Collisions of Cloud Droplets with a Rain Drop Investigated in the Mainz Vertical Wind Tunnel

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A Introduction

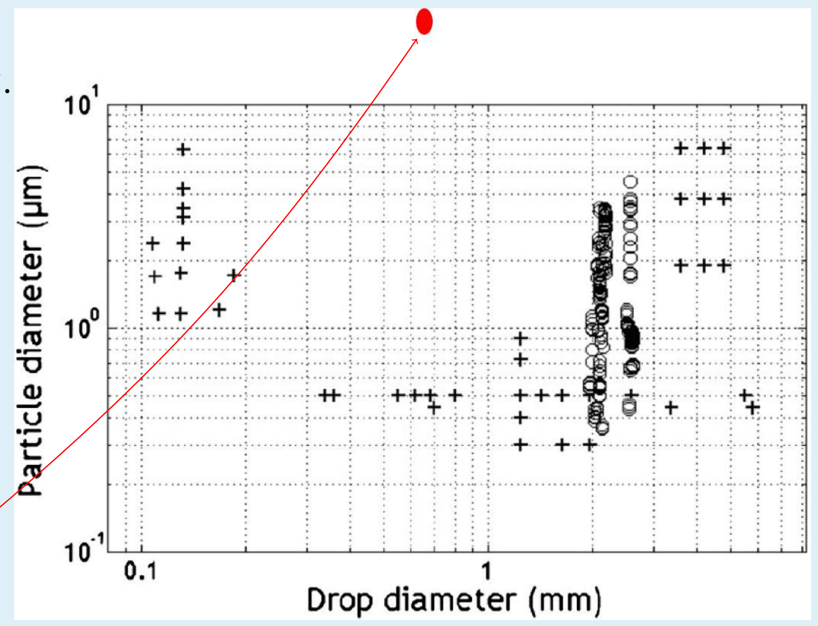
The collision–coalescence or collection process of droplets by drops is an important process in precipitation formation (Vohl et al., 2007) and aerosol scavenging by rain (Querel et al., 2014) especially from the point of view of cloud and climate models (Grabowski and Wang, 2013).

For the last few decades, measurements of collision parameters are based on measuring the collection integral, assuming constant conditions, and then inferring the collection efficiency in the integral:

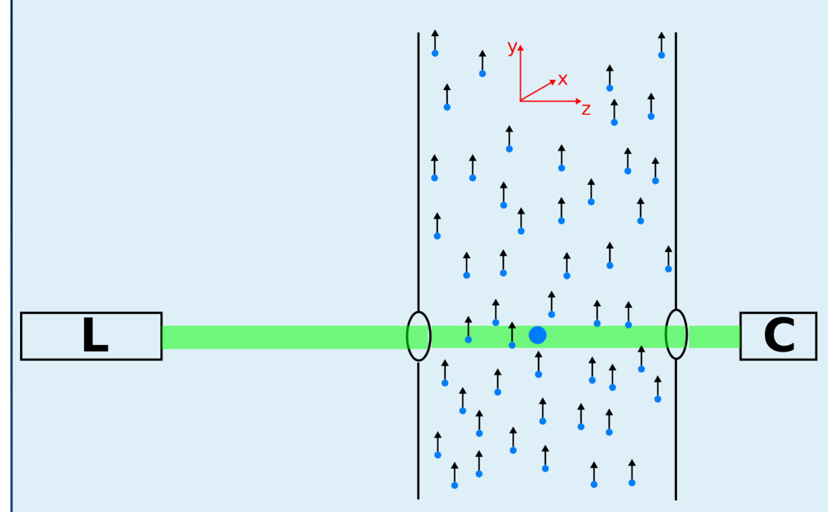
$$\frac{dM}{dt} = \int m(r)n(r)\pi(R+r)^2[V(R)-V(r)]\underline{E(R,r)}dr.$$

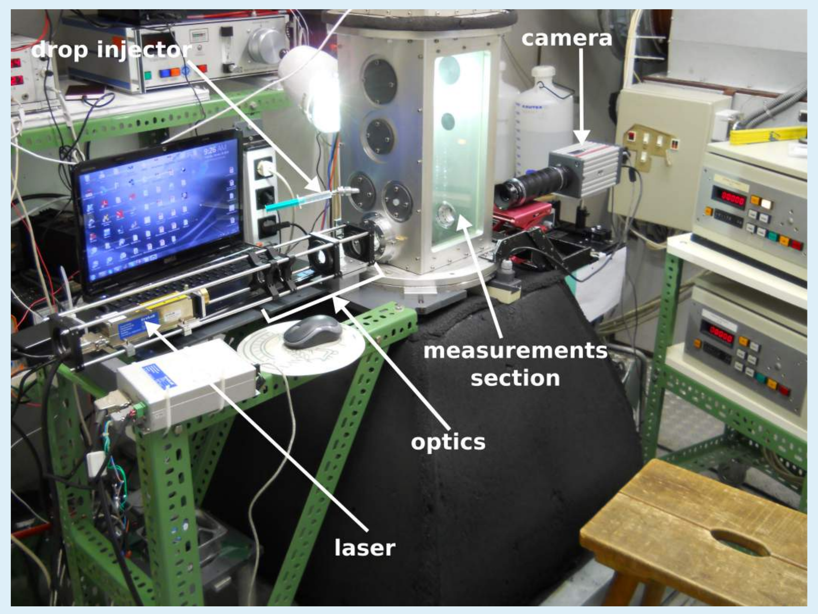
With digital in–line holography, we are able to measure the integrand directly, i.e. to measure the collision events themselves and their surrounding conditions simultaneously. To show proof of concept, we carried out an experiment in the Mainz vertical wind tunnel in a laminar flow using in–line holography. We have also chosen droplet and drop sizes that have not yet been measured (Querel et al., 2014).

We present details of the experimental setup, characterize the flow and show statistics of 105 collisions found in the data set length of ~45 s.



B Experimental setup





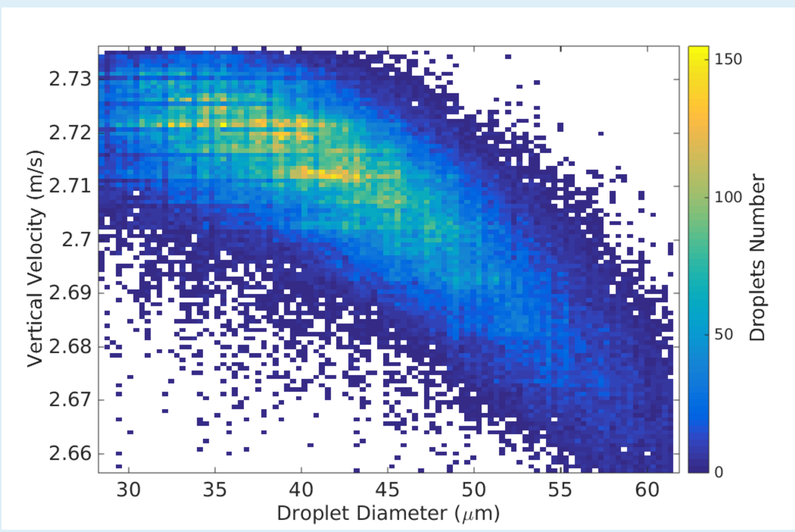
- L – laser
  - wavelength: 532 nm
  - frequency: 1040 Hz
- C – camera
  - resolution: 1280 × 1024 px
  - frame rate: 1040 fps
  - pixel size: 9.15 μm
- measurement section
  - sample volume dimensions: (x, y, z) = (9, 180, 12) mm
  - sample volume: 20 cm³

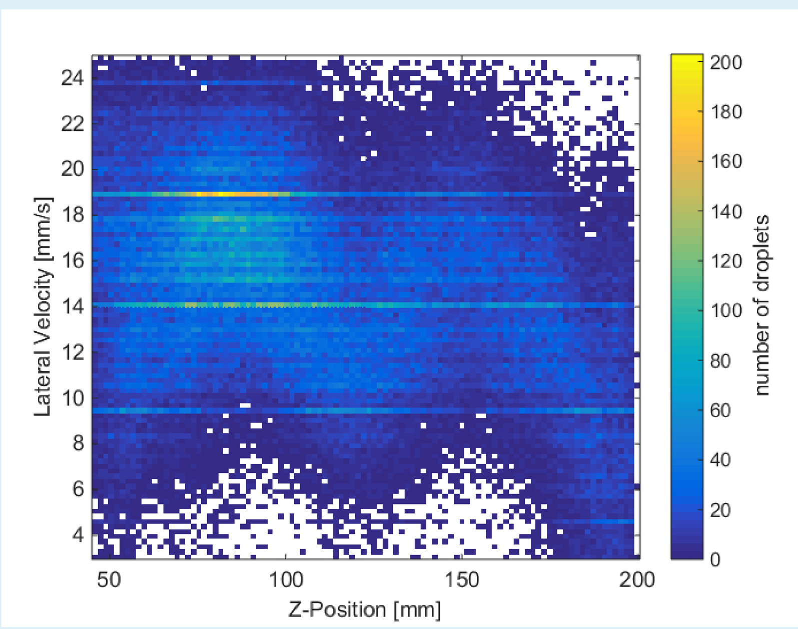
C Data set

- 17 data sets of 700–5550 holograms in each
- 46415 holograms in total what means ~45 s of data

D Flow structures

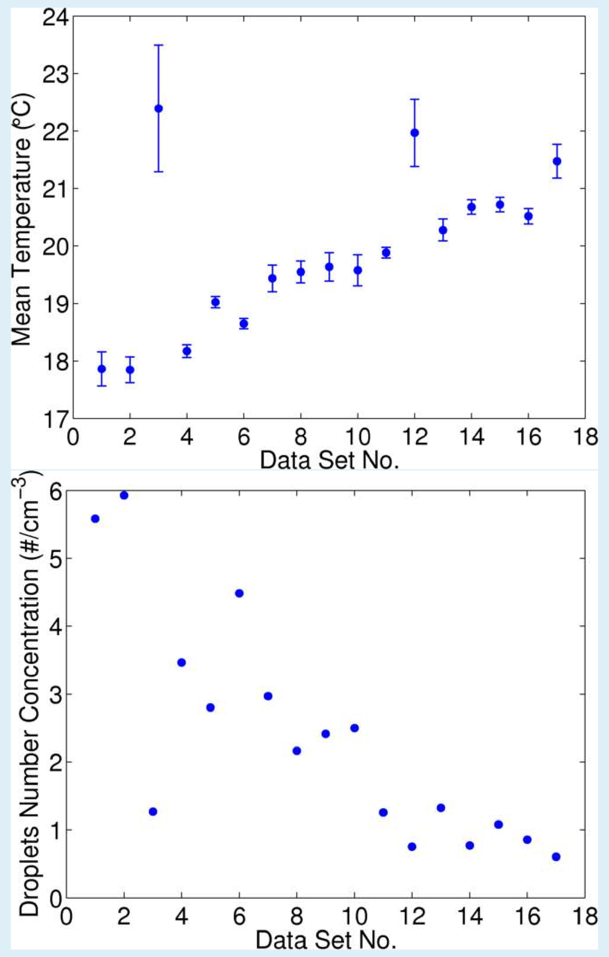
- on the basis of data set no. 9

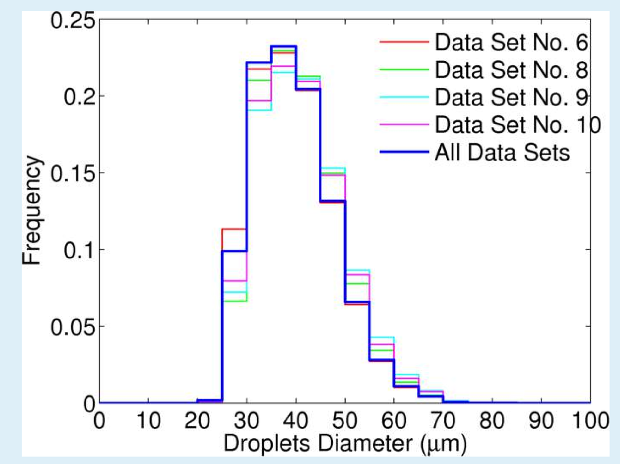




- Particle size is unbiased and uniform with position in the flow.
- Vertical velocity is laterally uniform in the sample volume.
- Droplet size has a strong correlation with its vertical velocity showing the expected dependence of sedimentation velocity on droplet size (left figure).
- Lateral velocity shows weak correlation with the lateral position (right figure).

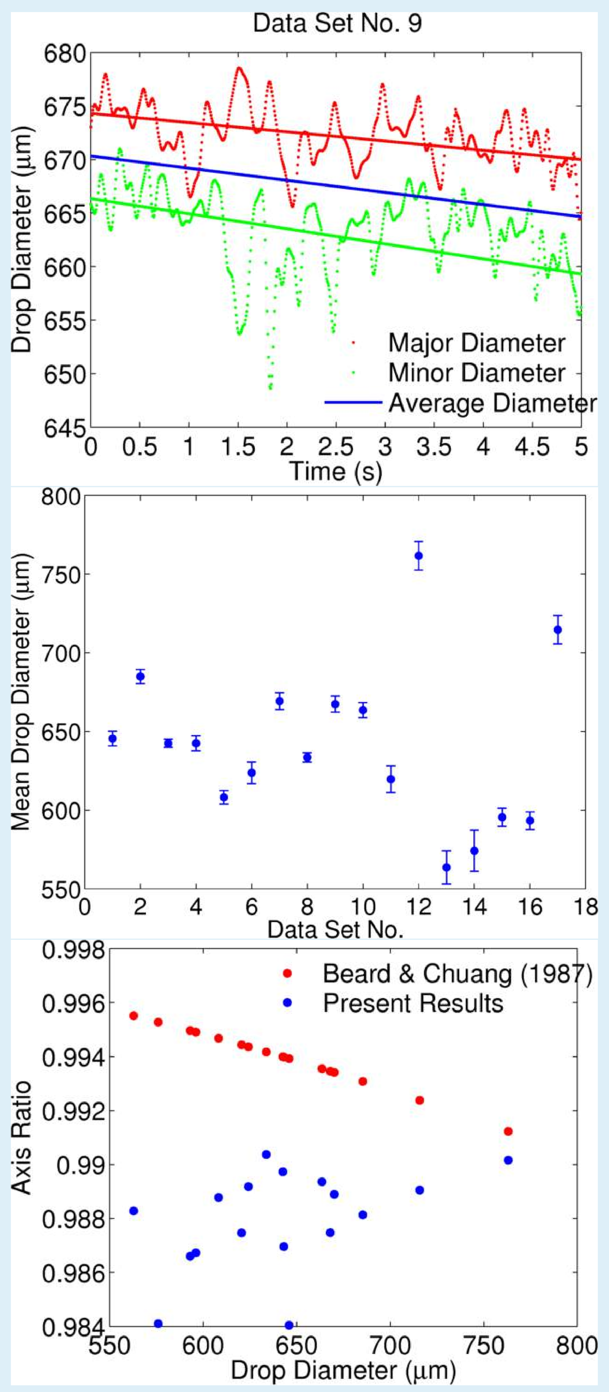
E Environment of collisions

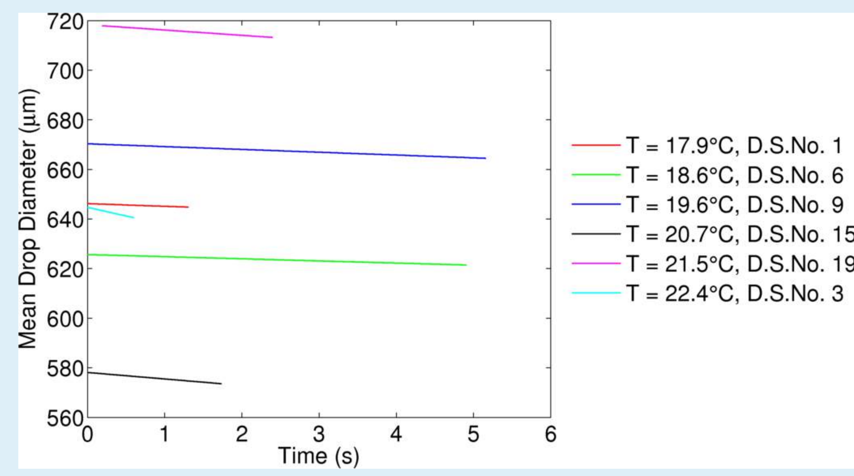




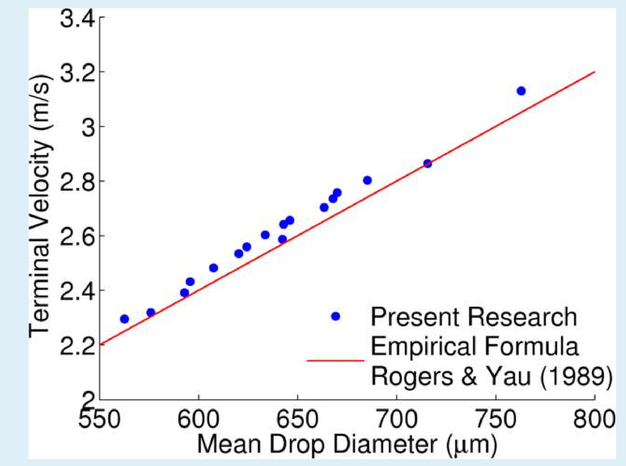
- Temperature: 17–23 °C
- Droplets diameters: 20–70 μm
- Density: 1–6 droplets/cm³

F Rain drops



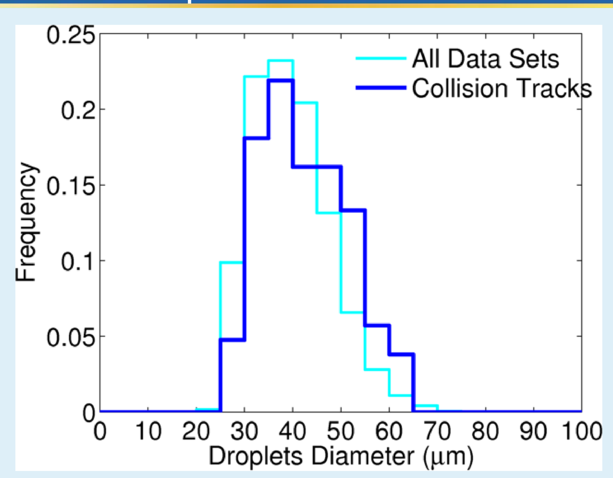


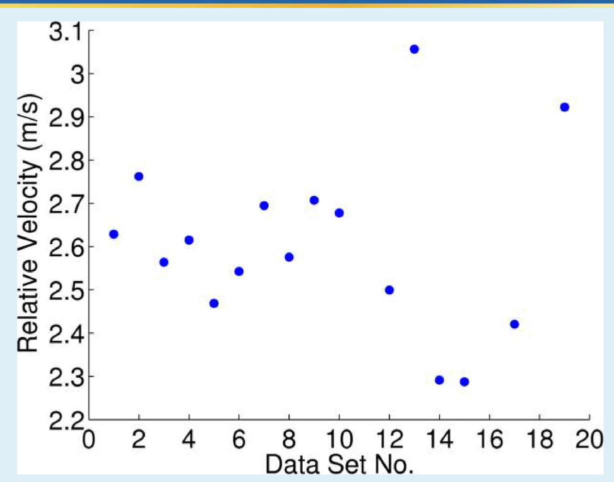
- Rain drop size shrinks in time, as evaporation is stronger than growth by collision-coalescence
- Drops diameters: 550–800 μm



- Terminal velocity: 2.3–3.1 m/s
- The minor diameter of a fitted ellipse about the rain drop is rather consistently one pixel or ~10 microns smaller than the major diameter perhaps due to droplet asphericity due to its fall (Szakall et al., 2010).

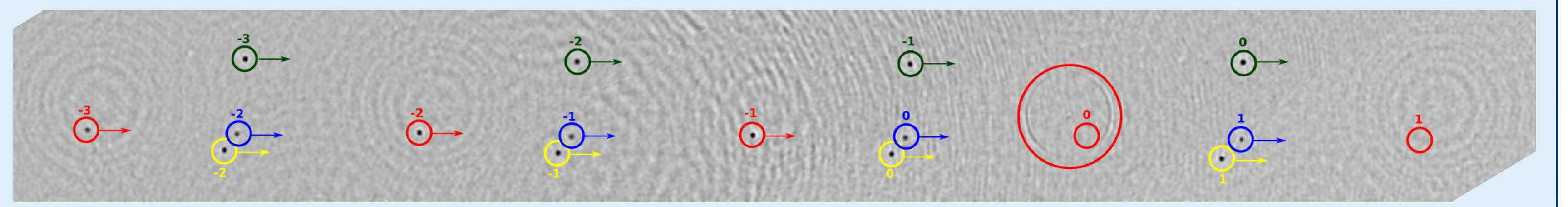
G Collision parameters

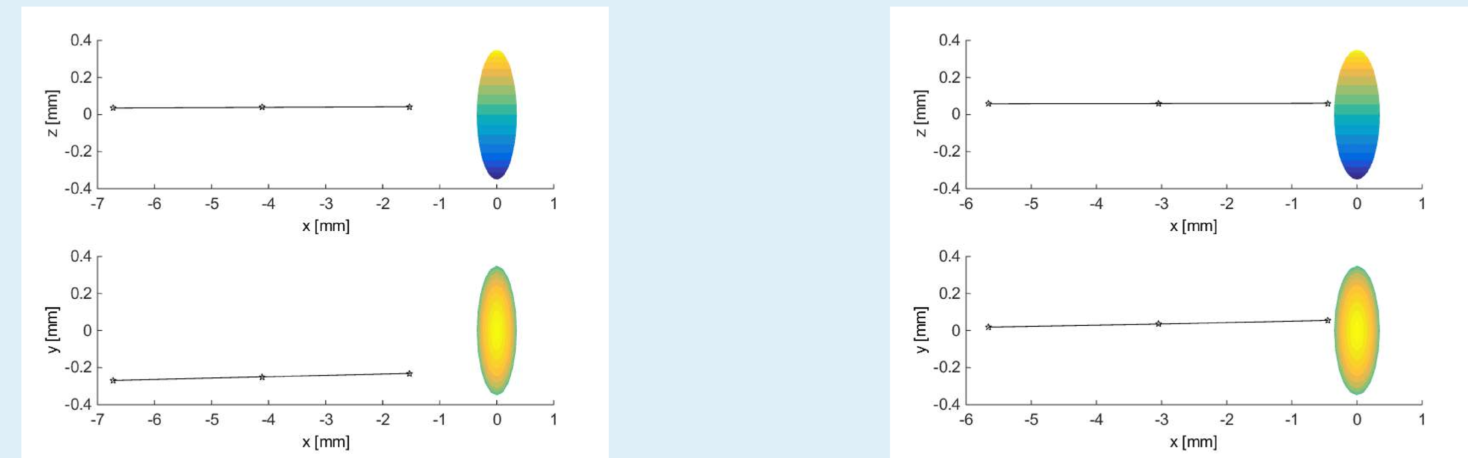




- Relative velocity for collision tracks: 2.3–3.1 m/s

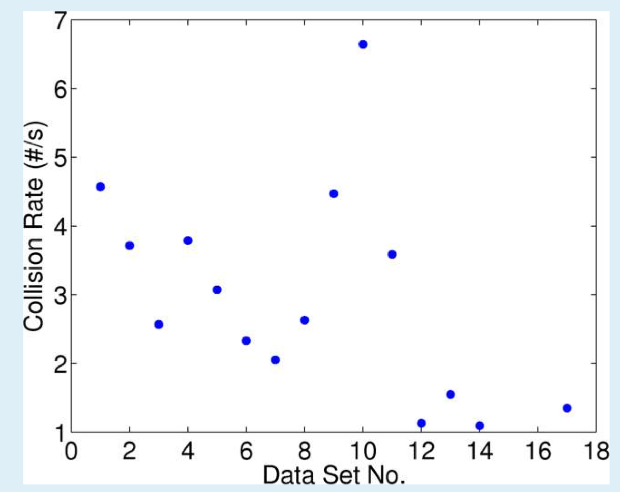
H Examples of single collisions

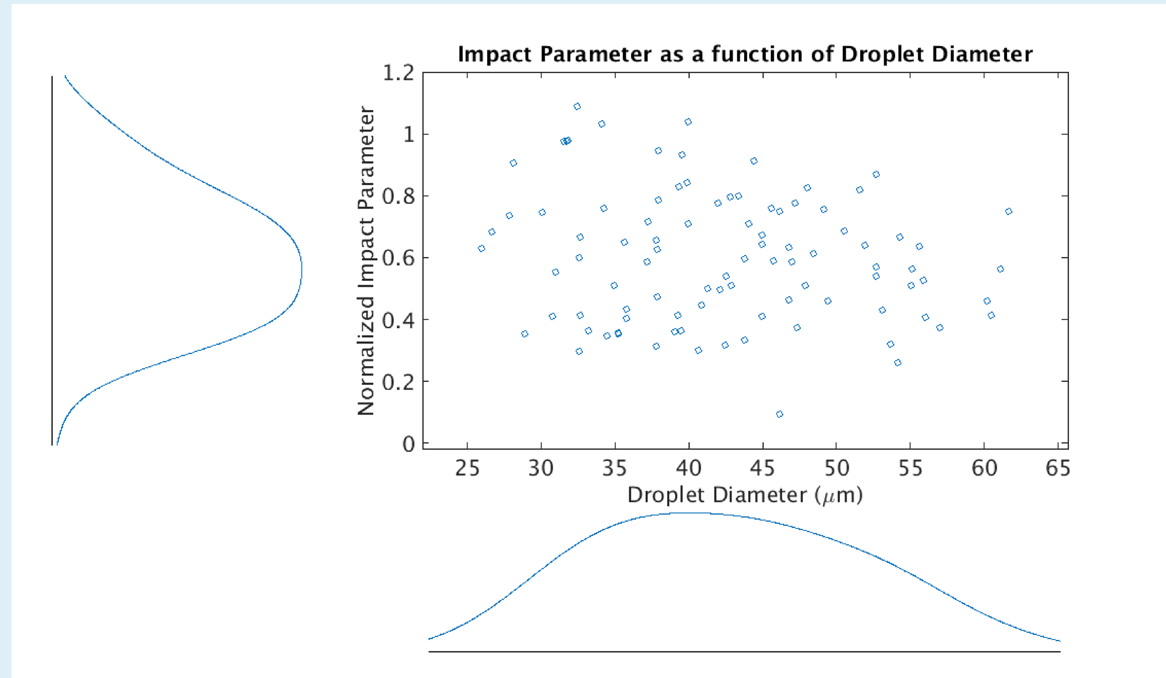




I Collision statistics

- 105 collisions confirmed manually
- 1–7 collisions per second
- 54 probable collisions that can not be confirmed bacause the drop was close to the edge of the hologram
- 1 to 4 point trajectories
- Histogram on the left shows distribution of impact parameter.





J Conclusions

- Proof of concept that we can observe collisions and likely–collisions of cloud droplets with rain drops in the Mainz vertical wind tunnel.
- We found 105 collisions and 54 probable collisions in 45 seconds of data.
- Drop and droplet sizes, impact parameter, flow characteristics (velocity field) are simultaneously measured.

K Future work

- We will use a filter to obtain more precise positions and sizes of the droplets in the collision tracks to refine the impact parameter and relative velocity.
- Higher–resolution and higher frame–rate camera to have better resolved tracks.
- More measurements of different droplets and drops sizes.
- Further automate detection of collision and likely–collisions.
- Automate droplet injection.

L Acknowledgements

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M References

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