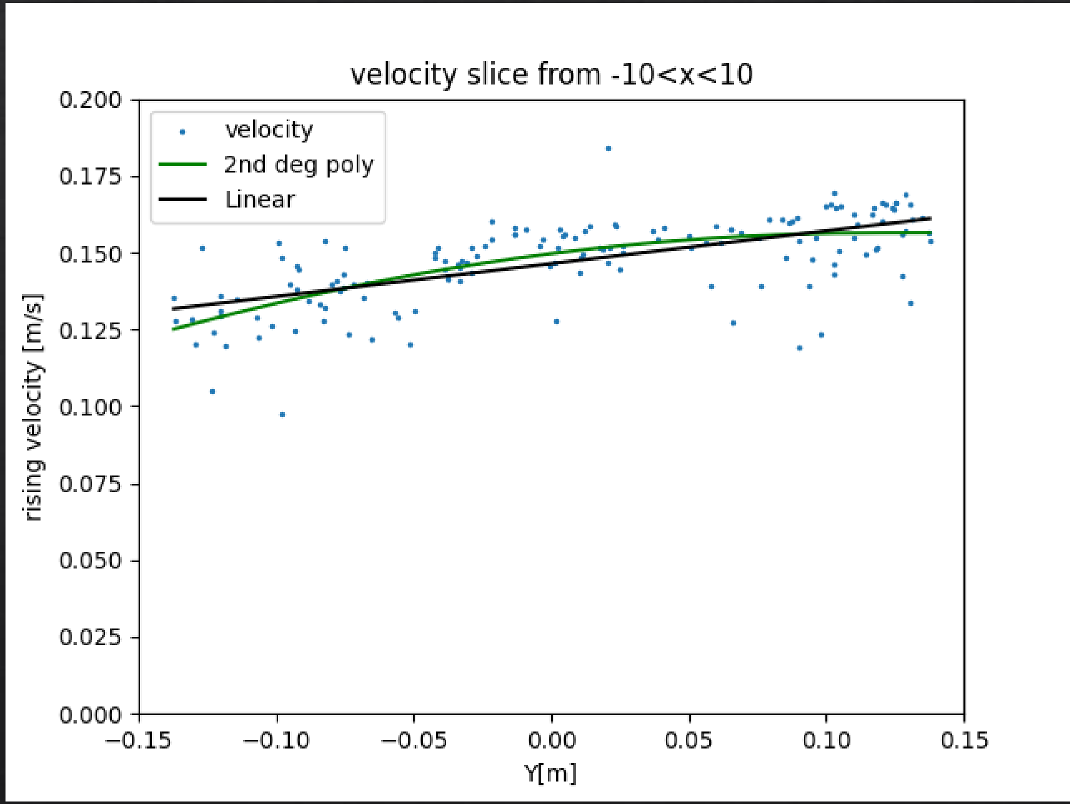
# Convection

- Two types of convection
- Looking at average velocities we can quantify this
- Start off with slice cuts and fittings, then an overall heatmap of velocities



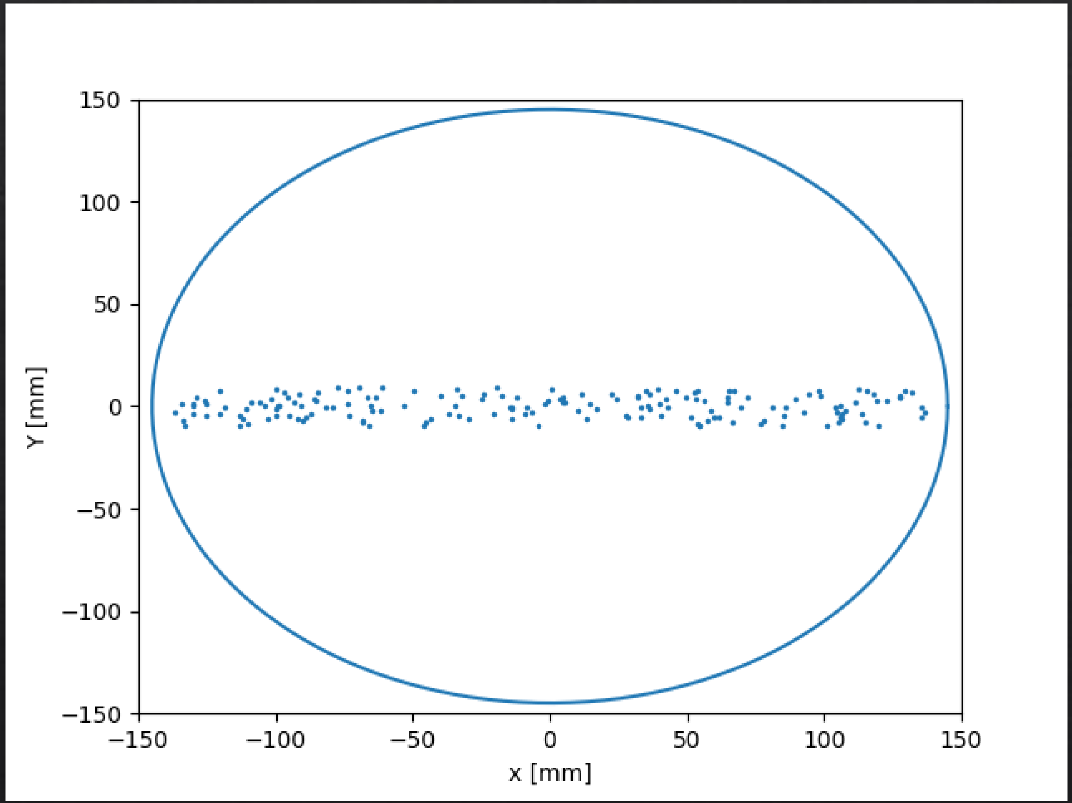
# X Slice

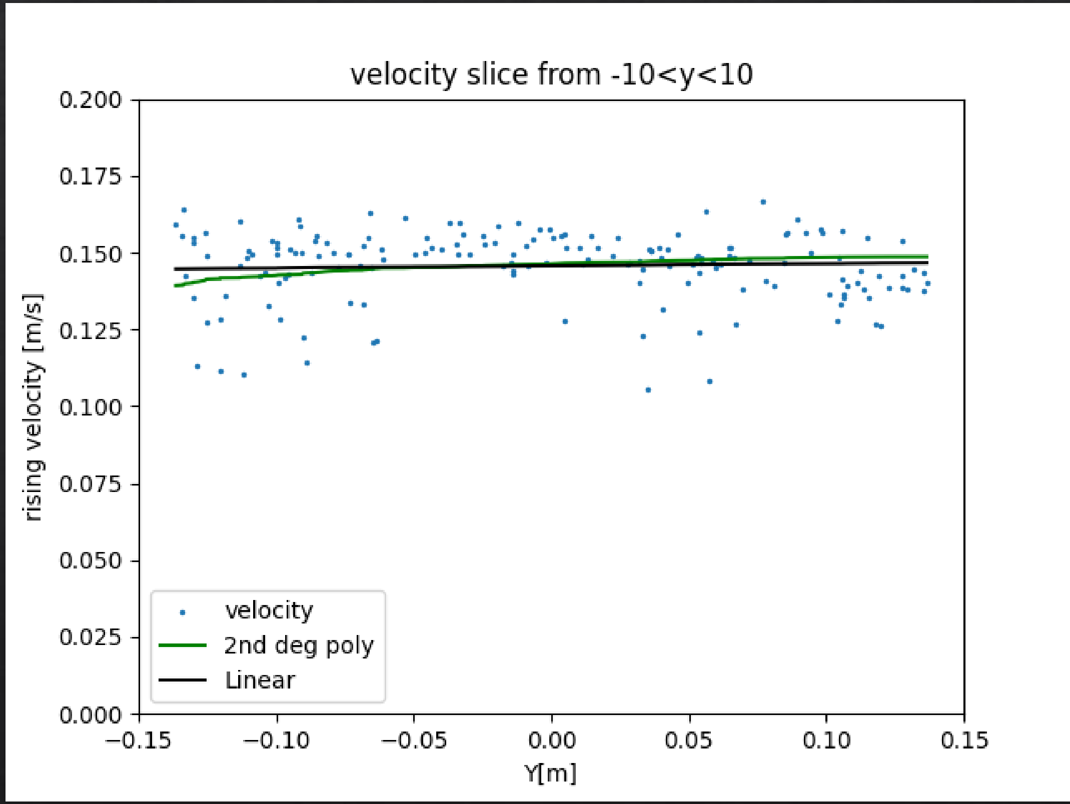



Linear regression fit: m = 0.11 +/- 0.01 (pearson) rvalue: 0.64, pvalue: 1e-18

# Y Slice

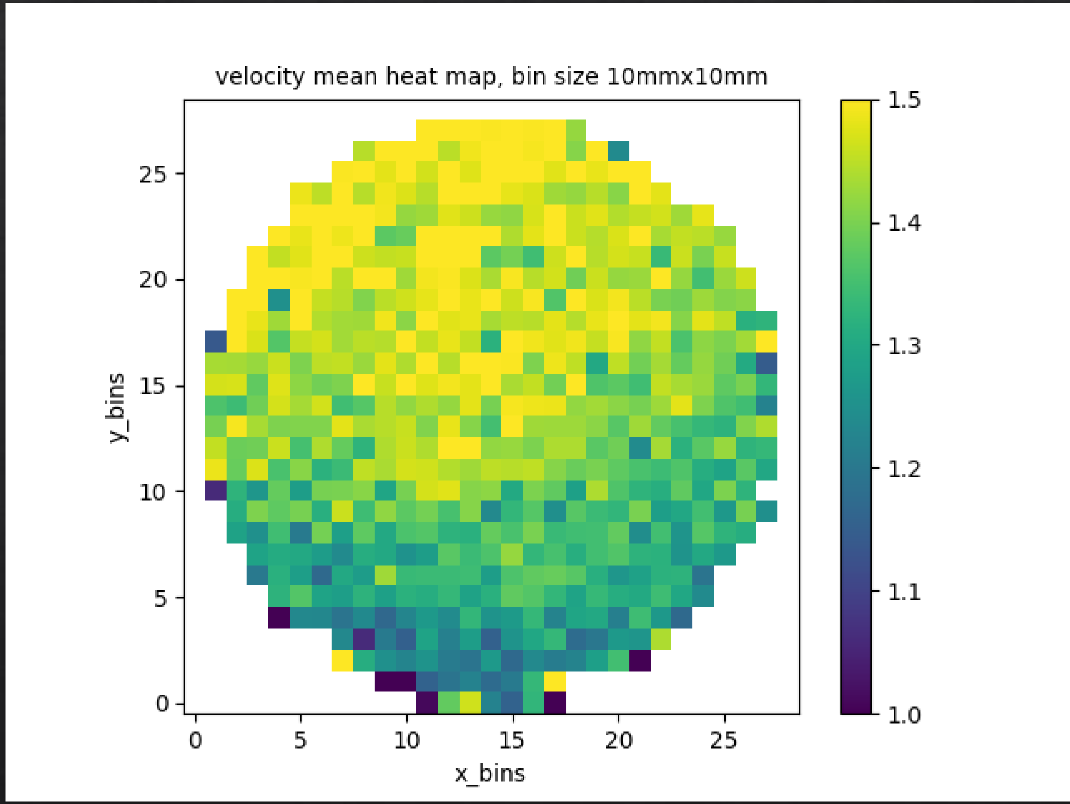


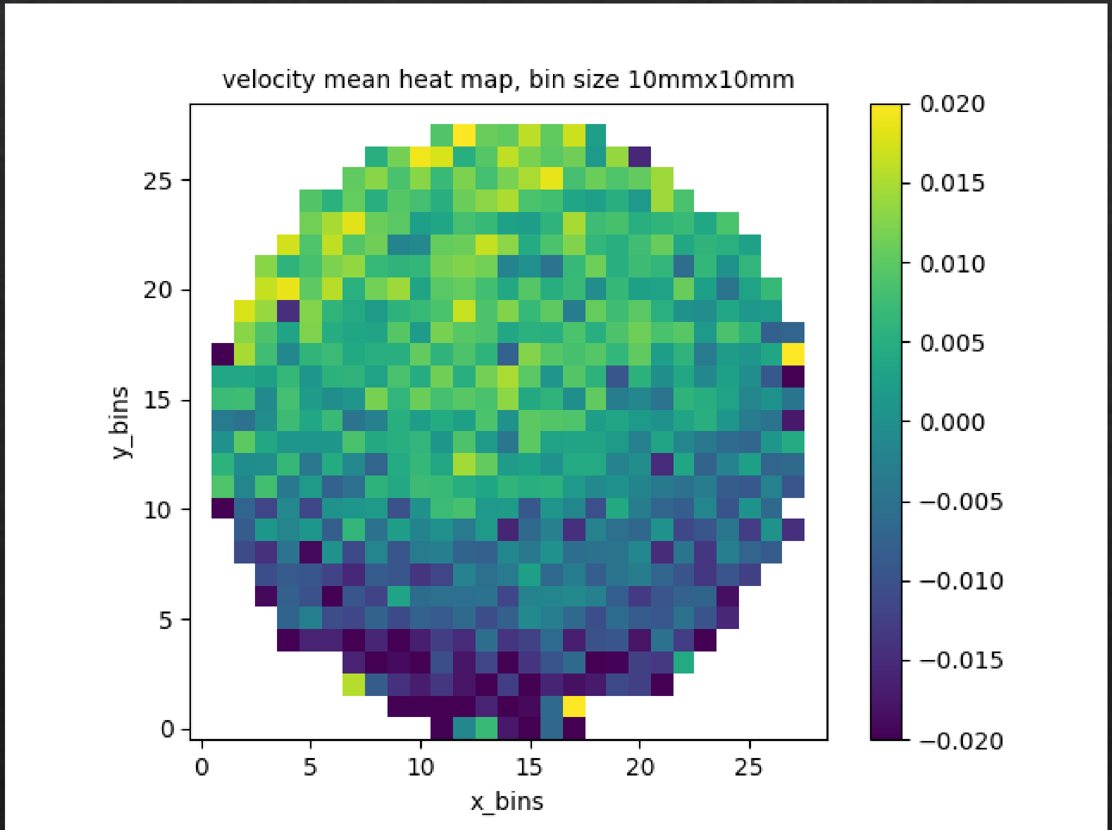

Linear regression fit: m = -0.007 +/- 0.010   (pearson) rvalue: -0.05, pvalue: 0.50

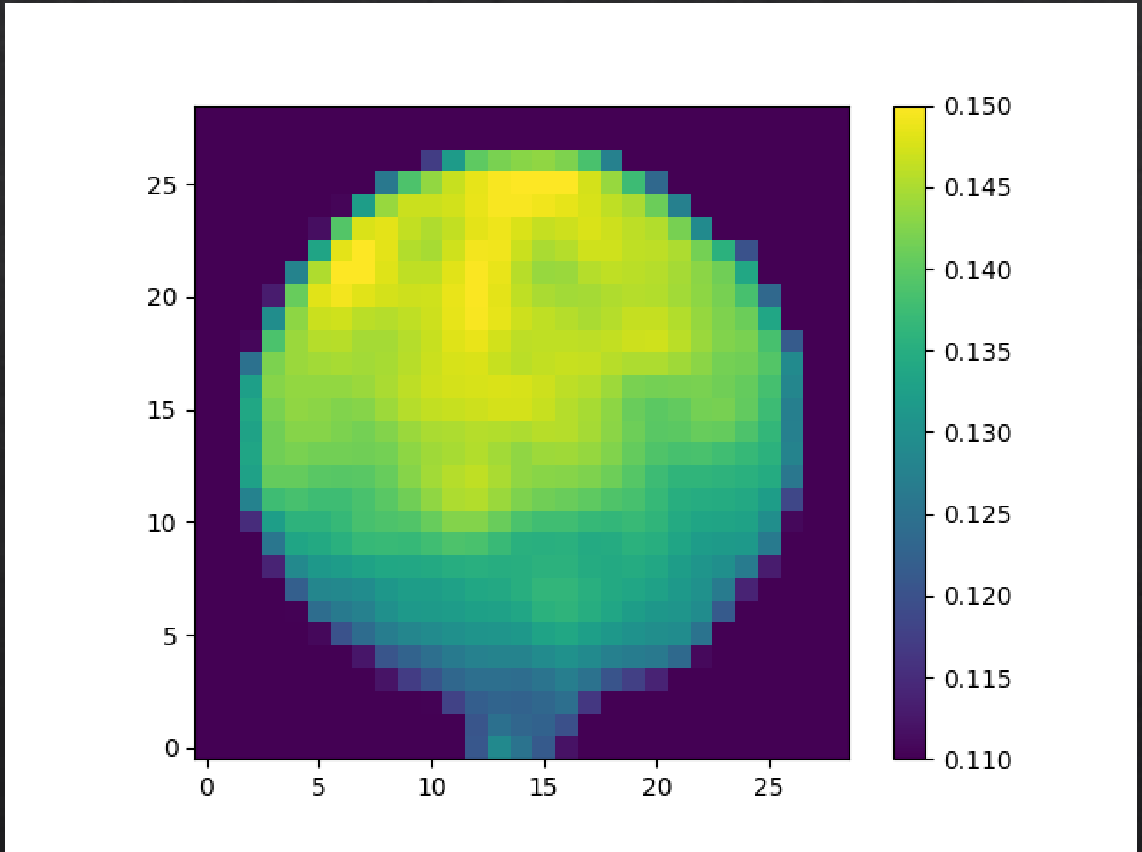
# Convection

- Heatmap of average velocity in 10mmx10mm area
- Clearly, there is a gradient
  - From the histogram and difference between x,y slices
- Difference between ends is roughly 0.03 [m/s]
  - Or +/- 0.015 [m/s] from average



Gaussian filter, sigma = 1 for Gaussian Kernel

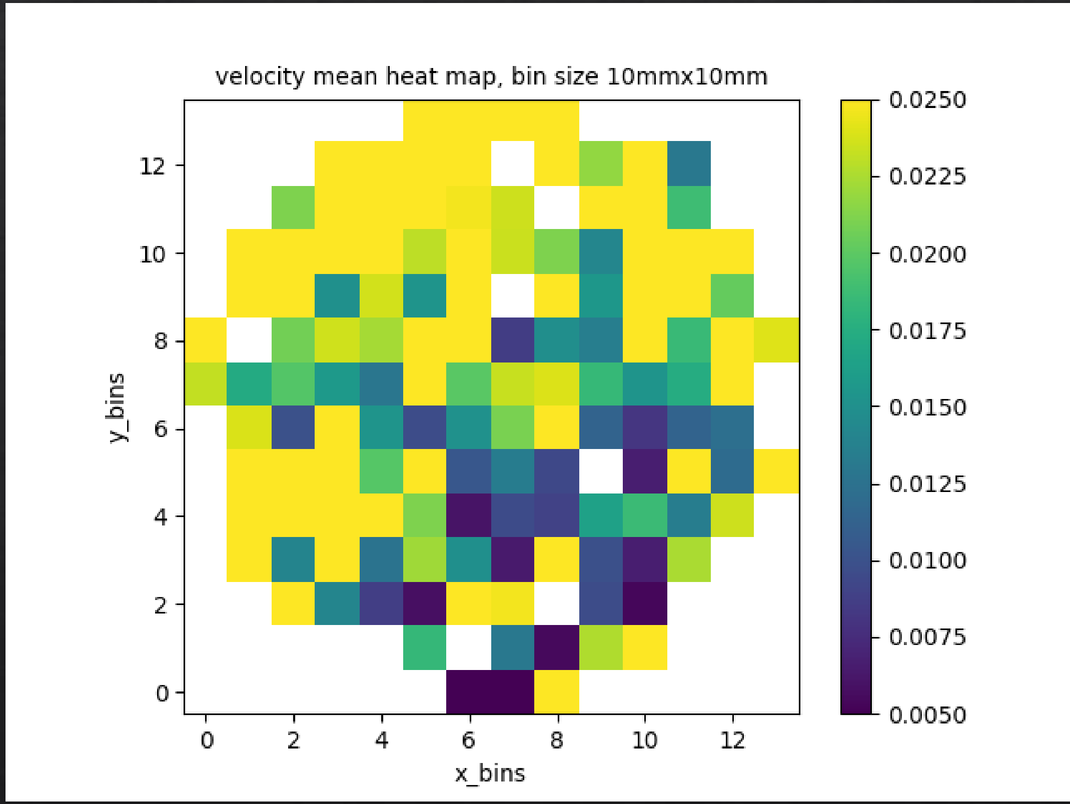



Avg: 0.144 m/s

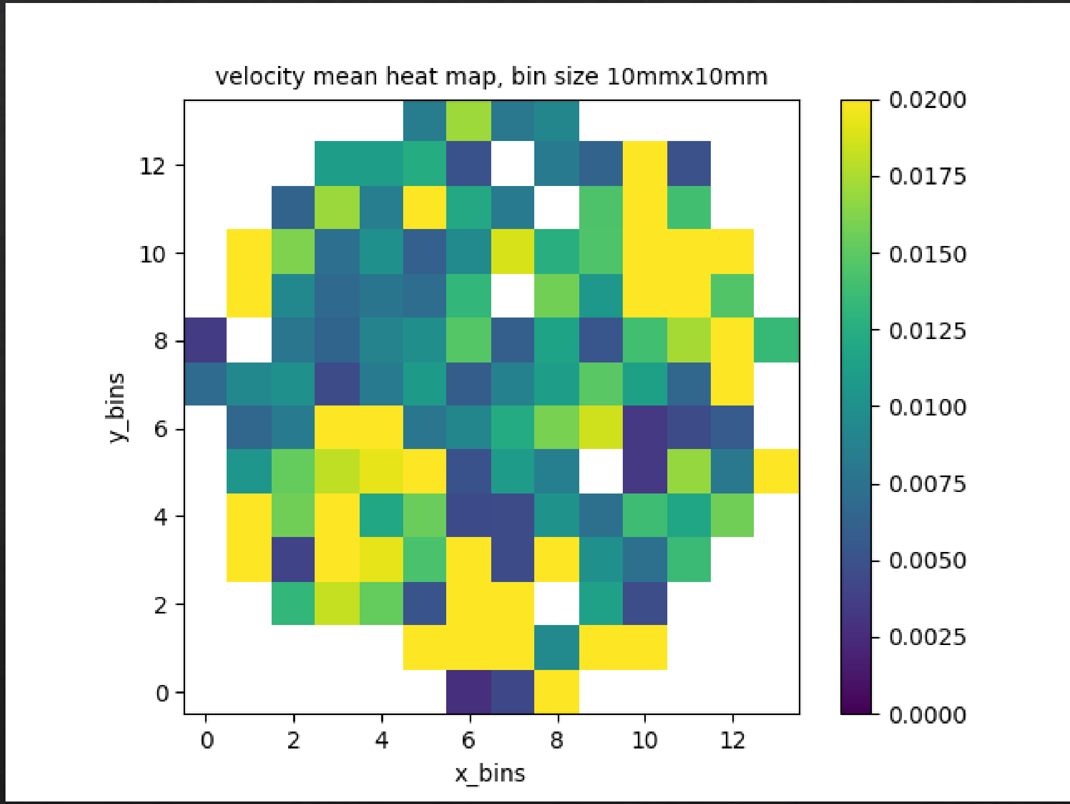
# Convection at Dome

- We expect the x,y positions to move near the top of the detector, following the convective flow pattern
- Plot of Y positions tracked near the dome
  - -50<z<100
- As bubbles rise on the far side, they will start to move towards the cameras to the near side, as shown in the heat map.



# Convection at Dome

- Similarly for the x position, at same z coordinate cut
- Currents run in the yz plane, therefore the x velocities are not very high



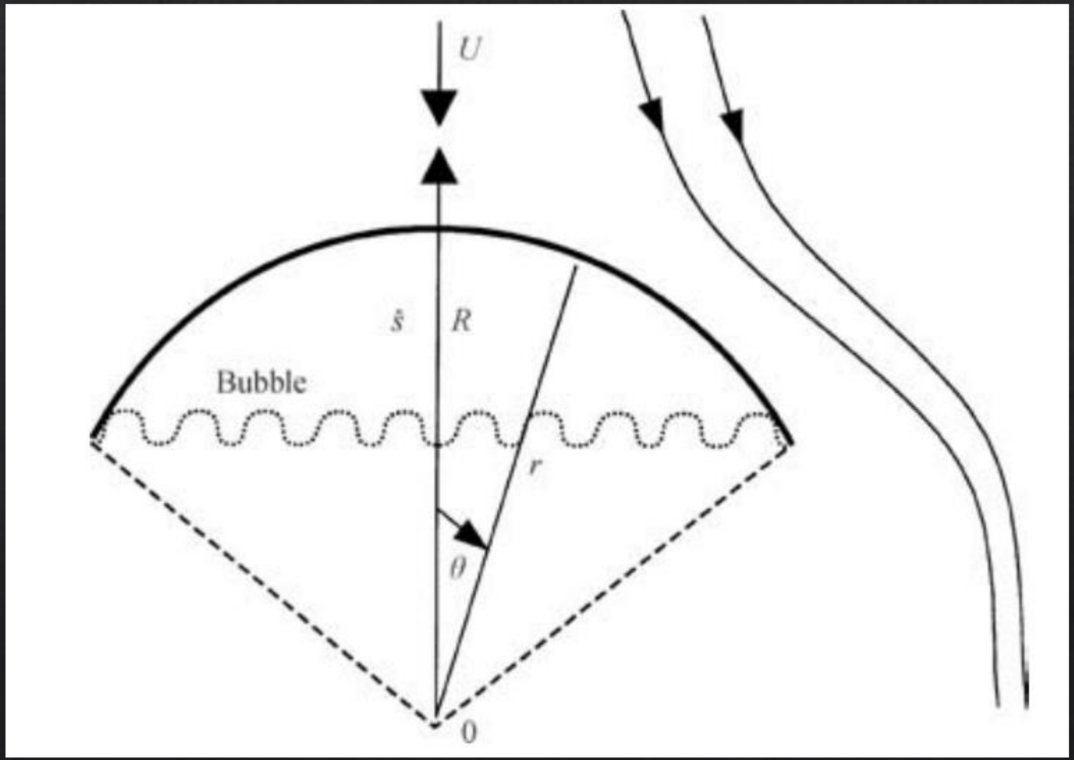

- Reconstruction near the IJ is rough, so the heatmaps didn't look very good in this region

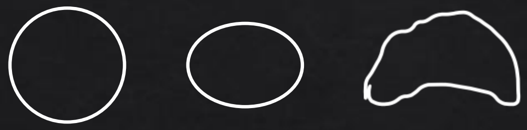
# Why is there convection?

- Possibly from the movement of the IJ
- Is this an artifact of poor reconstruction?
- Is there a known gradient of temperature in the detector?

# Bubble Shapes

- Bubble Start off Spherical, then turn into Spheroids and Spheroidal caps
- This process happens at small diameters.
  - Spherical caps form around 1 mm in diameter, tracker starts around 2mm
- Therefore, it is safe to say all tracked diameters of PICO follow this model.



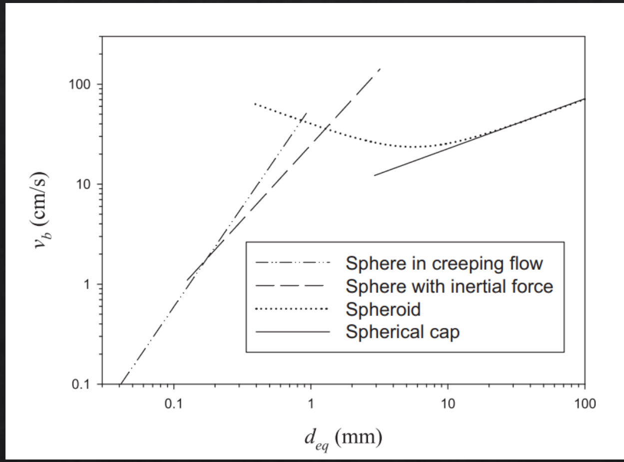



# Relationship Between Velocity and Radius

- Found one paper on the matter [1] (besides a few textbooks from the 50s)
- Derived the Rising velocity for Spherical cap bubbles

$$\frac{U}{\sqrt{gD}} = -\frac{8}{3}\frac{\nu(1+8s)}{\sqrt{gD^3}} + \frac{\sqrt{2}}{3}\left[1 - 2s - \frac{16s\sigma}{\rho g D^2} + \frac{32\nu^2}{gD^3}(1+8s)^2\right]^{1/2},$$

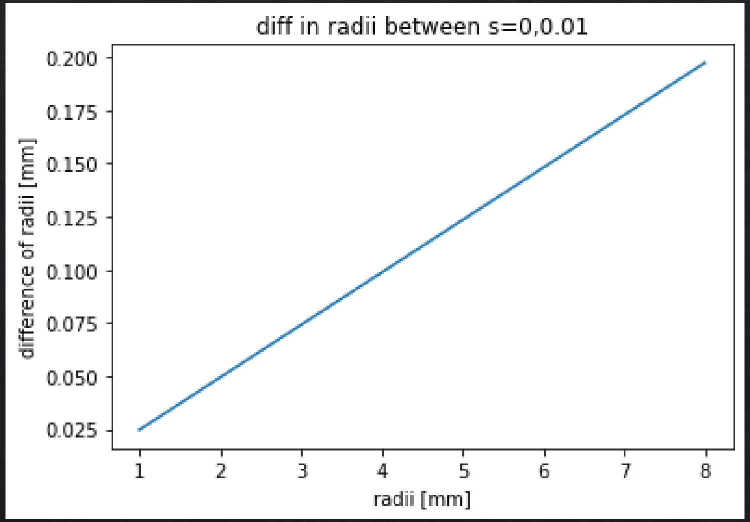
- p is density, v is kinematic viscosity of liquid, sigma is surface tension, D is diameter, U is rising velocity, and s is the deviation of the free surface from perfect sphericity

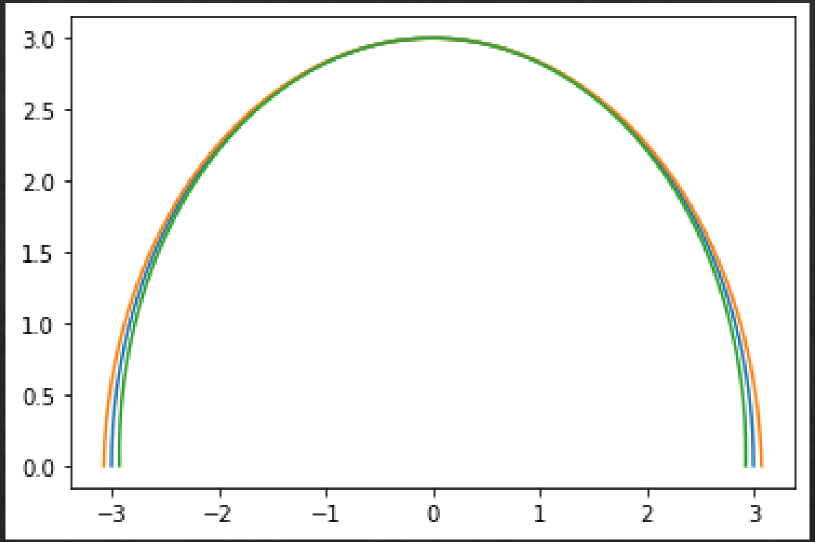


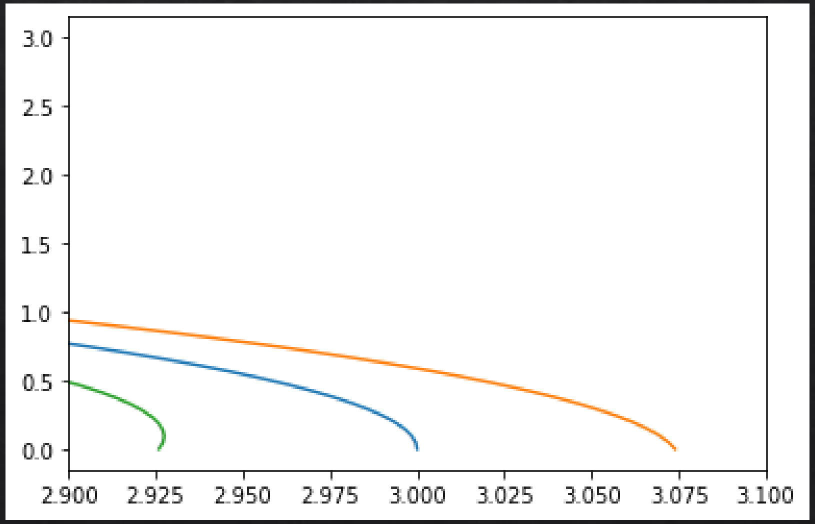

[1] D. Joseph, T. Funada, and J. Wang, "Rise velocity of a spherical cap bubble," *Potential Flows of Viscous and Viscoelastic Fluids*, pp. 42–50. doi:10.1017/cbo9780511550928.008

# Change in radii

- R(theta) = r(1+s * theta^2)
  - Change of 0.01 in s for plot
  - results in 0.075 mm change for 6mm dia bubble (at max)
  - Assume 5% error in reconstruction values, these changes are well within this

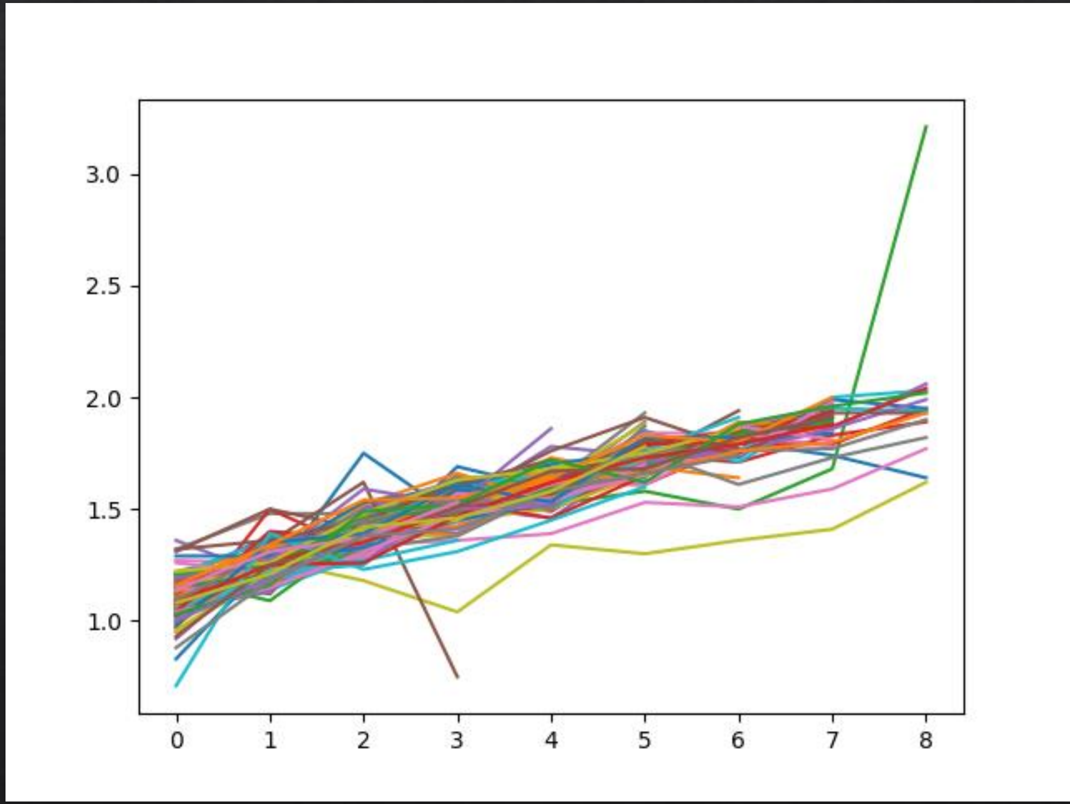


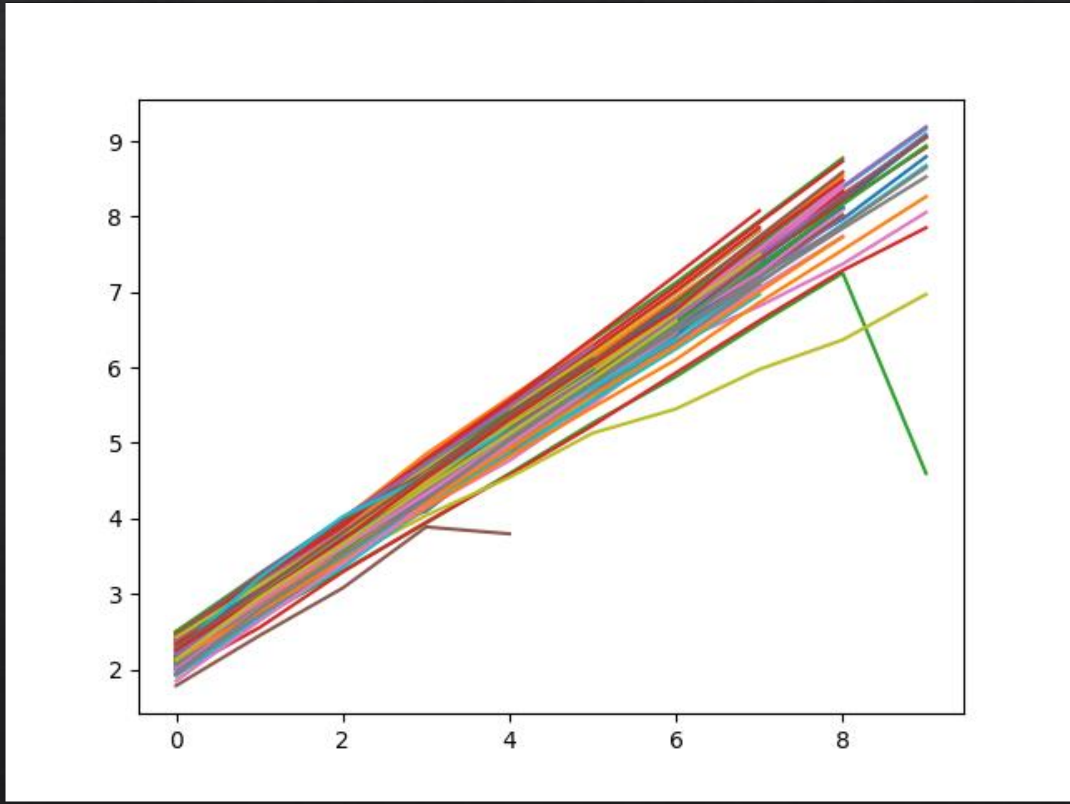
# Tracked Velocities

- Tracked velocities over 10ms intervals
- Initial thought was a square root dependence



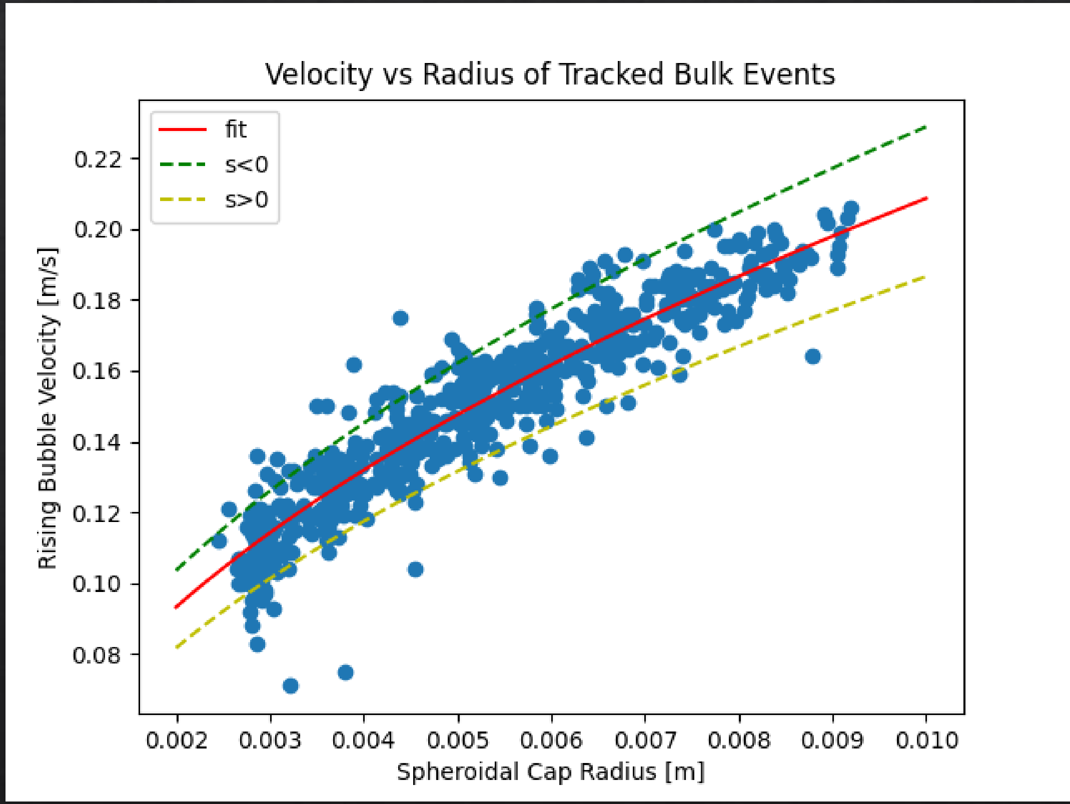
# Tracked Radii

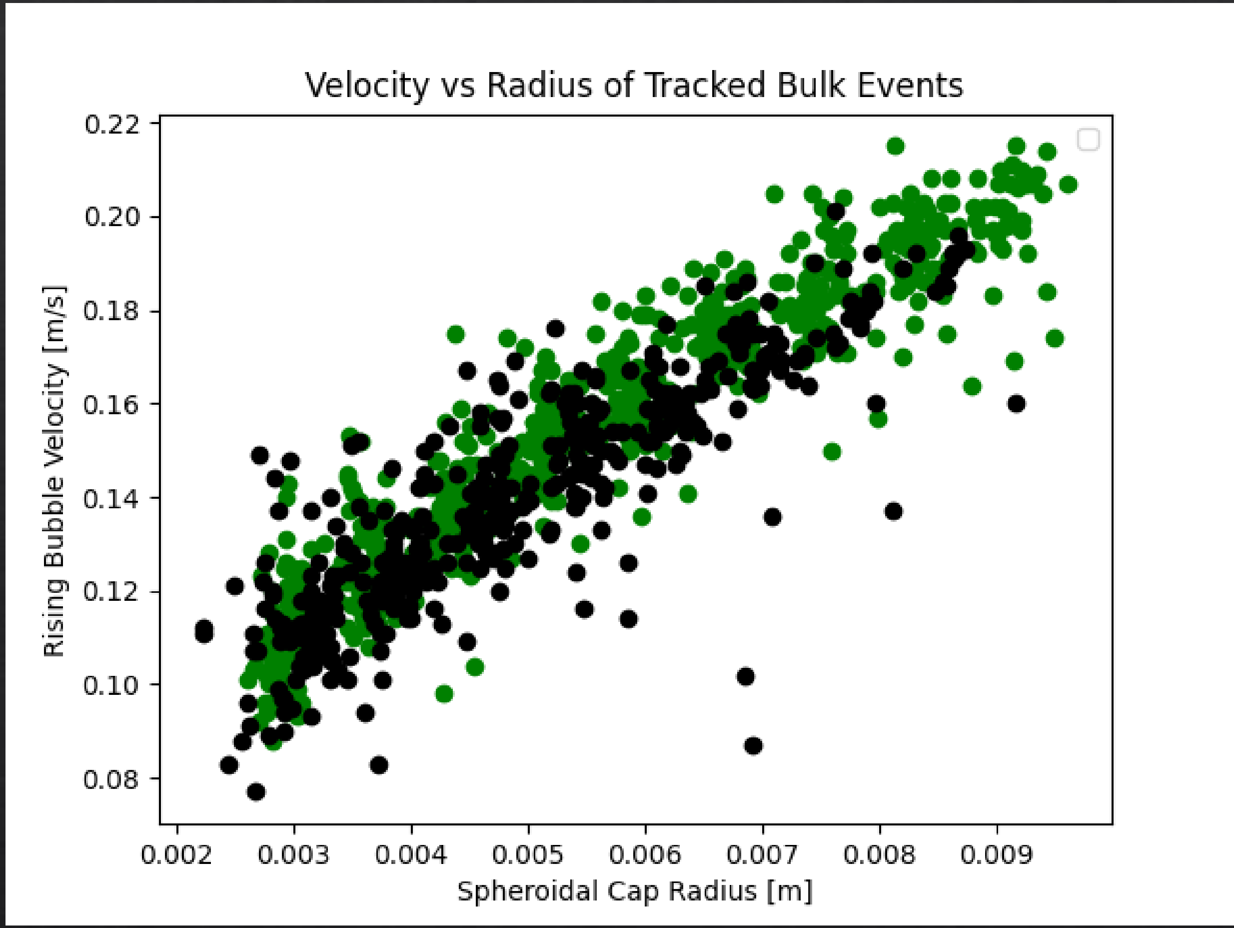
- Tracked radii over 10ms intervals
- Linear relationship in the bubble growth radius



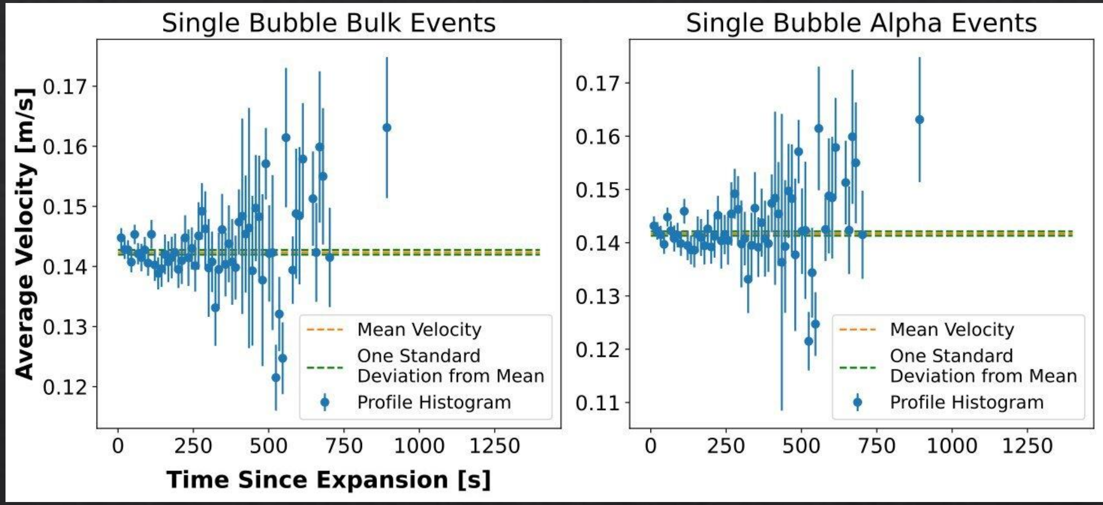
# Bubble Velocity vs Radii and Fits

- S = 0.0007 +/- 0.0020
  - Std: 0.01 [m/s]
- On average, the top hemispheres follow a perfectly spherical shape
- Green line: s = -0.01
- Yellow Line: s = 0.01
- A larger s means the bubble is blunted, so more drag and lower velocity
- A smaller s means its pointed, so less drag and higher velocity






Made by Chris (undergrad at UofA)




Green: Y>0
Black: Y<0

# Conclusion

- Convection
  - Clear signs visually and statistically
- Theoretical equation for velocity of bubble rising
  - Coefficient describing bubble shape explained
- Code is almost ready to submit
- Document rough draft done
- Moving forward
  - Track velocities over time, with the online monitoring page
  - Make some contour plots

# Thank you

Questions?

# Extra slides

The spherical cap bubble (figure 1) arises in the motion of large gas bubbles which take a lenticular shape. The analysis of the rise velocity of these bubbles which was given by Davies & Taylor (1950) is unusual since it is not computed from a balance of the drag and buoyant weight as it is for spherical gas bubbles (Levich 1949; Moore 1959, 1963; Taylor & Acrivos 1964; Miksis, Vanden-Broeck & Keller 1982; Ryskin & Leal 1984). Batchelor (1967) notes that "The remarkable feature of (the Davies–Taylor analysis) is that the speed of movement of the bubble is derived in terms of the bubble shape without any need for consideration of the mechanism of the retarding force which balances the effect of the buoyancy force on a bubble in steady motion".

[1] D. Joseph, T. Funada, and J. Wang, "Rise velocity of a spherical cap bubble," *Potential Flows of Viscous and Viscoelastic Fluids*, pp. 42–50. doi:10.1017/cbo9780511550928.008

[2]Batchelor, G.K. (1967) An Introduction to Fluid Dynamics. Cambridge University Press, San Diego, p. 203.