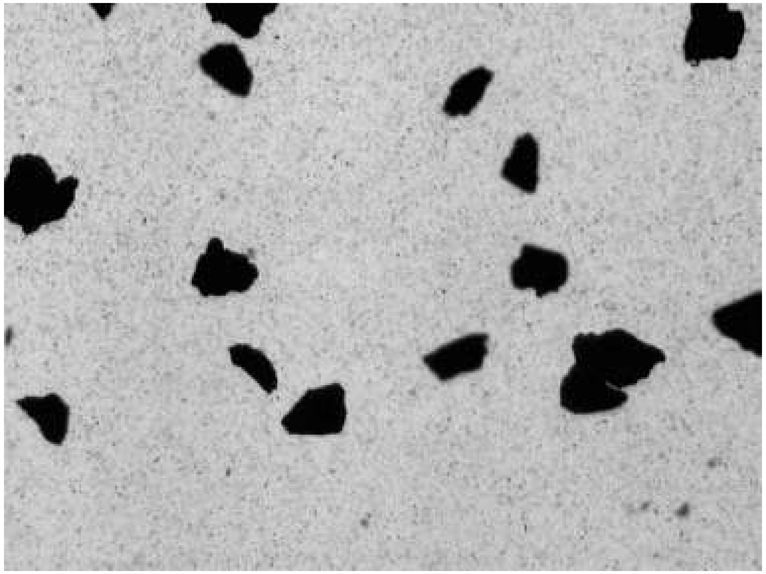
# Experimental Analysis of the Wall Collision of Irregular and Regular Shaped Non-Spherical Particles

M. Sommerfeld and Z. Qadir

**Mechanische Verfahrenstechnik**
**Zentrum Ingenieurwissenschaften**
**Martin-Luther-Universität**
**Halle-Wittenberg**
**06099 Halle (Saale), Germany**

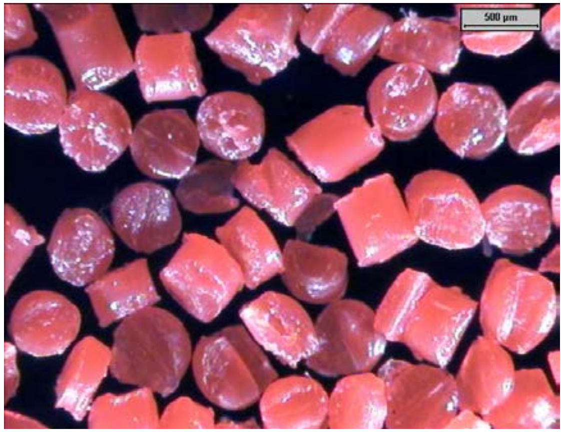
**www-mvt.iw.uni-halle.de**



# Introduction 1

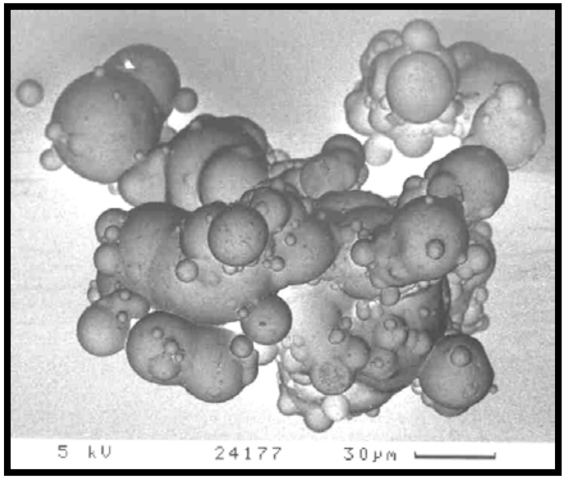
- Numerical predictions of dispersed two-phase flows rely generally on the **assumption of spherical particles**.
- However, in most practical situations and industrial processes the particles are irregular in shape or have a certain geometrical shape, (e.g. fibres, cylinders, discs, ...) or are even agglomerates.
- For modelling the motion of such non-particles in confined flows (i.e. pipes, cyclones, ...) the knowledge of the wall collision parameters (i.e. restitution and friction) is necessary.

**irregular particles**


**granulates**

**Agglomerate**



# Introduction 2

➢ **Modelling the wall collision of non-spherical particles is essential for a reliable numerical calculation of particle-laden confined processes.**

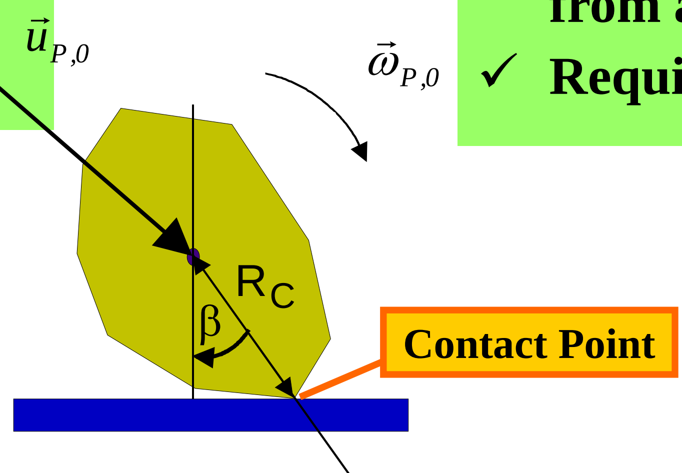
**Lagrangian treatment of non-spherical particle wall collisions**

**Regularly shaped non-spherical particles**

- ✓ **Tracking the orientation of the particles (Euler parameters or quaternions)**
- ✓ **Solving the impulse equations for non-spherical particles (Sommerfeld 2002)**

**Irregular non-spherical particles**

- ✓ **Solve the wall collision process for a spherical particle**
- ✓ **Draw the values for restitution and friction from a PDF**
- ✓ **Requires experiments !!!**



- For modelling the wall collision of irregular non-spherical particles the basic equations for spherical particles are used (point mass):
  - Non-sliding collision:

$$u_{P2} = \frac{5}{7}\left(u_{P1} - \frac{D_P}{5}\,\omega_{P1}^{z}\right)$$
$$v_{P2} = -e\,v_{P1}$$
$$w_{P2} = \frac{5}{7}\left(w_{P1} + \frac{D_P}{5}\,\omega_{P1}^{x}\right)$$

$$\omega_{P2}^{x} = \frac{2\,w_{P2}}{D_P}$$
$$\omega_{P2}^{y} = \omega_{P1}^{y}$$
$$\omega_{P2}^{z} = -\frac{2\,u_{P2}}{D_P}$$

  - Sliding collision:

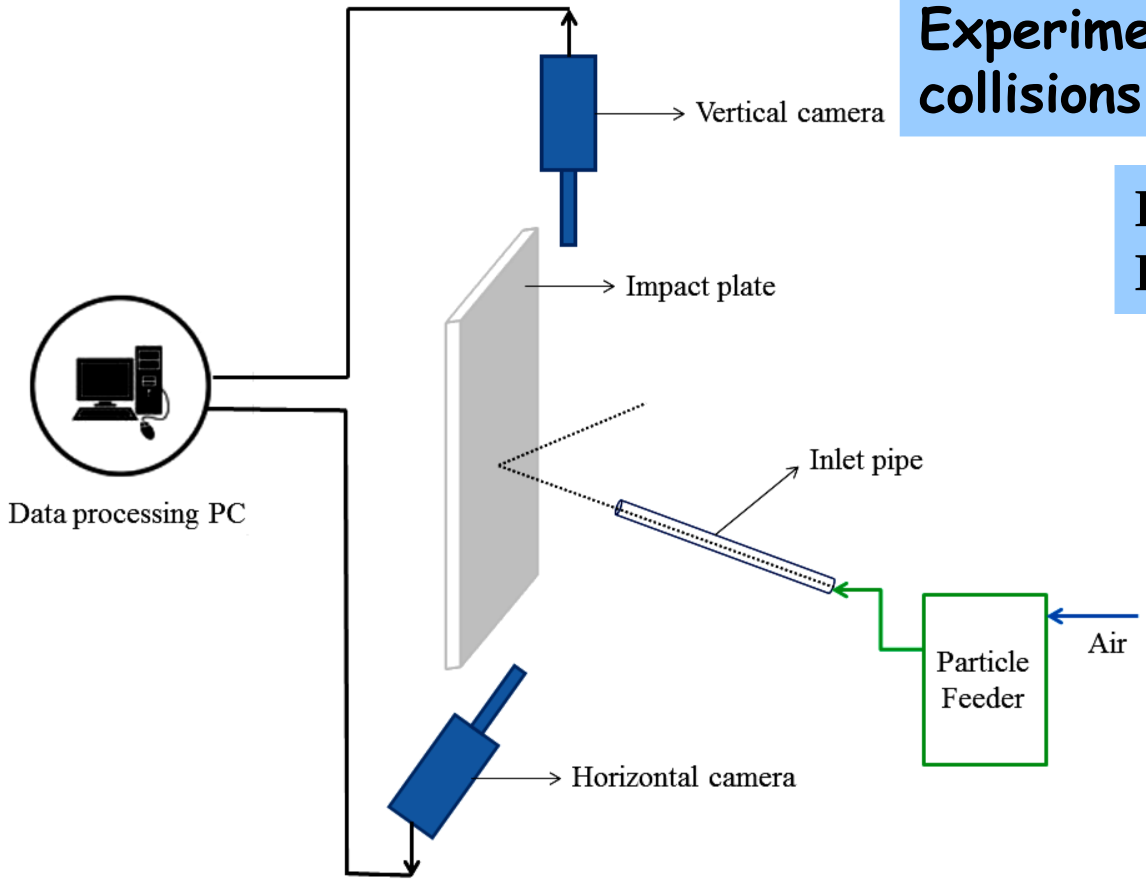
$$u_{P2} = u_{P1} + \mu_d\,\varepsilon_x\,(1+e)\,v_{P1}$$
$$v_{P2} = -e\,v_{P1}$$
$$w_{P2} = w_{P1} + \mu_d\,\varepsilon_z\,(1+e)\,v_{P1}$$

$$\omega_{P2}^{x} = \omega_{P1}^{x} - 5\,\mu_d\,\varepsilon_z\,(1+e)\frac{v_{P1}}{D_P}$$
$$\omega_{P2}^{y} = \omega_{P1}^{y}$$
$$\omega_{P2}^{z} = \omega_{P1}^{z} + 5\,\mu_d\,\varepsilon_x\,(1+e)\frac{v_{P1}}{D_P}$$

  - Condition for non-sliding:

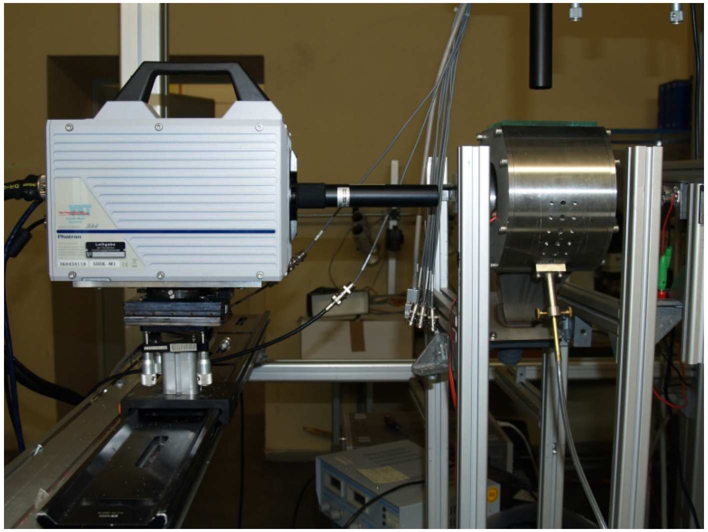
$$|u_{R1}| \le \frac{7}{2}\,\mu_0\,(1+e)\,v_{P1}$$

# Wall-Collision Experiments 1




**Experimental studies on wall collisions of non-spherical particles**

**Impact angles: 5° to 85°**
**Impact velocities: 8 and 24 m/s**



- Photron High Speed Video Camera, FASTCAM SA4 RV operated at 60,000 fps (resolution 256 * 192 Pixels)
- LED illumination back-lightning
- Telecentric lens of T80 series
- Magnification ratio of 1:1

- Summary of particle properties for the wall collision experiments

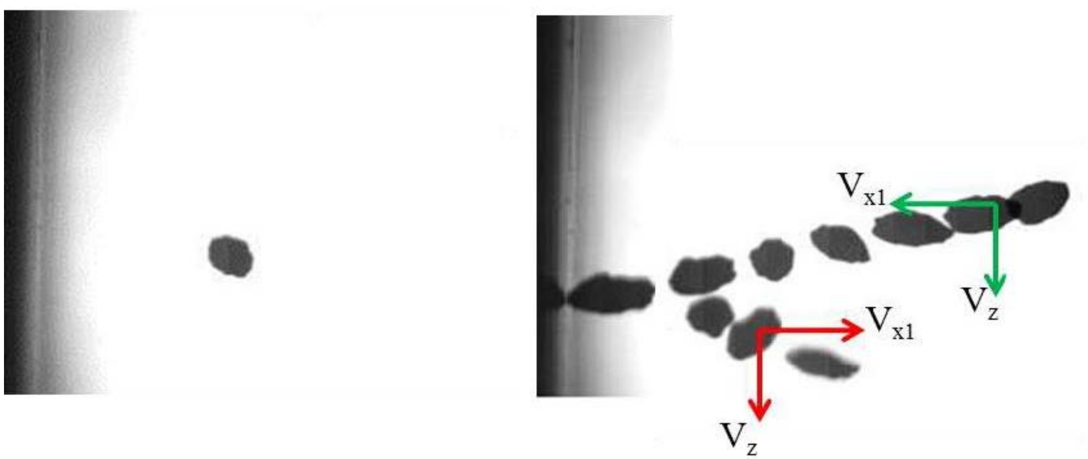
| Material | Density ($kg/m^3$) | Size Distribution Diameter (µm) | Mean size, VES (µm) | Sphericity |
|---|---|---|---|---|
| Cylinders * | 2500 | 500 | 500 | 0.779 |
| MC4 Duroplast | 1500 | 250 - 350 | 300 | 0.773 |
| Quartz Sand | 2400 | 200 - 300 | 250 | 0.851 |

**Cylinders (fishing rope): diameter 0.5 mm, length ~ 1.5 mm; axis ratio l/d=3**

- **Wall collision of an irregular particle (Duroplast particles MC-4, projection diameter 300 µm, ψ = 0.773, velocity: 16.3 m/s)**


horizontal camera

before and after collision




vertical camera

Before and after collision

- **Videos wall collision of cylindrical particles (Duroplast particles MC-4, projection diameter 300 µm, ψ = 0.773, velocity: 16.3 m/s)**

**horizontal camera view**

**vertical camera view**

➲ **The restitution ratios are determined from the ratio of the velocities obtained by the particle tracking routine:**

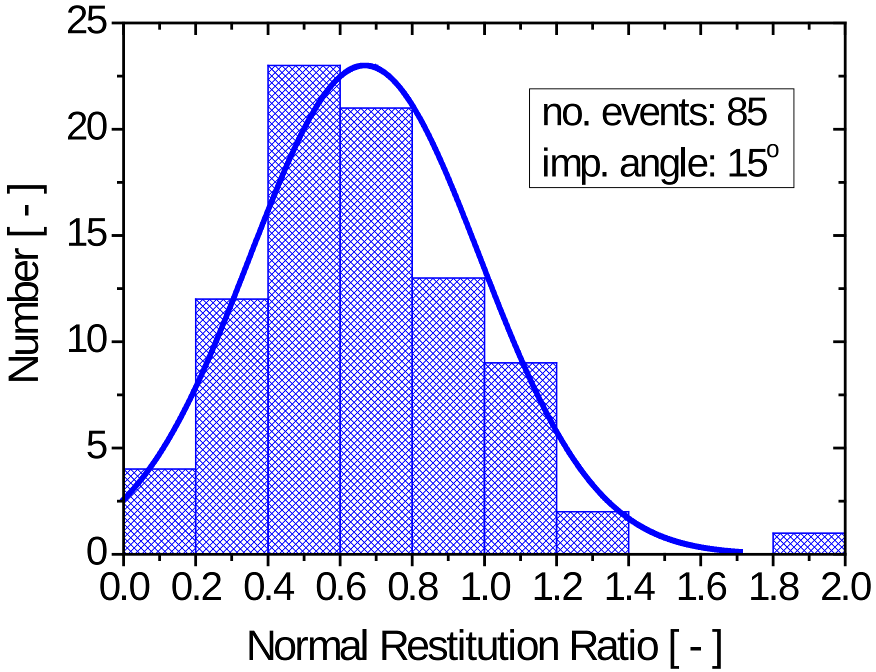
$$e = \left|\frac{V_2}{V_1}\right| \qquad e_n = \left|\frac{V_{y2}}{V_{y1}}\right| \qquad e_t = \frac{V_{x2}}{V_{x1}}$$

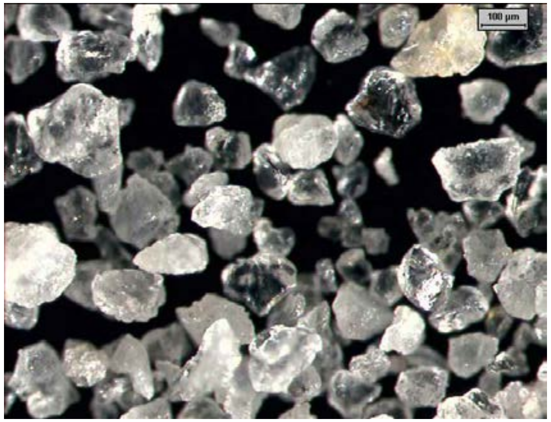
➲ **From the impulse equations for spherical particles the friction coefficient is obtained in the following way:**

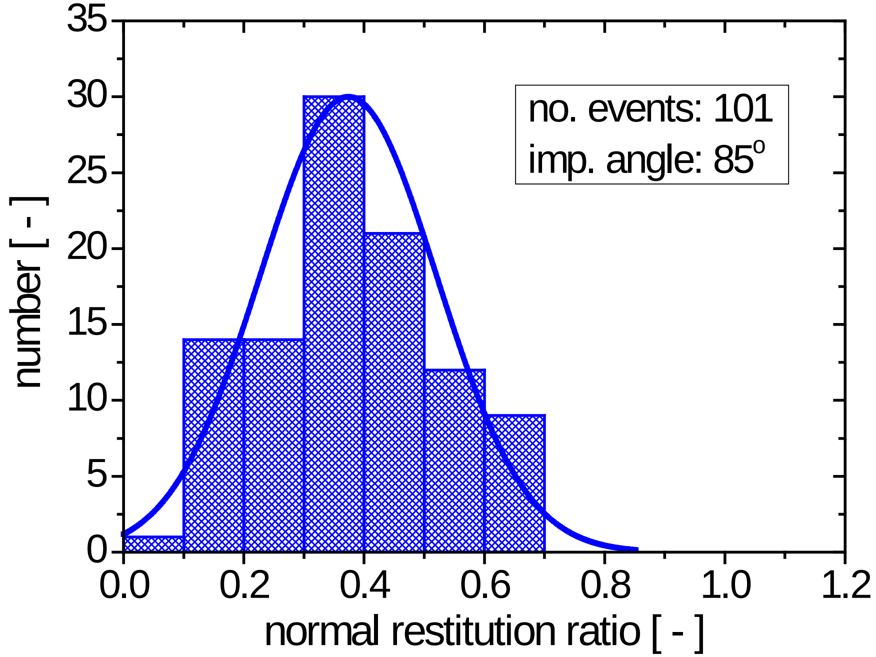
$$\mu = \frac{|V_{x1} - V_{x2}|}{(1 + e)\, V_{y1}}$$

# Results Wall-Collision 1

- PDF`s of **normal restitution ratio** for different impact angles (Quartz).

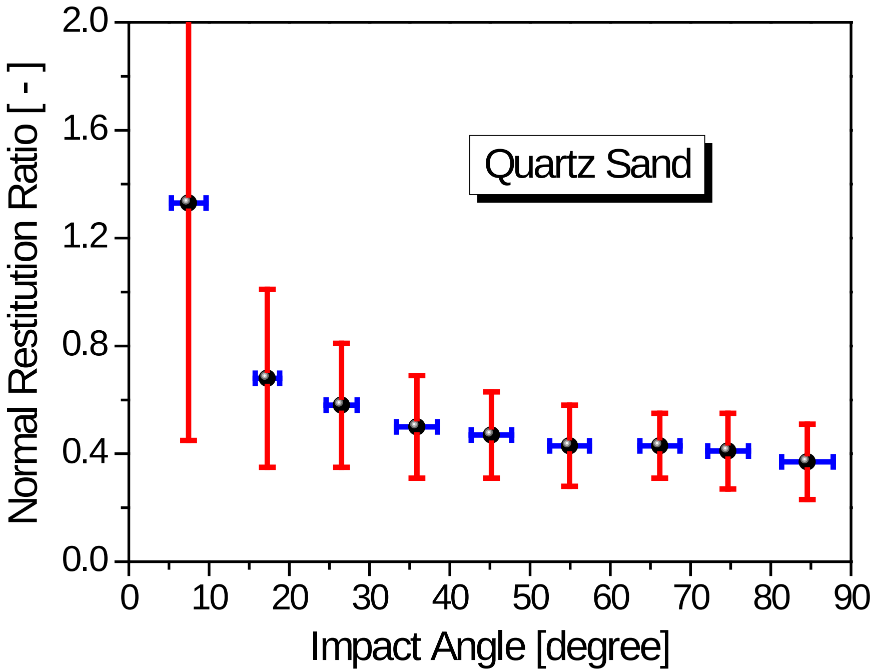


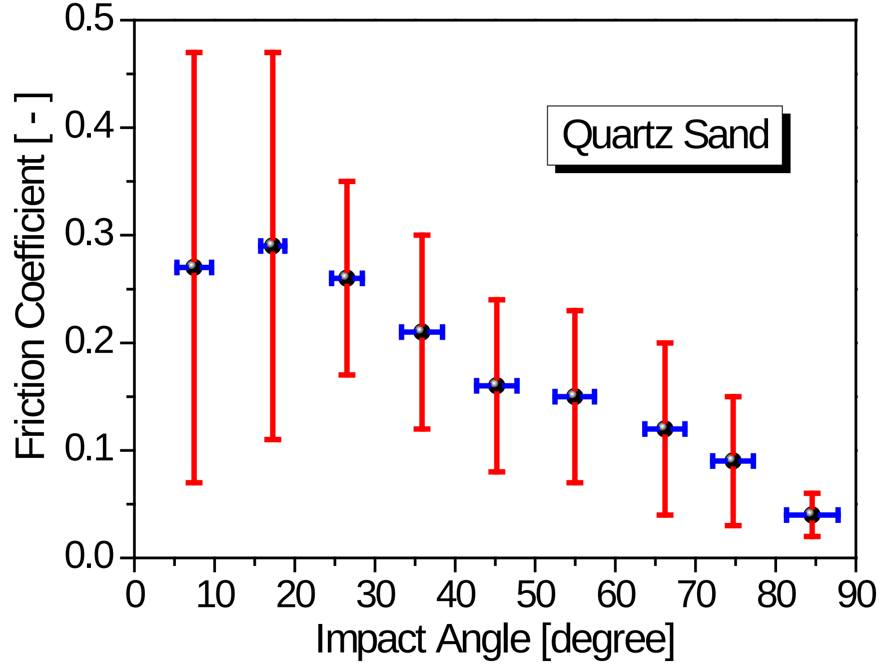



# Results Wall-Collision 2

➢ **Dependence of restitution and friction coefficients on the impact angle**

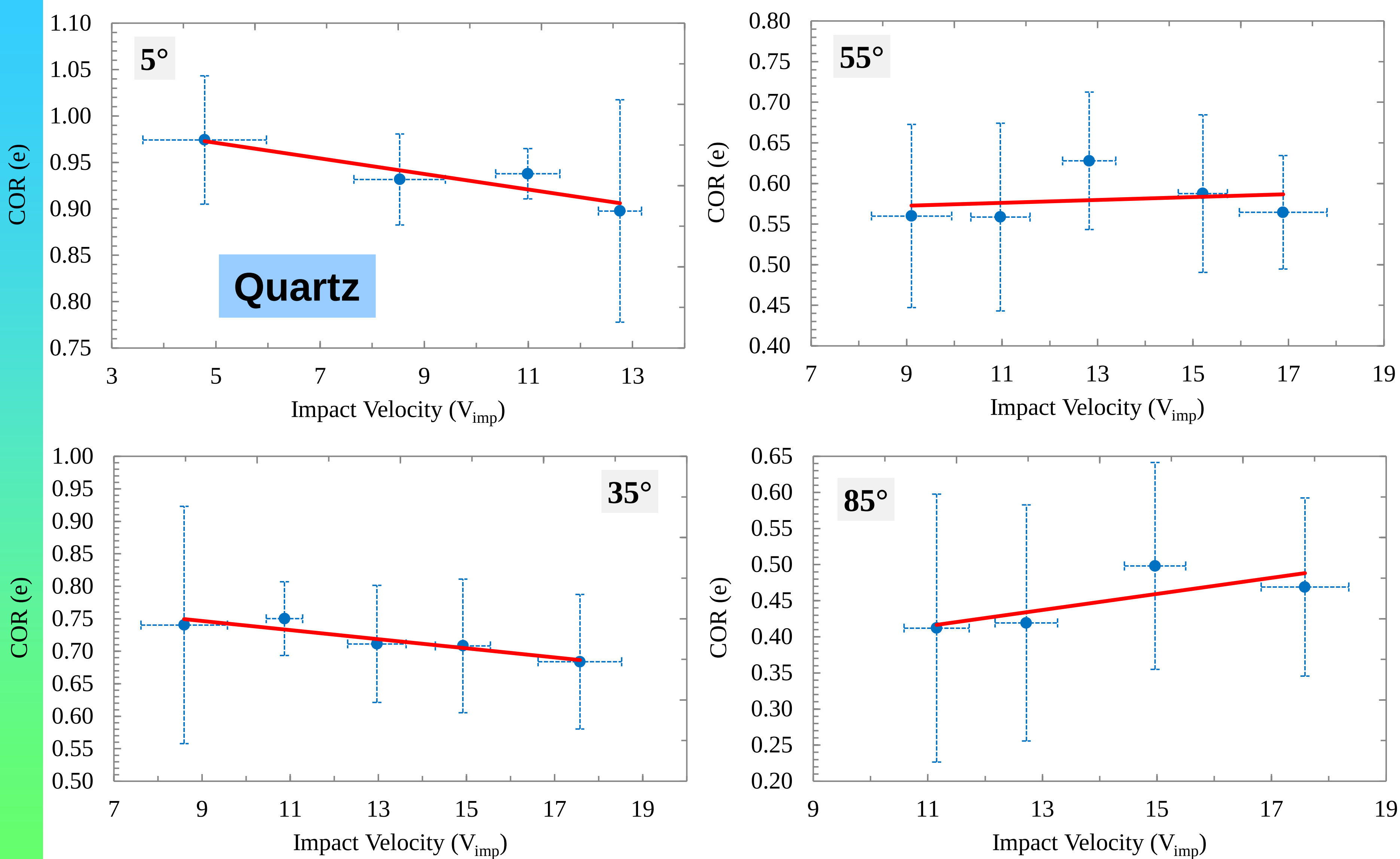



**Quartz**



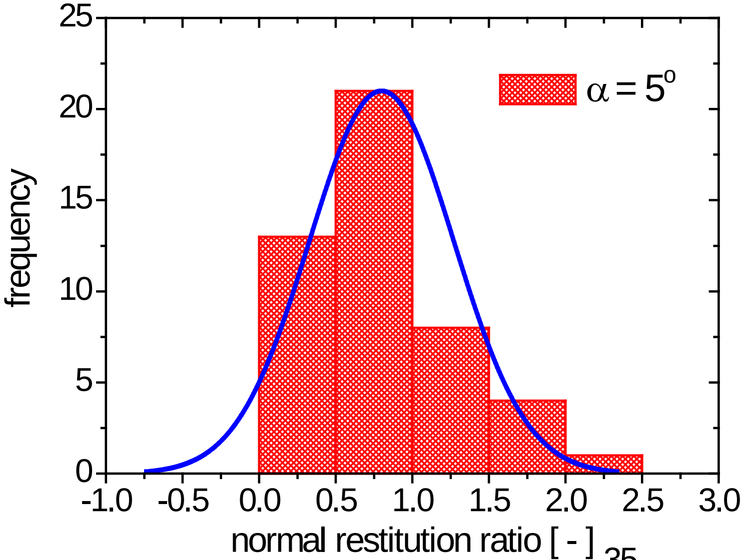
# Results Wall-Collision 3

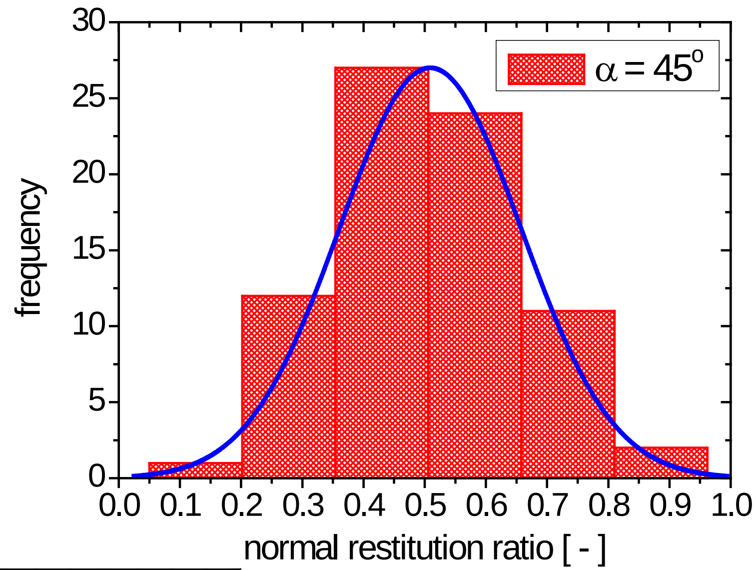
➢ **Dependence of total restitution coefficient on impact velocity:**

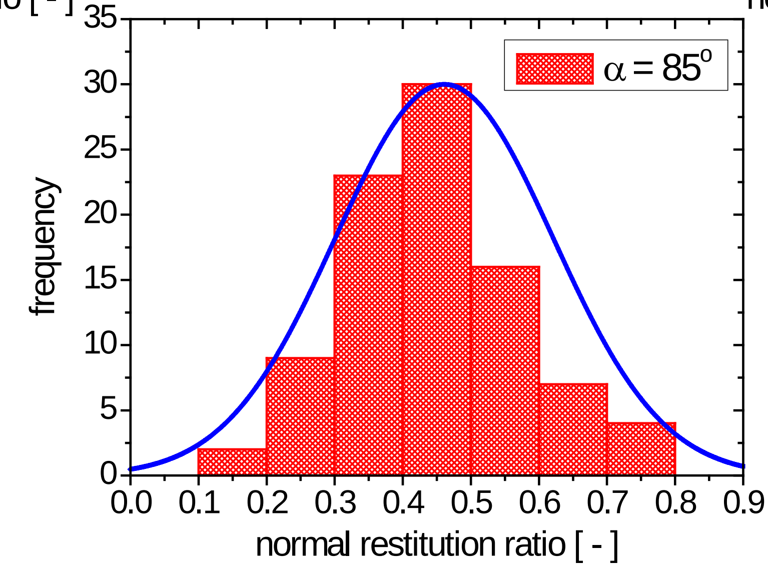


# Results Wall-Collision 4

☞ **PDF`s of normal restitution ratio for different impact angles (MC-4).**

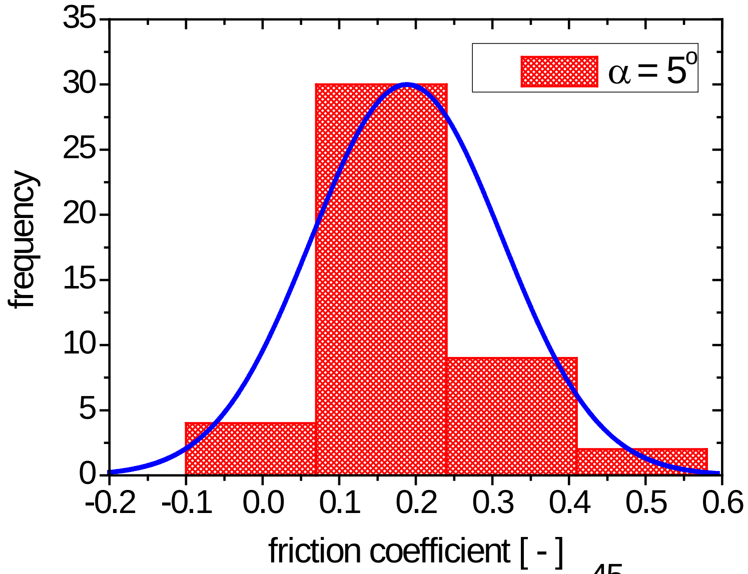


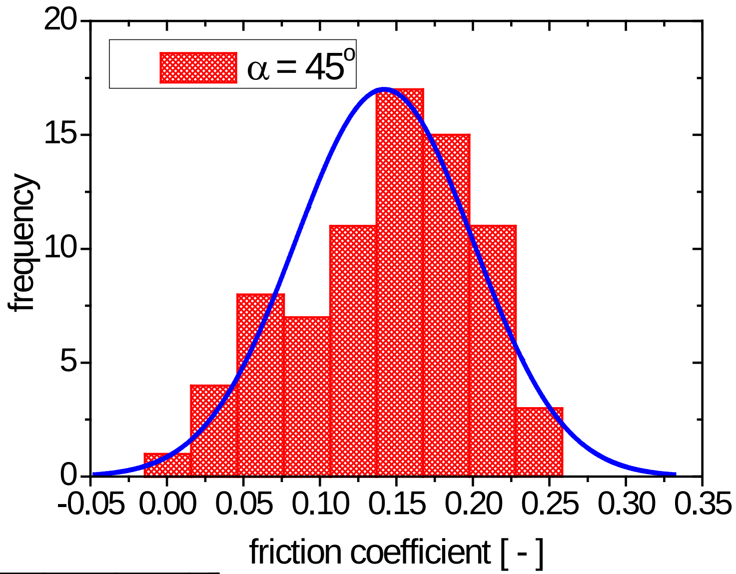



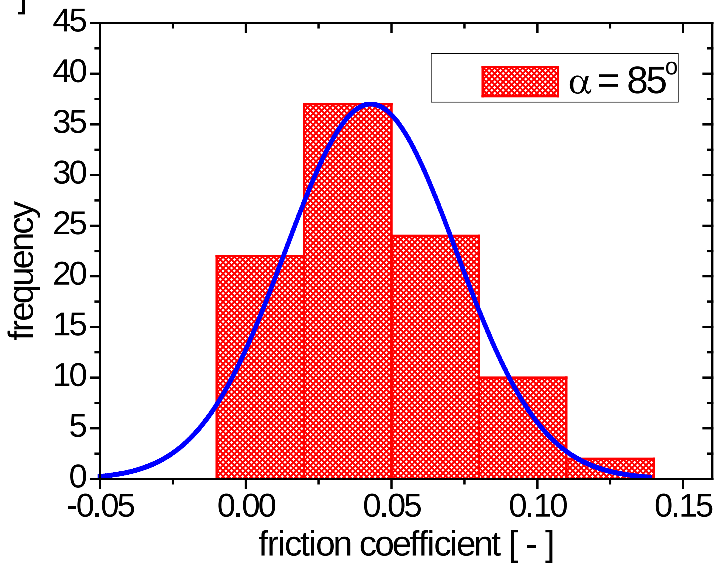



# Results Wall-Collision 5

☞ **PDF`s of friction coefficient for different impact angles (MC-4).**

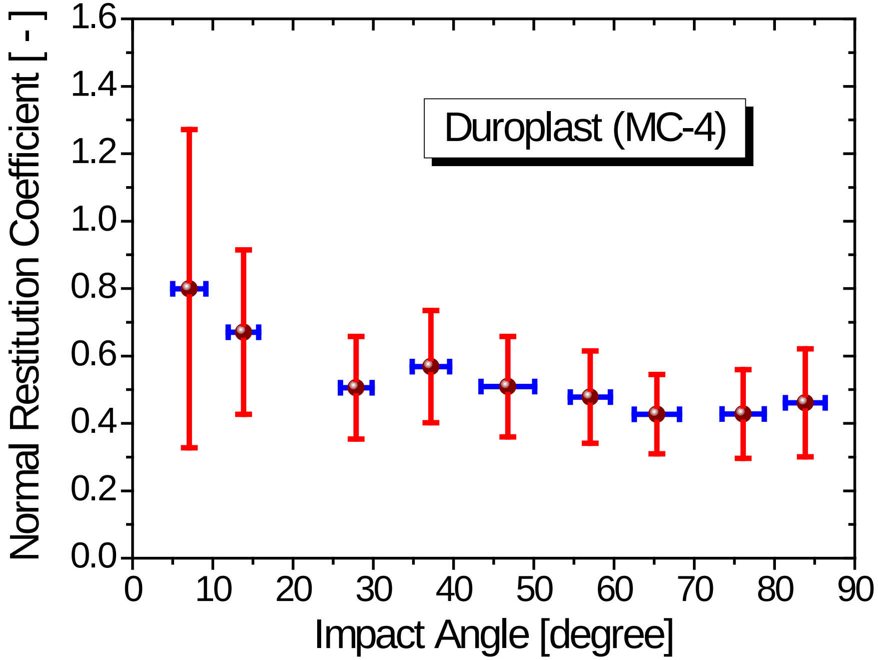


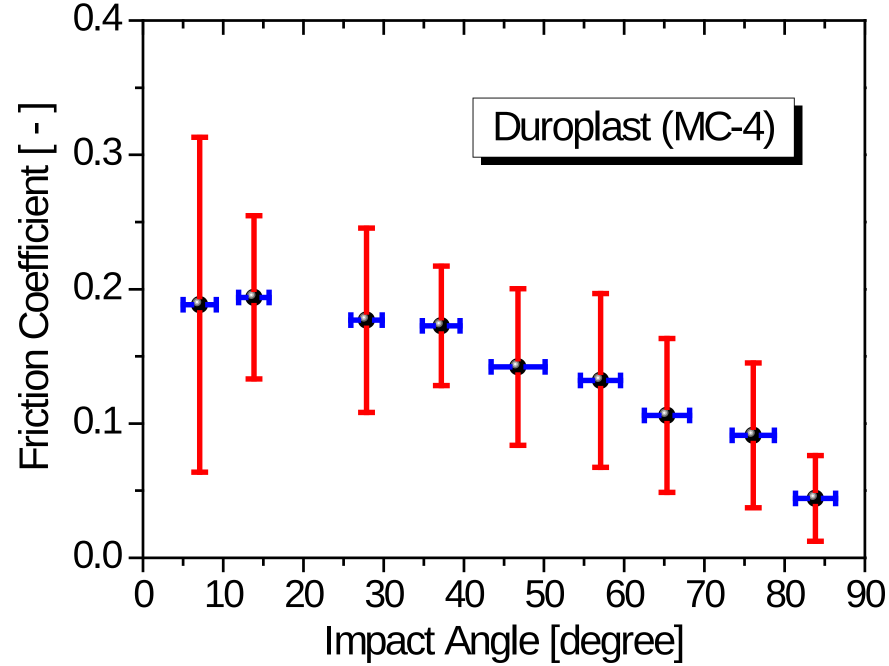



# Results Wall-Collision 6

☞ **Dependence of restitution and friction coefficients on the impact angle**



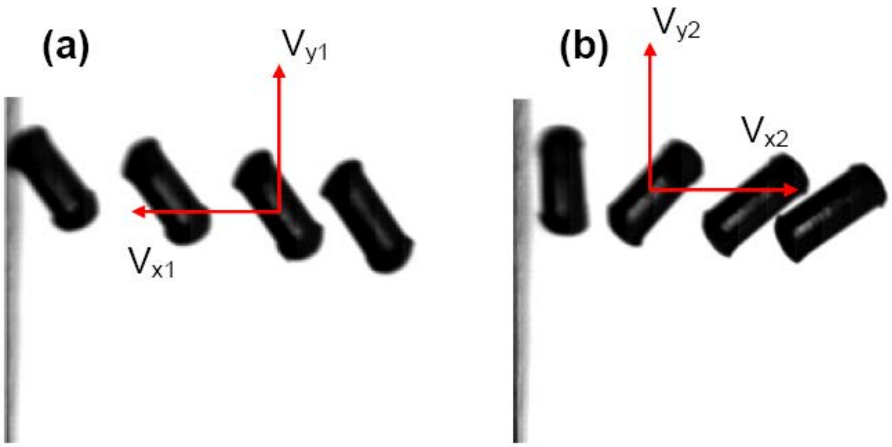

**For describing the dependence of mean values and standard deviation appropriate correlations are derived.**

**The instantaneous values are drawn from a normal distribution.**

**The wall collision process is calculated as for a spherical particle.**

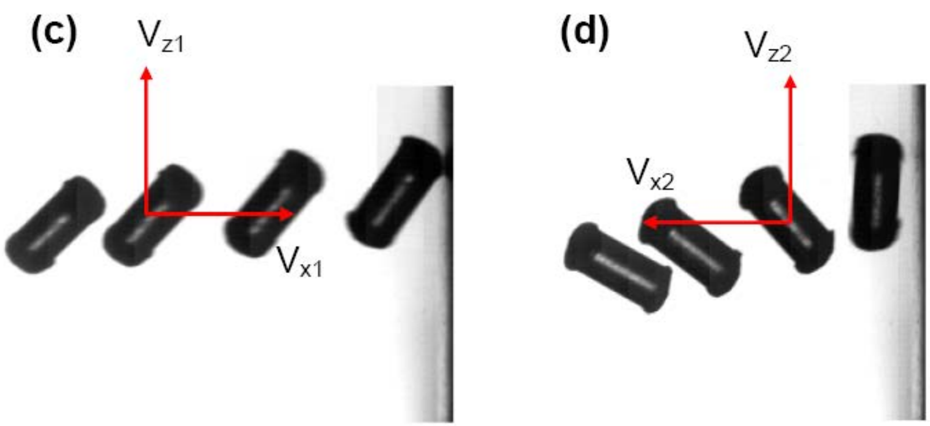
# Results Wall-Collision 7

- Wall collision of a cylindrical particle (cylinder diameter 500 µm, axis ratio L/D = 3, velocity: 16.3 m/s)




horizontal camera

before and after collision

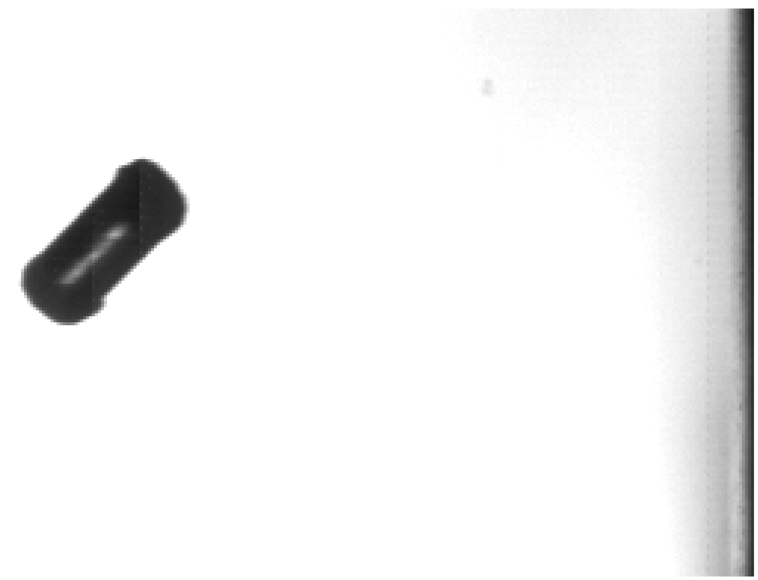



vertical camera

Before and after collision

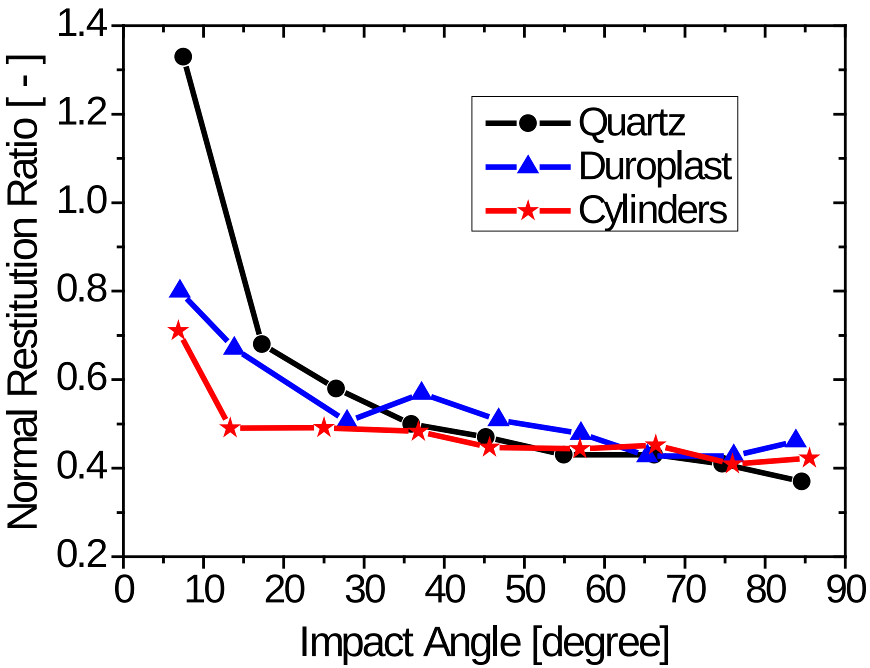
- Videos wall collision of cylindrical particles

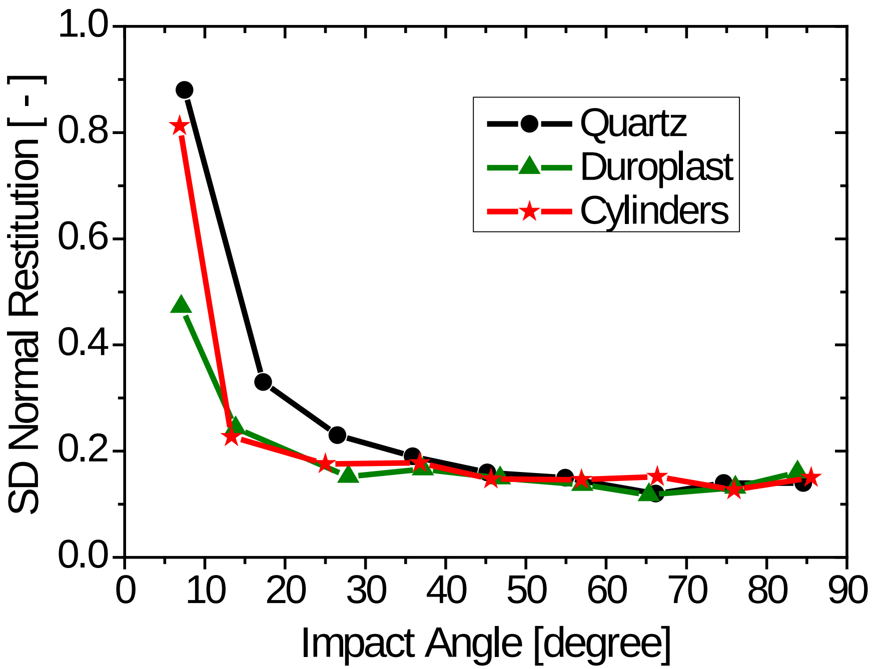
**horizontal camera view** **vertical camera view**



# Comparison 1

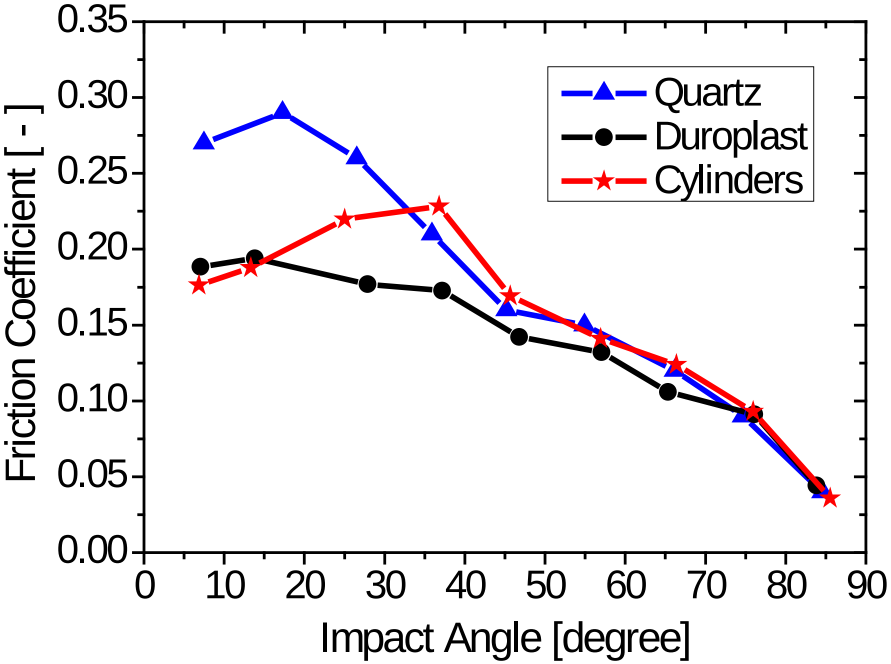
➲ **Comparison of the results for the regular and irregular non-spherical particles**

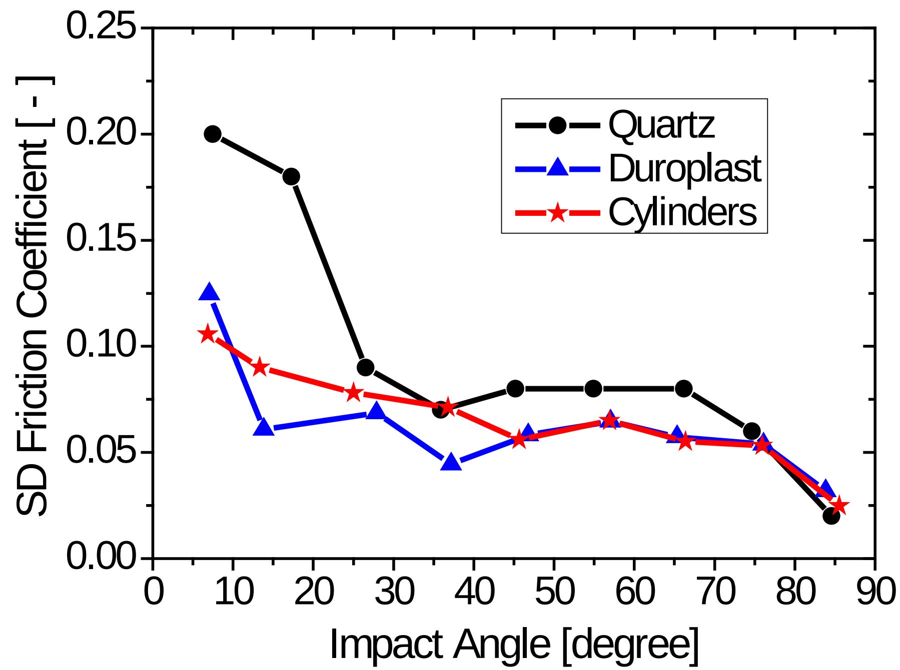


# Comparison 2

➲ **Comparison of the results for the regular and irregular non-spherical particles**



# Conclusions / Outlook

- A special test facility has been developed for analysing the wall collision process of non-spherical particles.
- The wall collision process was recorded by two perpendicularly installed high speed cameras.
- The wall collision angle was varied between about 5 to 85 degree.
- For each wall collision angle about 100 events were recorded and statistically evaluated.
- In the experiments regular and irregular shaped non-spherical particles with a size of several hundred microns were considered.
- Both the normal restitution ratio and the friction coefficient decreased with increasing impact angle.
- The standard deviation of both parameters remarkably increased with decreasing impact angle.
- For the irregular particles a stochastic wall collision model was developed based on the PDF`s of the two parameters.
- Further experiments will be conducted for cylinders with different aspect ratio.