Video analysis

Photron Fastcam Viewer
↳ Camera Software
→ chop main video into individual collisions (use arrows left and right of timeline) to chose start and end of video
→ save

Determine particle movement in pixels and use visible item with known size to calculate actual speed.

Tracking: "Image J" (Open source Program)
+ tool : click on particle on each frame to get movement in pixels
Alternatively : circle tool : fit circle, press control + M → circle center is listed

On each frame, mark all four positions in the same order to get data extracted from table automatically later (programm)

Save table of measurements. default ending is ~~possible~~ excel, other endings are possible.

Picture shows particles from two angles.

Video analysis

IDL code for analysis of positions table

_b before , _a after collision

coefficient of restitution: $\varepsilon = \frac{v_{after}}{v_{before}}$

Velocities

impact parameter = Stoßparameter (b)

$b/R \in [0,1]$ $\quad R = R_1 + R_2$ Particle Rad

Distance

$b = \sqrt{R^2 - v_R^2}$

Relative Velocity

Sometimes microgravity is not good / stable

-> particles drift off, odd numbers appear for the results

-> leave those files out.

Particles sometimes fragment

-> velocities befor collision measured, not after to see whether velocity is a reason for breaking

-> it seems not to be, it's rather weakness of particles rotation:

find two points on the particles that can be tracked throughout the video

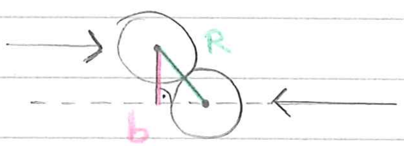
(worked for 1/5 of the videos)

Important Formulae

normalised impact parameter : $\frac{b}{R}$

impact parameter : b = centre of mass distance between the two projectiles, perpendicular to the collision
(Stoßparameter)

R = sum of the particles' radii



D_f = fractal dimension

r = radius of gyration

mass: $m \sim r^{D_f}$

ρ = aggregates density

ρ_0 = bulk density of constituent monomer grains

Volume filling factor:

$$\phi = \frac{\rho}{\rho_0} \quad (< 1)$$

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coefficient of restitution : $\varepsilon = \frac{v_a}{v_b}$ (ratio of relative velocities before and after encounter)

normalized translational energy : ε^2

linear Pearson correlation coefficient:

$$r = \frac{\sum_{i=0}^{n} (y_i - \bar{y}) \cdot (x_i - \bar{x})}{\sqrt{\sum_{i=0}^{n} (y_i - \bar{y})^2} \cdot \sqrt{\sum_{i=0}^{n} (x_i - \bar{x})^2}}$$

n: number of points (x_i, y_i)

$\bar{x}, \bar{y}$: mean values of x, y

r measures the strength of correlation between two variables x and y. $r = \pm 1$ indicates perfect positive / negative correlation, $r = 0$ indicates no correlation.

Haff: temporal rms-velocity evolution in an ensemble
(1983) of colliding particles

$$v(t) = \frac{1}{\frac{1}{v_0} + (1-\varepsilon) \cdot n \cdot \sigma \cdot t}$$

v: velocity

t: time

v_0: initial injection velocity

ε: coefficient of restitution

n: number density

$\sigma = 4\pi r^2$: collisional cross section

r: particle radius

Calculations for the Analysis of Parabolic Flight Data

23.10.2014

Information we want to derive:

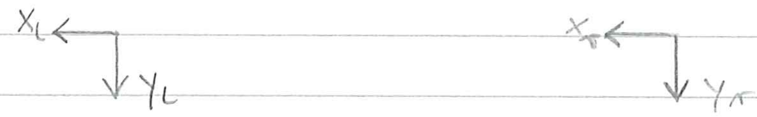
- coefficient of restitution : $\varepsilon = \frac{v_a}{v_b}$
  (v_a, v_b = relative velocities after / before encounter)
- compoments of ε parallel / perpendicular to $\vec{R}$
- distance of centers of masses at collision : $R = |\vec{R}|$
- normalized impact parameter : $\frac{b}{R}$
  (b : impact parameter = projection of R onto $\vec{v_b}$)
- relative velocities before / after encounter : $\vec{v_b}, \vec{v_a}$

Information we start with:

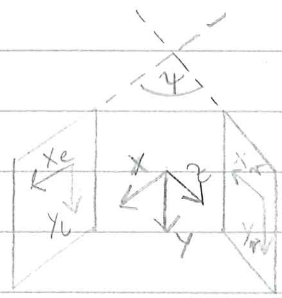
- position (2D of particles at certain times from two different viewing angles, in units of pixels) : px_L, py_L, px_r, py_r
- measures of guiding tube diameter in pixels and in mm : $D = (275 \pm 3)$ pixel $\hat{=} (9{,}85 \pm 0{,}05)$ mm
- angle between both views : $\Psi = 60°$
- timestep between two image frames : $\Delta t = \frac{1}{107}$ s

camera view:

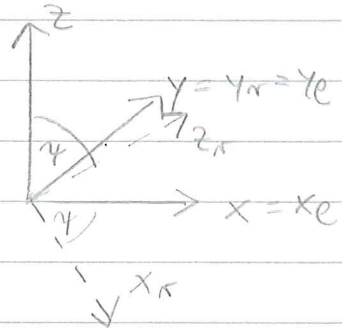
left hand   right hand



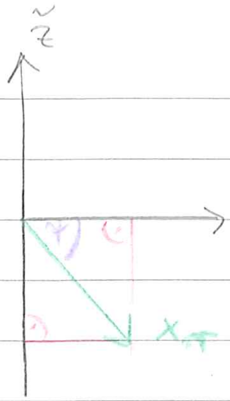
lab view:



rotation part:



y-axis fixed = piston-axis for all coordinate systems
choose x_e to be lab x-axis (not aircraft x-axis!!)



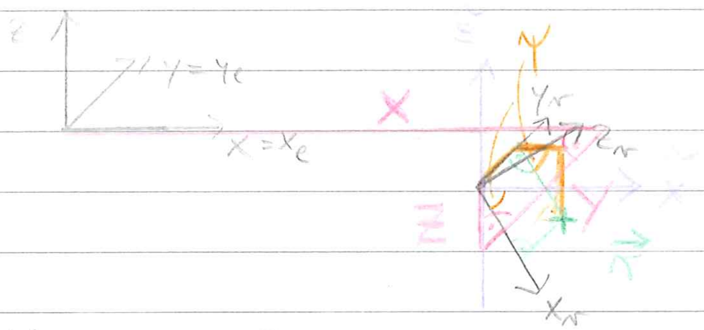
$\tilde{x}(x_r) = x_r \cdot \cos\gamma$

$\tilde{z}(x_r) = x_r \cdot \sin\gamma$

$\tilde{y} = y_r$

Attention: Coordinate systems e and r are not only rotated against each other, they have different origins as well !!! (Therefore $\tilde{x}, \tilde{y}, \tilde{z}$)

offset part:



$\Rightarrow$ offsets:

$X = x_e - \tilde{x}$, $Y = y_e - \tilde{y}$, $Z = z_e - \tilde{z}$

choose $Z = 0$

$\Rightarrow$ given: γ, x_e, y_e, z_e, x_r, y_r

wanted: X, Y, Z

24.10.2014

$$\text{Location: } \vec{r} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \begin{pmatrix} x_r \cos\gamma \\ y_r \\ x_r \sin\gamma \end{pmatrix} = \begin{pmatrix} x_e - x_r\cos\gamma + x_r\cos\gamma \\ y_e - y_r + y_r \\ z_e - x_r\sin\gamma + x_r\sin\gamma \end{pmatrix}$$

$$= \begin{pmatrix} x_e \\ y_e \\ x_r \sin\gamma \end{pmatrix}$$

Velocity: $\vec{v} = \frac{d\vec{r}}{dt} = \frac{\Delta \vec{r}}{\Delta t}$

$$\Delta r = \begin{pmatrix} x_e(t+\Delta t) - x_e(t) \\ y_e(t+\Delta t) - y_e(t) \\ \sin\psi \cdot (x_r(t+\Delta t) - x_r(t)) \end{pmatrix}$$

since $\vec{y}_r \parallel \vec{y}_e$: $\Delta y_r = \Delta y_e$ $\Rightarrow$ take average

$$\Rightarrow \quad \Delta r = \begin{pmatrix} x_e(t+\Delta t) - x_e(t) \\ \frac{1}{2}\left[y_e(t+\Delta t) - y_e(t) + y_r(t+\Delta t) - y_r(t)\right] \\ \sin\psi \cdot \left[x_r(t+\Delta t) - x_r(t)\right] \end{pmatrix}$$

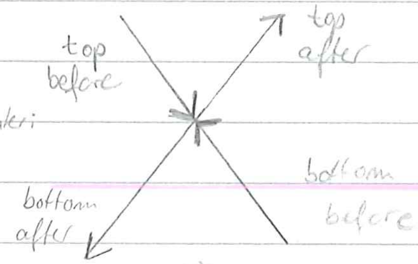
We have measurements of the position for several timesteps
$\Rightarrow$ fit

$$\vec{r}(t) = \vec{r}_0 + \vec{v} \cdot t \quad , \text{ fitparameters: } \vec{r}_0, \vec{v}$$

Result: absolute velocities (before and after encounter)

Position of encounter:

For each particle, the crossing of the trajectories before and after the encounter is the position of the encounter:



$\vec{r}_{0,before} + \vec{v}_{before} \cdot t = \vec{r}_{0,after} + \vec{v}_{after} \cdot t$

$\Rightarrow 0 = \vec{r}_{0,a} - \vec{r}_{0,b} + t \cdot (\vec{v}_a - \vec{v}_b)$

$\Rightarrow$ get $t_{encounter}$ $\Rightarrow \vec{r}_{encounter} = \vec{r}_{0,before} + t \cdot \vec{v}_{before}$

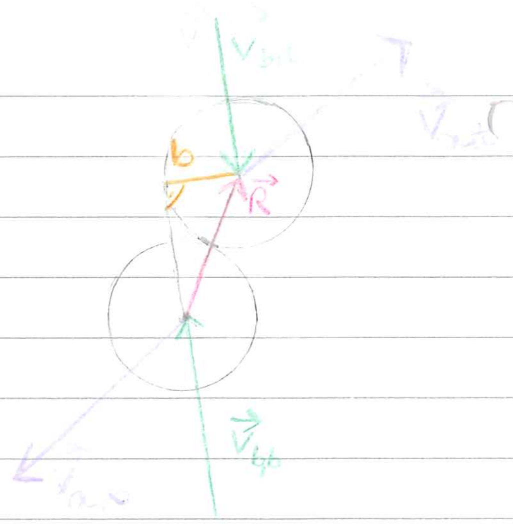
Distance of centers of masses at encounter:

$$R = |\vec{r}_{encounter,top} - \vec{r}_{encounter,bottom}| = |\vec{R}|$$

Relative velocities before and after encounter:

$$v_{r,b} = |\vec{v}_{r,b}| = |\vec{v}_{b,top} - \vec{v}_{b,bottom}| \quad , \quad v_{r,a} = |\vec{v}_{a,top} - \vec{v}_{a,bottom}|$$

coefficient of restitution:



$$\varepsilon = \frac{v_{r,a}}{v_{r,b}}$$

components parallel to $\vec{R}$:

$$v_{r,a,\parallel} = \frac{\vec{v}_{ra}^{\,T} \cdot \vec{R}}{R} \;,\; v_{r,b,\parallel} = \frac{\vec{v}_{rb}^{\,T} \vec{R}}{R}$$

$$\Rightarrow \varepsilon_{\parallel} = \frac{\vec{v}_{ra}^{\,T} \vec{R}}{\vec{v}_{rb}^{\,T} \vec{R}}$$

components perpendicular to $\vec{R}$:

$$v_{r,a,\perp} = \left| \vec{v}_{ra} - \frac{\vec{v}_{ra}^{\,T} \cdot \vec{R}}{R^2} \cdot \vec{R} \right| \;,\; v_{r,b,\perp} = \left| \vec{v}_{rb} - \frac{\vec{v}_{ra}^{\,T} \cdot \vec{R}}{R^2} \cdot \vec{R} \right|$$

$$\Rightarrow \varepsilon_{\perp} = \frac{v_{ra\perp}}{v_{rb\perp}}$$

impact parameter:

$\vec{b}$ = component of $\vec{R}$ perpendicular to $\vec{v}_{rb}$

$$b = |\vec{b}| = \left| \vec{R} - \frac{\vec{R}^{\,T} \vec{v}_{rb}}{v_{rb}^2} \cdot \vec{v}_{rb} \right|$$

normalized impact parameter:

$$b_R = \frac{b}{R}$$

Plan:
- Build python skript to do these calculations
- ✓ Make it in a way that only two data files are needed (particles before & particles after collision)
  → click top left, top right, bottom left, bottom right
- check whether results are comparable to those from Catherine's IDL skripts.

Error Analysis:

29.10.2014

Problem: fit routine in python produces weird error values
-> For now, I take an estimate of 1% error for all fitparameters
! -> Think about better solution (deviation from fit curve ...) for the future !

position of encounter: (for each particle, top or bottom)

$$\vec{r}_{encounter} = \left[\left(\vec{r}_{0,before} + t_{encounter} \cdot \vec{v}_{before} \right) + \left(\vec{r}_{0,after} + t_{encounter} \cdot \vec{v}_{after} \right) \right] \cdot \frac{1}{2}$$

$$\Rightarrow \Delta x_{encounter} = \frac{1}{2} \cdot \left[(\Delta x_{0,b})^2 + (\Delta x_{0,a})^2 + (\Delta t_e \cdot (v_{xb} + v_{xa}))^2 + (t_e \cdot \Delta v_{xb})^2 + (t_e \cdot \Delta v_{xa})^2 \right]^{1/2}$$ (error propagation)

or

$$\Delta x_{encounter} = \frac{1}{2} \cdot \left| (x_{0b} + t_e \cdot v_{xb}) - (x_{0a} + t_e v_{xa}) \right|$$ (deviation between trajectories)

=> calculate both and take maximum
for y, z analogue

distance of centers of masses at encounter time:

$$\vec{R} = \vec{r}_{encounter,top} - \vec{r}_{encounter,bottom}$$

$$\Rightarrow \Delta R_x = \sqrt{(\Delta x_{encounter,top})^2 + (\Delta x_{encounter,bottom})^2}$$

$$R = |\vec{R}| = \sqrt{R_x^2 + R_y^2 + R_z^2}$$

$$\Rightarrow \Delta R = \frac{1}{R} \sqrt{\left(\tfrac{1}{2} \cdot 2 \cdot \Delta R_x \cdot R_x\right)^2 + \left(\tfrac{1}{2} \cdot 2 \cdot \Delta R_y \cdot R_y\right)^2 + \left(\tfrac{1}{2} \cdot 2 \cdot \Delta R_z \cdot R_z\right)^2}$$
$$= \frac{1}{R} \sqrt{(\Delta R_x R_x)^2 + (\Delta R_y R_y)^2 + (\Delta R_z R_z)^2}$$

relative velocities: (before)

$$v_{rxb} = v_{rxb\,top} - v_{rxb\,bottom} \Rightarrow \Delta v_{rxb} = \sqrt{(\Delta v_{rxb\,top})^2 + (\Delta v_{rxb\,bottom})^2}$$

$$v_{rb} = \sqrt{(v_{rxb})^2 + (v_{ryb})^2 + (v_{rzb})^2} \Rightarrow \Delta v_{rb} = \frac{1}{v_{rb}} \sqrt{(\Delta v_{rxb} \cdot v_{rxb})^2 + \dots + (\Delta v_{rzb} v_{rzb})^2}$$

(after: analogue)

coefficient of restitution:

$$\varepsilon = \frac{v_{ra}}{v_{rb}} \quad \Rightarrow \quad \Delta\varepsilon = \sqrt{\left(\frac{\Delta v_{ra}}{v_{rb}}\right)^2 + \left(\frac{v_{ra}\cdot\Delta v_{rb}}{v_{rb}^{\,2}}\right)^2}$$

$$v_{ra\parallel} = \frac{1}{R}\sum_j \vec{v}_{ra}[j]\cdot\vec{R}[j]$$

$$\Rightarrow \quad \Delta v_{ra\parallel} = \sqrt{\left(\frac{\Delta R}{R^2}\cdot\sum_j \vec{v}_{ra}[j]\cdot\vec{R}[j]\right)^2 + \sum_j\left(\frac{1}{R}\,\Delta\vec{v}_{ra}[j]\cdot\vec{R}[j]\right)^2 + \sum_j\left(\frac{1}{R}\,\vec{v}_{ra}[j]\,\Delta\vec{R}[j]\right)^2}$$

v_{rb} analogue

$$\varepsilon_{\parallel} = \frac{v_{ra\parallel}}{v_{rb\parallel}} \quad \Rightarrow \quad \Delta\varepsilon_{\parallel} = \sqrt{\left(\frac{\Delta v_{ra\parallel}}{v_{rb\parallel}}\right)^2 + \left(\frac{v_{ra\parallel}\cdot\Delta v_{rb\parallel}}{v_{rb\parallel}^{\,2}}\right)^2}$$

$$v_{ra\perp} = \sqrt{\sum_j\left(\vec{v}_{ra}[j] - \vec{v}_{ra\parallel}[j]\right)^2}$$

$$\Rightarrow \quad \Delta v_{ra\perp} = \frac{1}{v_{ra\perp}}\cdot\sqrt{\sum_j\left[\Delta\vec{v}_{ra}[j]\cdot\left(\vec{v}_{ra}[j] - \vec{v}_{ra\parallel}[j]\right)\right]^2 + \sum_j\left[\Delta\vec{v}_{ra\parallel}[j]\cdot\left(\vec{v}_{ra}[j] - \vec{v}_{ra\parallel}[j]\right)\right]^2}$$

$$\Gamma \quad \vec{v}_{ra\parallel} = \frac{1}{R^2}\cdot\vec{R}\cdot\sum_j \vec{v}_{ra}[j]\cdot\vec{R}[j]$$

$$\Rightarrow \quad \vec{v}_{ra\parallel}[j] = \frac{1}{R^2}\cdot\vec{R}[j]\cdot\sum_k \vec{v}_{ra}[k]\cdot\vec{R}[k]$$

$$\Rightarrow \quad \Delta\vec{v}_{ra\parallel}[j] = \sqrt{\left(2\,\frac{\Delta R}{R^3}\cdot\vec{R}[j]\cdot\sum_k \vec{v}_{ra}[k]\cdot\vec{R}[k]\right)^2 + \left(\frac{1}{R^2}\,\Delta\vec{R}[j]\cdot\left(\sum_k \vec{v}_{ra}[k]\cdot\vec{R}[k] + \vec{v}_{ra}[j]\cdot\vec{R}[j]\right)\right)^2 + \sum_k\left(\frac{1}{R^2}\,\vec{R}[j]\cdot\Delta\vec{v}_{ra}[k]\cdot\vec{R}[k]\right)^2 + \sum_{k\neq j}\left(\frac{1}{R^2}\,\vec{R}[j]\cdot\vec{v}_{ra}[k]\cdot\Delta\vec{R}[k]\right)^2}$$

30.10.2014

$$\vec{V}_{rall} = \vec{R} \cdot \frac{\sum_j \vec{V}_{ra}[j]\,\vec{R}[j]}{\sum_j \vec{R}[j]^2}$$

$$\Rightarrow \vec{V}_{rall}[j] = \vec{R}[j] \cdot \frac{\sum_k \vec{V}_{ra}[k]\,\vec{R}[k]}{\sum_k \vec{R}[k]^2}$$

$$\Rightarrow V_{rallx} = R_x \cdot \frac{V_{rax}R_x + V_{ray}R_y + V_{raz}R_z}{R_x^2 + R_y^2 + R_z^2} = \frac{V_{rax}R_x^2 + V_{ray}R_yR_x + V_{raz}R_zR_x}{R_x^2+R_y^2+R_z^2}$$

$$\boxed{\frac{\partial V_{rallx}}{\partial R_x}} = \frac{(2V_{rax}R_x + V_{ray}R_y + V_{raz}R_z)\cdot(R_x^2+R_y^2+R_z^2) - (V_{rax}R_x^2 + V_{ray}R_yR_x + V_{raz}R_zR_y)\,2R_x}{(R_y^2+R_y^2+R_z^2)^2}$$

$$= \frac{2V_{rax}R_x^3 + V_{ray}R_yR_x^2 + V_{raz}R_zR_x^2 + 2V_{rax}R_xR_y^2 + V_{ray}R_y^3 + V_{raz}R_zR_y^2}{(R_x^2+R_y^2+R_z^2)^2}$$

$$+ \frac{2V_{rax}R_xR_z^2 + V_{ray}R_yR_z^2 + V_{raz}R_z^3 - 2V_{rax}R_x^3 - 2V_{ray}R_yR_x^2 - 2V_{raz}R_zR_x^2}{(R_x^2+R_y^2+R_z^2)^2}$$

$$= \frac{-V_{ray}R_yR_x^2 - V_{raz}R_zR_x^2 + 2V_{rax}R_xR_y^2 + V_{ray}R_y^3 + V_{raz}R_zR_y^2}{(R_x^2+R_y^2+R_z^2)^2}$$

$$+ \frac{2V_{rax}R_xR_z^2 + V_{ray}R_yR_z^2 + V_{raz}R_z^3}{(R_x^2+R_y^2+R_z^2)^2}$$

$$= \frac{2V_{rax}R_x(R_y^2+R_z^2) + V_{ray}R_y(R_y^2+R_z^2-R_x^2) + V_{raz}R_z(R_y^2+R_z^2-R_x^2)}{R^4}$$

$$= \frac{2V_{rax}R_x(R_y^2+R_z^2) + (V_{ray}R_y + V_{raz}R_z)\cdot(R_y^2+R_z^2-R_x^2)}{R^4}$$

$$= \frac{2V_{rax}R_x \cdot R^2 - 2V_{rax}R_x^3 + (V_{ray}R_y + V_{raz}R_z)\cdot R^2 - 2(V_{ray}R_y + V_{raz}R_z)R_x^2}{R^4}$$

$$= \frac{2V_{rax}R_x \cdot R^2 + (V_{ray}R_y + V_{raz}R_z)\cdot R^2 - 2\cdot(V_{rax}R_x + V_{ray}R_y + V_{raz}R_z)R_x^2}{R^4}$$

$$= \frac{\vec{V}_{ra}^T \cdot \vec{R} \cdot R^2 + V_{rax}R_x \cdot R^2 - 2\,\vec{V}_{ra}^T\vec{R} \cdot R_x^2}{R^4} = \boxed{\frac{\vec{V}_{ra}^T\vec{R}\cdot(R^2 - 2R_x^2) + V_{rax}R_x \cdot R^2}{R^4}}$$

$$\boxed{\frac{\partial V_{rallx}}{\partial R_y}} = \frac{V_{ray}R_x \cdot R^2 - \vec{V}_{ra}^T\vec{R}\cdot R_x \cdot 2R_y}{R^4} = \boxed{\frac{R_x}{R^4}\cdot\left(V_{ray}\cdot R^2 - 2\vec{V}_{ra}^T\vec{R}R_y\right)}$$ R_z analog

$$\boxed{\frac{\partial V_{rallx}}{\partial V_{rax}} = \frac{R_x^2}{R^2}}$$

$$\boxed{\frac{\partial V_{rallx}}{\partial V_{ray}} = \frac{R_yR_x}{R^2}}$$ V_{raz} analog

$$\Rightarrow \Delta V_{ra\parallel x} = \Bigg[\left(\Delta R_x \cdot \frac{\vec{v}_{ra}^{\,T} \cdot \vec{R} \cdot (R^2 - 2R_x^2) + v_{rax} R_x R^2}{R^4} \right)^2 + \left(\Delta R_y \frac{R_x}{R^4} \cdot (v_{ray} R^2 - 2 \vec{v}_{ra}^{\,T} \vec{R} R_y) \right)^2$$

$$+ \left(\Delta R_z \frac{R_x}{R^4} (v_{raz} R^2 - 2 \vec{v}_{ra}^{\,T} \vec{R} R_z) \right)^2 + \left(\Delta v_{rax} \cdot \frac{R_x^2}{R^2} \right)^2$$

$$+ \left(\Delta v_{ray} \cdot \frac{R_y R_x}{R^2} \right)^2 + \left(\Delta v_{raz} \cdot \frac{R_z R_x}{R^2} \right)^2 \Bigg]^{1/2}$$

$$\Rightarrow \Delta \vec{v}_{ra\parallel}[j] = \Bigg[\left(\Delta \vec{R}[j] \cdot \frac{\vec{v}_{ra}^{\,T} \cdot \vec{R} \cdot (R^2 - 2\vec{R}[j]^2) + \vec{v}_{ra}[j] \cdot \vec{R}[j] \cdot R^2}{R^4} \right)^2$$

$$+ \sum_{k \neq j} \left(\Delta \vec{R}[k] \cdot \frac{\vec{R}[j]}{R^4} \cdot (\vec{v}_{ra}[k] R^2 - 2 \vec{v}_{ra}^{\,T} \vec{R}\, \vec{R}[k]) \right)^2$$

$$+ \sum_{k} \left(\Delta \vec{v}_{ra}[k] \cdot \frac{\vec{R}[k] \cdot \vec{R}[j]}{R^2} \right)^2 \Bigg]^{1/2}$$

Vector Projection in General: $\vec{a}$ onto $\vec{b}$, $a = |\vec{a}|$, $b = |\vec{b}|$

$$\Rightarrow \vec{c} = \vec{b} \cdot \frac{\vec{a}^{\,T} \cdot \vec{b}}{b^2}$$

$$\Rightarrow \Delta \vec{c}[j] = \Bigg[\left(\Delta \vec{b}[j] \cdot \frac{\vec{a}^{\,T} \vec{b} \cdot (b^2 - 2\vec{b}[j]^2) + \vec{a}[j] \cdot \vec{b}[j] \cdot b^2}{b^4} \right)^2$$

$$+ \sum_{k \neq j} \left(\Delta \vec{b}[k] \cdot \frac{\vec{b}[j]}{b^4} \cdot \left(\vec{a}[k] \cdot b^2 - 2 \vec{a}^{\,T} \vec{b}\, \vec{b}[k] \right) \right)^2$$

$$+ \sum_{k} \left(\Delta \vec{a}[k] \cdot \frac{\vec{b}[k] \cdot \vec{b}[j]}{b^2} \right)^2 \Bigg]^{1/2}$$

Vector length: $c = |\vec{c}| = \sum_j \vec{c}[j]^2$

$$\Rightarrow \Delta \vec{c} = \frac{1}{c} \cdot \sqrt{\sum_j (\Delta \vec{c}[j] \cdot \vec{c}[j])^2}$$

Perpendicular component of vector projection: $\vec{a}$ on $\vec{b}$

$$\vec{d} = \vec{a} - \vec{b} \cdot \frac{\vec{a}^{\,T} \vec{b}}{b^2}$$

$$\Rightarrow \vec{d}[j] = \vec{a}[j] - \vec{b}[j] \cdot \frac{\sum_k \vec{a}[k]\, b[k]}{\sum_k a[k]\, b[k]}$$

$$d_x = a_x - b_x \cdot \frac{a_x b_x + a_y b_y + a_z b_z}{\cancel{b_x}^2 + b_y^2 + b_z^2} = \frac{a_x b_x^2 + a_x b_y^2 + a_x b_z^2 - a_x b_x^2 - a_y b_y b_x - a_z b_z b_x}{b_x^2 + b_y^2 + b_z^2}$$

$$= \frac{a_x b_y^2 + a_x b_z^2 - a_y b_y b_x - a_z b_z b_x}{b_x^2 + b_y^2 + b_z^2}$$

$$\boxed{\frac{\partial d_x}{\partial b_x}} = \frac{(-a_y b_y - a_z b_z) b^2 - (a_x b_y^2 + a_x b_z^2 - a_y b_y b_x - a_z b_z b_x) \cdot 2 b_x}{b^4}$$

$$= \frac{-a_y b_y b^2 - a_z b_z b^2 - 2 a_x b_y^2 b_x - 2 a_x b_z^2 b_x + 2 a_y b_y b_x^2 + 2 a_z b_z b_x^2}{b^4}$$

$$= \frac{-b^2 \cdot (\vec{a}^T \vec{b}) + b^2 \cdot a_x b_x - 2 a_x b_x \cdot b^2 + 2 a_x b_x b_x^2 + 2 \vec{a}^T \vec{b} \cdot b_x^2 - 2 a_x b_x b_x^2}{b^4}$$

$$= \boxed{\frac{\vec{a}^T \vec{b} \cdot (2 b_x^2 - b^2) - a_x b_x b^2}{b^4}}$$

$$\boxed{\frac{\partial d_x}{\partial b_y}} = \frac{(2 a_x b_y - a_y b_x) \cdot b^2 - (a_x b_y^2 + a_x b_z^2 - a_y b_y b_x - a_z b_z b_x) \cdot 2 b_y}{b^4}$$

$$= \frac{2 a_x b_y b^2 - a_y b_x b^2 - 2 a_x b_y^3 - 2 a_x b_z^2 b_y + 2 a_y b_y^2 b_x + 2 a_z b_z b_y b_x}{b^4}$$

$$= \frac{2 a_x b_x^2 b_y + 2 a_x b_y^3 + 2 a_x b_z^2 b_y - a_y b_x^3 - a_y b_x b_y^2 - a_y b_x b_z^2 - 2 a_x b_y^3}{b^4}$$

$$+ \frac{-2 a_x b_y b_z^2 + 2 a_y b_x b_y^2 + 2 a_z b_z b_y b_x}{b^4}$$

$$= \frac{2 a_x b_x^2 b_y + a_y b_x b_y^2 - a_y b_x^3 - a_y b_x b_z^2 + 2 a_z b_z b_y b_x}{b^4}$$

$$= \frac{-a_y b_x \cdot b^2 + 2 a_y b_x b_y^2 + 2 a_x b_x^2 b_y + 2 a_z b_z b_y b_x}{b^4}$$

$$= \frac{-a_y b_x b^2 + 2 \cdot \vec{a}^T \vec{b} \cdot b_x b_y}{b^4} = \boxed{\frac{b_x}{b^4} \cdot (2 b_y \vec{a}^T \vec{b} - a_y b^2)}$$

$$\boxed{\frac{\partial d_x}{\partial a_x} = \frac{b_y^2 + b_z^2}{b^2}}$$

$$\boxed{\frac{\partial d_x}{\partial a_y} = -\frac{b_y b_x}{b^2}}$$

$$\Rightarrow \Delta d_x = \Big[\Big(\Delta b_x \cdot \frac{\vec{a}^T\vec{b}\,(2b_x^2 - b^2) - a_x b_x b^2}{b^4} \Big)^2 + \Big(\Delta b_y \cdot \frac{b_x}{b^4}\big(2 b_y \vec{a}^T\vec{b} - a_y b^2\big)\Big)^2$$

$$+ \Big(\Delta b_z \frac{b_x}{b^4} \big(2 b_z \vec{a}^T\vec{b} - a_z b^2\big)\Big)^2 + \Big(\Delta a_x \frac{b_y^2 + b_z^2}{b^2}\Big)^2 + \Big(\Delta a_y \frac{b_y b_x}{b^2}\Big)^2$$

$$+ \Big(\Delta a_z \frac{b_z b_x}{b^2}\Big)^2 \Big]^{1/2}$$

$$\Rightarrow \Delta \vec{d}[j] = \Big[\Big(\Delta \vec{b}[j] \frac{\vec{a}^T\vec{b}\,(2\vec{b}[j]^2 - b^2) - a_x b_x b^2}{b^4}\Big)^2$$

$$+ \sum_{k \neq j} \Big(\Delta \vec{b}[k] \frac{\vec{b}[j]}{b^4} \big(2\vec{b}[k]\, \vec{a}^T \vec{b} - \vec{a}[k]\, b^2\big)\Big)^2$$

$$+ \Big(\Delta \vec{a}[j] \frac{b^2 - b[j]^2}{b^2}\Big)^2 + \sum_{k \neq j} \Big(\Delta \vec{a}[k] \frac{\vec{b}[j]}{b^2} \vec{b}[k]\Big)^2 \Big]^{1/2}$$

normalized impact parameter:

$$b_R = \frac{b}{R} \qquad \Rightarrow \Delta b_R = \sqrt{\Big(\frac{\Delta b}{R}\Big)^2 + \Big(\frac{b \cdot \Delta R}{R^2}\Big)^2}$$

Better way to estimate fit errors:

For each trajectory, the fit is in principle a linear regression.
→ take the standard errors for this type of fit (i.e. deviation of measurements to curve).

$$\Delta a = \sqrt{(\Delta y)^2 \frac{m}{\Delta}} \quad , \quad \Delta b = \sqrt{(\Delta y)^2 \frac{[xx]}{\Delta}}$$

where: $a = \text{slope} \mathrel{\hat{=}} v$, $b = \text{offset} \mathrel{\hat{=}} r_0$ ($y = a \cdot x + b$)

$\Delta = m \cdot [xx] - [x] \cdot [x]$, m = number of data points (x_i, y_i)

$$[x] = \sum_{i=1}^{m} x_i \quad , \quad [xx] = \sum_{i=1}^{m} x_i^2 \quad , \quad (\Delta y)^2 = \sum_{i=1}^{m} (a \cdot x_i + b - y_i)$$

How to estimate the error of the encounter time t_e?
If we had only two trajectories instead of twelve, we would calculate t_e as:

$$x_{b0} + v_{xb} \cdot t_e = x_{a0} + v_{xa} \cdot t_e \Rightarrow x_{b0} - x_{a0} = (v_{xa} - v_{xb}) \cdot t_e$$

$$\Rightarrow t_e = \frac{x_{b0} - x_{a0}}{v_{xa} - v_{xb}}$$

Then we would do error propagation. Problem: We have several trajectories that do not meet at the same time, so we could calculate six encounter times. We get only one, because the fit is programmed to optimize the trajectories towards meeting at the same encounter time (which they don't).
We could calculate the six individual encounter times and from them a mean value. The error of the mean value would then be the maximum of the error from error propagation and the standard deviation of the mean.
-> Try to take this value as error for t_e.

for each t_e:

$$\Delta t_e = \left[\left(\frac{\Delta x_{b0}}{v_{xa} - v_{xb}} \right)^2 + \left(\frac{\Delta x_{a0}}{v_{xa} - v_{xb}} \right)^2 + \left(\frac{\Delta v_{xa} (x_{b0} - x_{a0})}{(v_{xa} - v_{xb})^2} \right)^2 + \left(\frac{\Delta v_{xb} (x_{b0} - x_{a0})}{(v_{xa} - v_{xb})^2} \right)^2 \right]^{1/2}$$

$$\Rightarrow \text{average: } t = \frac{1}{6} \sum_{i=1}^{6} t_{ei}, \quad \Delta t_1 = \frac{1}{6} \sqrt{\sum_{i=1}^{6} (\Delta t_{ei})^2}$$

$$\Delta t_2 = \sqrt{\frac{1}{6 \cdot (6-1)} \sum_{i=1}^{6} (t_{ei} - t)^2}$$

31.10.2014

Somtimes errorpropagation leads to very high errors (when picture quality is bad). For now, I will choose the maximum of Δt_1 and Δt_2, but if this is larger than the timestep between two frames (dt), I will take dt as an error instead.

Problem: For some reason, I get huge errors whenever I do a vector projection
→ Check formulas and find out at what point the errors become so big.

To Do: ~~Write all results to file~~

The main source for the huge errors seems to be in the way I estimate the error for the vector $\vec{R}$ pointing from one center of mass to the other at the encounter time.
At the moment, I take the maximum of the error via propagation and the error via deviation.
In almost all cases, the error via propagation is very big, leading to a big $\Delta\vec{R}$ and to huge errors for all projections involving $\vec{R}$.

Convert pixels to mm:

P pixel $\hat{=}$ M mm , $P = 275 \pm 3$, $M = 9{,}85 \pm 0{,}05$

$$x(\text{pixel}) = \frac{M}{P} \cdot x(\text{mm}) = \tilde{x}$$

$$\Delta\tilde{x} = \sqrt{\left(\Delta x \cdot \frac{M}{P}\right)^2 + \left(\frac{\Delta M}{P} x\right)^2 + \left(\frac{M \Delta P}{P^2} x\right)^2}$$

$$= \sqrt{\left(\Delta x \cdot \frac{M}{P}\right)^2 + x^2 \cdot \left(\left(\frac{\Delta M}{P}\right)^2 + \left(\frac{M \Delta P}{P^2}\right)^2\right)}$$

new names: conversion $:= \frac{M}{P}$, delta_conversion $:= \sqrt{\left(\frac{\Delta M}{P}\right)^2 + \left(\frac{M\Delta P}{P^2}\right)^2}$

? Question: The error for the conversion is only useful for the absolute values. Whenever we use normalised values I would leave it away. Since that is hard to do, I would leave it away completely. OK?

Questions for Supervision meeting

04.11.2014

? Question: How much is the budget for the new camera including all additional costs (like computer, software, lenses + mirrors, etc.)
1000 to 50 000

? Question: Would it be better to rewrite the python script for the data analysis to let python determine the encounter time and split up the data in two arrays (for before and after)?
Yes

Christmas Travels:

17.12.: Hooke Soc Christmas Party
19.12.: last working day Helen

5.-9. Jan: Braunschweig
Organise Skype Meeting with Helen on 8th or 9th Jan
Take Harddrive to Braunschweig for Data transport
Vacation: intranet → staff → My View → View Absence → Request New → Holiday
Travel Insurance: intranet → staff → travel → travel insurance
(declare splitting up into travel and work parts)
ask Anita if there is anything else to fill

new Laptop: intranet → IT → IT intranet → ordering equipment or software → product catalogue

Lab: How to make and handle amorphous ice
→ Papers: T. Loerting, J. Blum, (Proposal, Japanese Group)
Gundlach 11, Jim et al Icarus 2011
Bar Nun

Vapour deposition preferable to droplet freezing.
Watch how Anita & Natalia grow ice

- Fit pump & pressure gauge to bottom (put pistons in without mold)
- Close chamber and test pumping & pressure read out

- Find differences between last setup and new regulations
- Schedule for Meeting with NOVESPACE

in Braunschweig have a look at flight tool box

CAD: ask Jürgen & Daniel for original drawing
Olivier uses CAD
DPS & MCT mailing list

Lab: Start working on LabView program, see whether I can get pistons moving etc.

Summary of previous flights

2006	2007	2007	2008	2010	flight year
warm dust	cold dust	small ice	1,5cm ice	1,5cm ice / chemistry	particles
hydraulic	hydraulic	hydraulic	motor	motor	pistons
one	double 60°	double 60°	double 48,8°	double 48,8°	view
I will get the data in Jan.		A&A, accepted	Icarus	"chemistry" (will go to A&A)	paper
45 ESA	46 ESA	11 DLR	12 DLR	15 DLR	

conference proceedings
2007 → archive

Preparation of water ice particles for parabolic flight:

- Keep particles in a bucket of liquid Nitrogen
- Place bucket inside the cold Coliseum, N_2 vapour will flood coliseum volume and reduce water vapour
- Coliseum is cooled down to liquid N_2 temperature
- Quickly place particles in the Coliseum holes (≈ 5 min)
- Remaining water freezes to walls, not to particles, who evaporate N_2 for the minutes in air
- Close experiment and pump out
- Water will go away without freezing to particles

What happens to particles after collision:

Nobody really knows, they don't show up, bouncing around when the experiment is opened, they are melted away.

05.01.2015

Visit Braunschweig

Labor

feine Tröpfchen: Inhalator Pari Boy Sx
Teilchen: 1,5 µm radius Tropfen (mittel) Größenverteilung gut studiert an diesem Modell)
Wenn man einen langen Schlauch anschließt am Ausgang sollte sich Verteilung ändern.

Variante 1: Metallkiste in Stickstoffbad. Inhalator sprüht in Kiste, Behälter im Boden kann Proben auffangen.

Variante 2: direkt in flüssigen Stickstoff sprühen
→ Schlauch in Stickstoff stecken, sonst gehen die nicht rein sondern werden vom Dampf nach oben getragen
• Dewar mit Loch und Hahn im Boden. Stickstoff größtenteils verdampfen lassen und das restliche gemisch mit Proben durch Hahn ablassen.

Inhalator nicht gut für große Menge
Variante 1 effizienter, aber aufpassen wegen Stick Effekten.

Pferde inhalator hat größeren Durchsatz ×10 und größere Tröpfchen ×2

Beam splitter 1: verspiegeltes Prisma + 2 Spiegel (Höhe und Winkel verstellbar)

Proben formen: Metall schalen, doch auf einer Seite mit Spritze einfüllen. Einfrieren

Lichts Gleichstrom flackert nicht "Lumitronix"

Beamsplitter 2: Prisma (#1 deutlich flexibler was Abstand und Winkel angeht).

Idee: Vielteilchenexperiment.
Zwei Teilchen gehen im Mini-Fallturm besser
Vielteilchenexperimente gehen im Mini-Fallturm nicht.
brauchen lange Zeit der Parabeln
Schüttelmechanismus benötigt
"gegen Restschwerkraft anschütteln"
Haftung ca im $1 \frac{cm}{s}$-Bereich bei Eisteilchen
→ Kleinere Geschwindigkeiten möglich als bei Zweiteilchen Experimente

Amorphes Eis muss auf 100 K gehalten werden. Wandelt sich bei ca. 140 K in kristallines Eis um. geht nicht wirklich auf Parabelflug
unter 10^{-3} mbar ist Aufwärmrate klein. Kann man Vakuum so gut halten wenn Pumpen aus sind?

Eisteilchen mit Spritze in $l. N_2$: ab 5mm Ø bildet sich Spannungsgradient, der die Kugeln in zwei Hälften sprengt.

Vielteilchen: Nachteile: Sichtbarkeit (Verdecken durch andere Teilchen), geringere Auflösung, größeres Sichtfeld

Teilchen kommen vor Piston vorns. Beschleunigungsrampe bringt nix. 06.01.2015
Abbildungsmaßstab: Pistondurchmesser. jeden Tag neu bestimmen.
Flug 3 zuerst auswerten
Bei Fragmentation masseverlust abschätzen (Aufpassen, dass es keine Anhaftung war)
Data from Nov 2007 (46th ESA campaign); First check of videos

Flug 2:

✓ ✗ C01 : nicht gut (mehrere)
✓ C02 : groß auf klein
✓ ✗ C03 : nur ein Teilchen
different fit ✓ ✗ C04 : groß auf klein (zerbricht)
✓ ✗ C05 : geht so (mehrere)
different fit ✗ C06 : klein auf klein, nicht geschafft, nur 2 Bilder nach Stoß
✓ ✗ C07 : auswertbar, mehrere Stöße (zerbricht), mehrere Teilchen
✓ ✗ C08 : auswertbar, abpraller
✓ C09 : groß auf klein, auswertbar, Abpraller
✓ C10 : viele kleine Teilchen, ein Stoß
✓ ✗ C11 : groß auf groß, Abpraller, gut
✓ C12 : groß auf klein, 2 Stöße
✓ ✗ C13 : viele kleine, 1 Stoß
✓ C14 : viele, 1x klein auf klein, 1x klein auf groß
✓ ✗ C15 : mehre Stöße, groß-klein und klein-klein

Flug 3

✓ ✓ C16 : gut, groß auf groß
in this book H ✗ C17 : 1 Stoß, groß auf groß
✓ C18 : 1 Stoß, groß auf groß
H ✓ ✗ C19 : mehrere Teilchen, mehrere Stöße, schwer zu unterscheiden
H ✓ ✗ C20 : gut, 1 Stoß, groß-groß
✓ C21 : wahrscheinlich kein Stoß, Rotation vorher
✓ C22 : 2 Stöße groß auf klein
H ✓ ✓ C23 : 1 Stoß groß auf groß
✓ C24 : 1 Stoß groß auf klein
this book H ✓ C25 : eigentlich dreier Stoß, aber kleinstes Teil ignorieren
this book H ✗ C26 : Doppelstoß; 1 groß-groß, 1 groß-klein
✓ ✓ C27 : erst groß-klein, dann groß-groß
✓ ✓ C28 : gut, 1 Stoß: groß-groß
✓ ✗ C29 : gut, 1 Stoß, groß-klein
✓ ✓ C30 : 1 Stoß groß-groß, 1 Stoß groß-klein

✓ C31 : 1 Stoß groß-groß
✓ ✗ C32 : später mit verändertem Kontrast anschauen Haftung? (vermutlich nicht)
✓ ✗ C33 : 2 Stöße hintereinander, groß-groß
✓ ✗ C34 : 2 Stöße hintereinander, groß-groß
✓ ✗ C35 : 1 Stoß, groß-klein, viele Teilchen
✓ C36 : 1 Stoß, groß-klein
✓✓ C37 : 1 Stoß, groß-groß, evtl. einige klein groß, schwer zu sehen
H ✓ ✓ C38 : 1 Stoß, groß-groß 07.01.2015
✓ ✗ C39 : 1 Stoß, fragmentation, groß-groß
✓ ✗ C40 : 1 Stoß, fragmentation, groß-klein
✓ ✗ C41 : 2 Stöße, groß-klein, helligkeit bearbeiten
✓ C42 : ~~mit~~ 1 Stoß mittel-klein (30.03.2015)
H ✗ C43 : 1 Stoß, fragmentation, groß-groß, evtl. Oberflächenänderung bei größeren Teilchen
H ✓ ✗ C44 : 2 Stöße, groß-groß, groß-klein
✓ ✗ C45 : 1 Stoß, groß-groß
H ✓ ✓ C46 : 1 Stoß, groß-groß, evtl. fragmentation (obere Grenze abschätzen)
blasse Teilchen heller machen: Image -> 8-bit -> Adjust -> Threshold -> unteren Regler nach Rechts schieben. -> set -> apply -> ok
H ✗ C47 : 1 Stoß, groß-klein
H ✓ ✗ C48 : 1 Stoß, groß-groß
✓ ✓ C49 : 2 Stöße, groß-groß (möglicherweise zu wenig Bilder zwischen den Stößen
✓ C50 : 1 Stoß, groß-groß
H ✓ ✗ C51 : mehrere Stöße, groß-groß und groß-klein

Flug 1 C01_F1_P00 : Wolke von kleinen Teilchen
heller machen: Images -> 8-bit -> adjust -> contrast -> maximum runter -> set -> apply to all open images -> apply -> ok
nicht alle einzeln auswerten, sondern kleinste und größte Geschwindigkeit und Masse raussuchen und Box machen. aufpassen dass alle, die rausfliegen und reingeflogen sind (fragmentation ausschließen) zählen.
C02_F1_P06 : mehrere kleine Teilchen

Target vom Anfang mit Ende vergleichen und schauen, ob es gewachsen ist

Bildverarbeitung und Glättung vor Auswertung

C03_F1_P06: evtl. 2 kleine von oben

C04_F1_P06: 1 Stoß, groß

~~C05_F1_P07: weg~~ gelöscht

~~C06_F1_P07: weg~~ umbenannt C05_F1_P07

C06_F1_P08: mehrere Stöße (groß + klein)

C07_F1_P08: mix

C08_F1_P09: evtl. 2 Stöße, klein

C09_F1_P09: mehrere Stöße, groß + klein

C10_F1_P09: viele kleine Stöße

C11_F1_P10: mix

C11_F1_P11: mix (kein Piston)

C12_F1_P11: Teilchen nur vor den Stoß sichtbar, schwer auszuwerten

C13_F1_P11: mehrere Stöße, groß + klein

C14_F1_P12: mix

C15_F1_P12: mix

C16_F1_P12: mix

16 doppelt → alle folgenden Nummern um eins verschieben

17 C16_F1_P13: mix — 03.02.2015: improved video shows incoming particle but quality still too low to see result of collision

18 C17_F1_P13: 1 Abpraller aber Restbeschleunigung → nicht quantitativ auswertbar

19 C18_F1_P13: 2 kleine Stöße

20 C19_F1_P14: mehrere Stöß, groß + klein

21 C20_F1_P14: 1 großer + 1 kleiner

22 C21_F1_P14: 1 Stoß, groß

23 C22_F1_P15: 2 Stöße, klein

24 C23_F1_P15: viele kleine Stöße

25 C24_F1_P15: 1 kleiner Stoß, restbeschleunigung (vermutlich, könnte auch van-der-Waals sein)

26 C25_F1_P16: mix

27 C26_F1_P16: viele Stöße, groß + klein

28 C27_F1_P16: mix

29 C28_F1_P17: mix

30 C29_F1_P17: mix

31 C30_F1_P18: 1 Stoß, groß

32 C31_F1_P18: mehrere Stöße, Target wackelt, warum auch immer

33 C32 - F1_P18: mehrere Stöße, groß+klein, Kamera wackelt

mehrere Targetbilder mit gleichen Sichtwinkeln für Vergleich aufbereiten. (morgen 13:00)

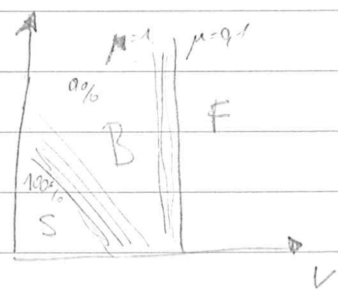
8.01.2015

Im ImageJ kann man Bilder / Videos voneinander abziehen (Process → Image Calculator)
→ Masse-gewinn des Targets dokumentieren und ausrechnen
Wenn Bilder gegeneinander verschoben sind, erstmal Maske auf Bilder setzen und die verschieben, dann Bildausschnitte abziehen.

Auswertung der Daten:
Auftragung Projektilmasse (m_p) gegen Geschwindigkeit
(Targetmasse $m_T \gg m_p$) (Target kann auch größeres Projektil sein)
Daten sortieren nach Sticking, Bouncing, Fragmentation.
→ drei Symbole im Plot
(Fragmentation nur wenn Projektil richtig kaputt. Mini-Ecke bricht ab zählt nicht)

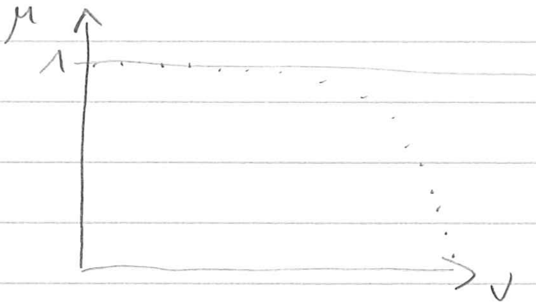
Übergang zwischen S und B fließend

Symbole
B P–T
P–P
S
F



Zwei Parameter geändert: Fluffigkeit und Temperatur
(gegenüber älteren Daten) fluffiger Bäder

Ausserdem: Auftragen μ gegen v ($\mu = \frac{m_{after}}{m_{before}}$ vom zubrochenen Teilchen), v Geschw.



Restitutionskoeffizient wird wieder streuen
-> uninteressant

Kein Colourcoding!!!
(Farbenblindheit)

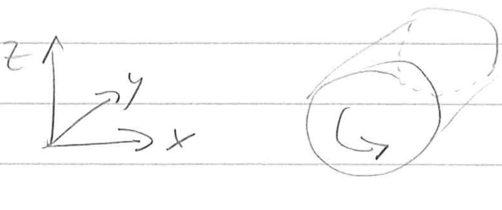
Massenbestimmung: Fläche in beiden Blickwinkeln bestimmen und Mitteln -> als Kreis oder Ellipse betrachten -> Volumen aus mittleren Radius bestimmen

Alle Teilchen, die würfelförmig sind in den Videos sind aus Staubkuchen geschnitten, alle unregelmäßigen sind gebrochen.

Für m_P gegen v wurde früher alles aufgetragen was im Massenverhältnis 1 zu 100 war (m_P zu m_T)

Ideen für die Zukunft:

Amorphes Eis geht nicht wegen Temperatur
zwei-Teilchenstöße gehen im Fallturm besser
$\frac{1}{100}$ g, 10 cm Volumen: ungefähr $0{,}1\,\frac{m}{s}$ ist kleinstmögliche Geschwindigk.
-> mm bis cm Teilchen im Sonnensystem haben solche Geschwindigkeiten
Vielteilchenexperiment mach -> permanent schütteln
Haupt-Restbeschleunigung im Flugzeug ist nach oben und unten
mögliche Aufbau "Waschmaschinentrommel"



rauhe Wände, rotiert
Beobachtung von der Seite möglich

Teilchen morgens laden und bei jeder Parabel die gleichen verwenden.
Wenn Pistons und Schraube ausgebaut sind ist Vakuum besser und Temperatur steigt langsamer.
Trommel müsste komplett vom Kühlschild umschlossen sein.
Problem: Motor finden, der unter solchen Bedingungen arbeitet.
braucht wieder Durchführungen
kalte Experimente mit Bewegung sind schwierig, hoher Verschleiß bei Teilen.
Beobachtung am besten im Durchlicht. (LED-Array, optik vor und hinter Kammer)
Teilchenanzahl: opt. freie Weglänge : $l = \frac{1}{n\sigma'}$ (Sichtlänge)

Bsp: 5 mm Ø , $\sigma' = 20\, mm^2$

$$n = \frac{100}{10^6\, mm^3}$$

$$\text{Sichtlänge} = \frac{10^6}{20 \cdot 100}\, mm = 500\, mm$$

Ziel: $l = 1000 \Rightarrow n = \frac{50}{10^6\, mm^3}$

Stoßzeit : $\tau = \frac{1}{4 n \sigma' v}$

$$= \frac{1000\, mm\, s}{4 \cdot 100\, mm} = 2{,}5\, s$$

5 mm Ø Aggregate , 50 Teilchen → optisch dünn
≈ 10 Stöße pro Teilchen pro Parabel

09.01.2015

Transition Temp from amorphous to crystalline ice goes up with higher pressures, will be ≈ 200 K for 10^{-4} mbar

For mixtures of ice and dust, use dark dust to distinguish it from ice on the videos, e.g. mix SiO_2 with C (1%)

04.02.2015

Analyse Data from 46th ESA Campaign (Braunschweig / 2007)

I used the subtract_median_background macro on all videos and adjusted contrast and brightness afterwards. Now track each particle on left, then on right view. (→ 2 files)

Flight 1: (with target)

C01_F1_P00: Cloud of small particles

Frame	appearing particles	#
40	1	not trackable
41	1	
42	2	
44	1	
45	3	biggest one: # 1
47	1	
48	2	
49	2	
50	2	
51	2	
52	2	
53	2	
54	1	
55	1	
56	1	
58	2	
60	4	
61	1	
62	2	
64	1	
65	3	

It's almost impossible to track so many small particles manually. I would have to colour mark each of them and then run the video again to be sure, I track the right ones.

Flight 2:

C02_F2_P05: one big particle colliding with two smalle particles, collision 1 ≈ frame 9, collision 2 ≈ frame 13

idea: track movement of each particle in each view in a new file → 3 particles, two views, = 6 files
use circles to estimate particle size
start with left view, then right view
save files as Results_[collision]_[flight]_[parabola]_[particle]_[view].xls
example: Results_C02_F2_P05_p1_l.xls
↗ now analysis works nicely

23.03.2015

✓ C04_F2_P06: one big particle collides with one small particle, small one fragments
after that, big particle collides with two very small particles who are hard to track
→ analyse later

✓ C05_F2_P06: one big particle collides with several medium-sized particles → they fragment. Hard to track
→ analyse later

✓ C06_F2_P06: two median sized particles collide and bounce very few frames after collision.
→ try analysis
Problem: with too few data points, the loop for testing different encounter times does not run.
→ this collision has only one or two frames for the second particle before the collision
→ do not analyse for now

21.10.2015 #1 from top
#2 from bottom

14.01.2015

PDRA Meeting

ISIS dec analysis:
✓ tweak factor: fit temp dependence only
(no time dependence)

✓ make summary PDF for Sunday:
bullet points on differences we see
questions we have, ...

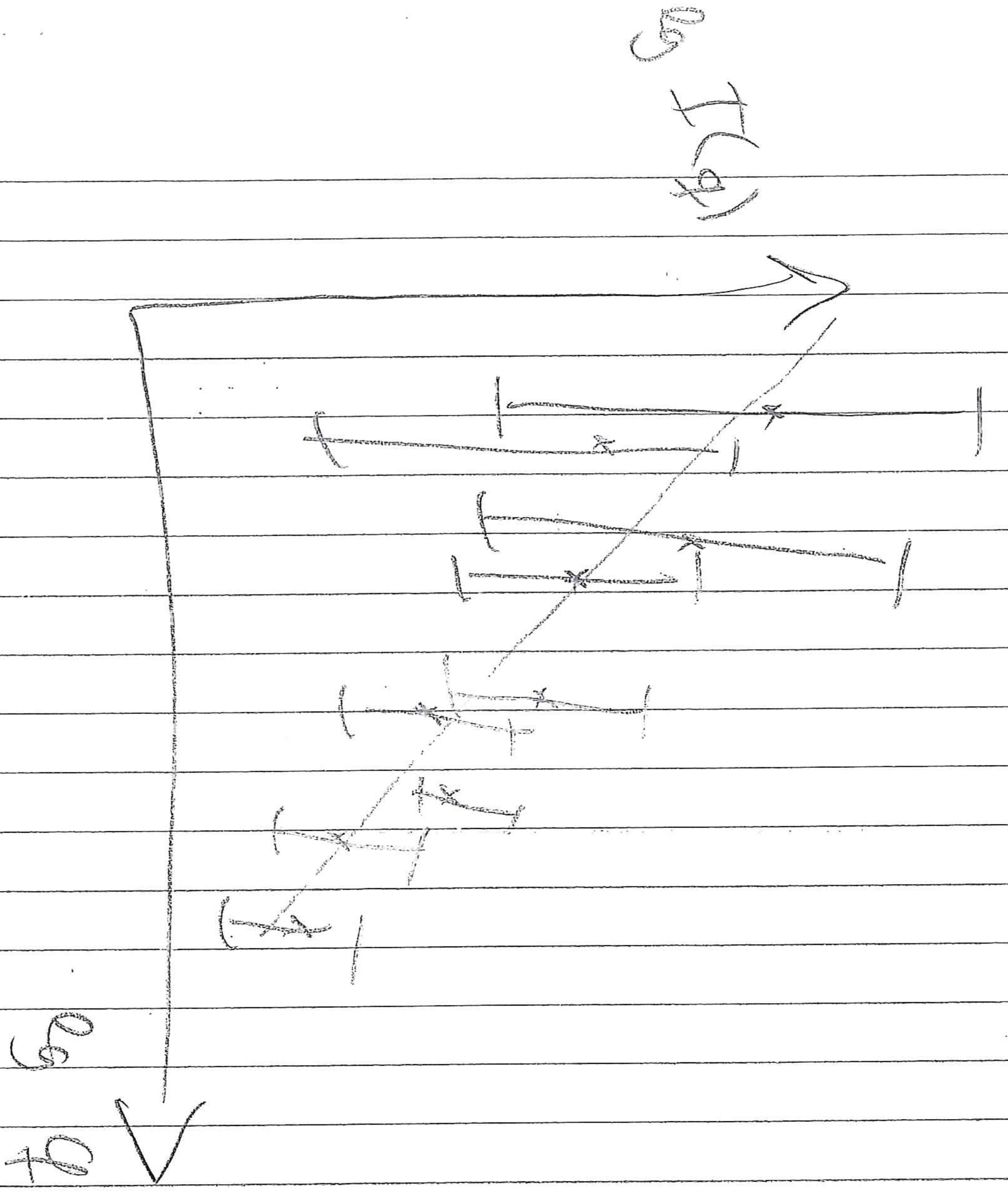
topics for tomorrow's meeting:

10.02.2015

- Parabolic flight proposal
- data analysis:
  * cold dust: look at modified COR plots
    look at mixed outcome analysis
    (notebook)
  * ISIS Dec: • tweak factor: 1 h averages scatter.
    • background shift in mint files as well
    • how to do uncertainties for β?
    • fit-limits for β? ('model dependent')
- Conference: DPS in Pasadena (16.-21.10.2016)?
  papers more important → no for now

11.02.2015

ISIS analysis: • use constant tweak factor for
final analysis
• send background plot to ISIS people (mint)
• try weighted fit → should include data
uncertainties for uncertainties of fit parameters
• manually fit stupid data sets



maybe they can arrange for me
↗ to have half a day with
SANS people and
discuss what I did

- β-range → ask ISIS people
look for book on Helen's shelf or papers on
glass / soft condensed matter
- fit range for β-fit → plot numbers of range
borders vs temperature (maybe porod region
is moving) do same for Porod range

Collisions: split data up for papers binary first
paper multiple / comparison with warm
second paper (warm only qualitatively)

26.02.2015

PDRA Meeting

Sabrina.Gaertner

From: Sabrina.Gaertner
Sent: 26 August 2015 16:29
To: Helen Fraser
Subject: subjects for PDRA meeting

Hi Helen,

Here is a list of things that I would like to talk about. It's too much for tomorrow's meeting, so I've marked the most important ones red.

- √ DPS abstract (I mixed up character and word counts earlier, so the one I sent you can be roughly twice as long as it currently is)
- √ Parabolic flight proposal redo page 11 picture of setup in plane
- Support rack design up-to-date pictures of racks
- √ ISIS: Skype doodle touch pads instead of mouse
- Lab:
  - Leak
  - Temperature readout – connector? USB 1 or 2 – Helen might have cable
  - Fire pistons manually (I have borrowed a power supply to generate +/-5V from Fraser Robertson, which I need to return tomorrow afternoon. Once we are sure whether we need + or – 5V, he will build the required thing for us.)
- Collision Analysis:
  - √ Velocities determined by different people vary a lot due to pixel-mm conversion (measuring the piston diameter). Do better statistics for my calibration (one value for each video → average)
  - √ Rotation analysis qualitatively or ~~quantitatively~~?
  - Watch more PF videos (13 left)
  - √ Analysis of particle-target collisions? Wait
- Time plan for parabolic flight preparations, papers etc. Ok

See you tomorrow,
Sabrina

√ When is next ISIS run?

16th Nov – 20th Nov

→ Move flight 1 day

30th Nov – 4th Dec

21.09.2015

Topics for next PDRA Meeting:

- watch more collision videos

✓ - Support Rack design → comments in latest dropbox docx (monitor mounting, tool box)

~~- leak~~

✓ - status of EPOS unit

- usb 1 to usb adaptor (temperature readout)

✓ - decide on touchpad for support rack

- money for DPS conference?
- room for DPS conference → single/double? general rule?

Support Rack

- keep Toolbox
- move monitors to the front of rack
  if need be, we can increase frame size of rack to cover all of monitor height

EPOS:

- give files Helen found to E-workshop

Touchpad:

- ergo, medium size, without buttons

07.10.2015

Topics for next PDRA meeting:

~~- watch more collision videos~~

- usb 1 to usb adaptor (temperature readout) ✓
- money for DPS conference?
- room for DPS conference → single/double? general rule?

~~- EPOS files~~

✓ - support rack → aren't monitors too close to eye at front of rack? no, fine

✓ - video analysis: * How about using change in centre-of-mass velocity / COR as uncertainty indicator?
  * discuss results from airplane tilt calculations

✓ - mass calculations in Salter 2009 (I get $1{,}6 \cdot 10^{-6}$ to $4{,}3 \cdot 10^{-2}$ g instead of 0,01 - 3 g) / later papers more reliabel

23.03.2015

Continue with Analysis of Data from
46th ESA Campaign (Braunschweig 12007)

√ C08_F2_P09: Collisions of several particles (small to medium) with one big particle
particle 4 can only be tracked before collision, I do not see it afterwards
→ sticking ?
particle 5 cannot be seen in right view after collision (must be hidden under ~~the~~ particle 1)
particle 6 hard to see in right view after collision (is on top of particle 1)
⇝ analyse later

C09_F2_P09: one collision: big #1 - medium #2, bouncing
analysis works nicely

C10_F2_P10: one collision: medium #1 - small #2, bouncing
analysis works nicely

C11_F2_P14: two collisions: big-big, big-small
when I ~~plot~~ plot the trajectories, there is clear evidence that the two big particles collide again, at the same time or slightly later than the big-small collision.
⇝ fit routine does not work
⇝ analyse later

C12_F2-P17: two collisions, each big #1 - medium #2 + #3

24.03.2015

I found some mistakes in the fit-routine, solved them, redo fit of C02, C09, C10.
⇝ analysis works nicely

√ C13_F2_P18: one collision, medium small
analysis works, but trajectory of larger particle looks bent. Might be residual gravity, might be problem in determining particle center → check later

25.03.2015

C14_F2_P21: two collisions, medium-medium, medium-big
H
bottom #1, top #2, top #4, bottom #3

collision 1: bottom particle suddenly changes direction in frame 28 without visible collision the other particles don't, so not residual gravity → what is it? probably hit the bottom → ignore
when I ignore the data points 28 and later for particle 1, the fit works nicely

C15_F2_P24: several particles collide at more or less the same time, not all of them can be tracked after the collisions
→ analyse later

C01_F2_P04: one collision, medium-medium, one particle fragments, one of the fragments can be tracked after the collision, the other is flying into a group of other particles, not clear whether it hits any, not visible on all frames
→ analyse later

C03_F2_P06: one big particle collides with three small particles, none of the small particles can be seen after collision. → sticking?
→ analyse later

C07_F2_P08: several big and medium sized particles collide at more or less the same time, after collision a lot of small particles are visible, but it can't be seen, which of the particles fragmented
→ analyse later

pixel to mm calibration for flight 2:
piston diameter = 5 mm
left position on average 250 px
right position on average 388 px
⇒ piston diameter = 138 px

26.03.2015

Supervision Meeting

Experiment - redesign: order 4 more bars to put the piston motors on and keep the xy bracket that are inside at the moment

Talk Carole: ~~"change cm to mm in picture with forces~~
~~take some bits from "key parameters slide"~~
results; ~~take out picture~~, ~~put in video + and graphs → having probability for COR~~
instead of fixed value
put ~~also~~ video of ice collisions
~~no dust results~~, put chemistry result ~~→ no effect~~
~~acknowledgements merge with Title slide~~

Data Analysis:

(✓) C04_F2_P06: small particle fragments into three
get velocities before and after collision
the very small particles that can't be tracked
→ special cases at the end of paper

(✓) C05_F2_P06: get as much size and kinetic information as possible → qualitative analysis

C06_F2_P06: try to analyse it by putting line through 2 points → see where result is in comparison to other particles

(✓) C08_F2_P09: "potential sliding", get as much information as possible on the others.

02.04.2015

(✓) C13_F2_P18: it looks like the big particle hits two small particles → redo fit that way

C03 all but the first one stick

26.03.2015

Flight 3:

pixel to mm calibration:

piston diameter = 5 mm
left position on average : 232 px
right position on average : 362 px
=> piston diameter = 130 px

C16_F3_P01 : one collision, big-medium. some very small fragments chipped of, each only traceable in one of the two views → wrong
analysis works nicely → analysed later

C17_F3_P01 : at least two collisions at almost the same time, one medium - medium, one medium very small. before the collision, there is another very small particle visible which is clearly not involved in the collision. after the collision this particle most likely hits another medium particle (not involved in the collision). after that, I don't see the small particle any more → sticking? No
how to analyse the first collision? Ignore the medium - small - collision in finding the trajectories for the medium - medium collision?
→ analyse later → 16.10.2015

14.4.15
second view of video:
the first particle from the bottom might hit the second one from the top. I don't think, the second one from the top hits one of the particles involved in the other collision.
The small particle flys along the first one from the bottom, probably without hitting anything.
There are two tiny particles at the very bottom, that I would ignore.

C18_F3_P02 : one collision; big #1 - medium #2
analysis works nicely

C19_F3_P03 : several big, medium, and small particles colliding at more or less the same time, lot of ~~sm~~ very small fragments chipped off, no hints of sticking
→ analyse later

C20_F3_P04 : two big particles collide, at leat two small fragments get chipped off, later two small particles pass, probably without collision
→ analyse later

C21_F3_P05: ~~maybe~~ one collision, big-medium, hard to see
→ get trajectories and try to fit
plotted trajectories show evidence of collision
when I let python determine the encounter time, it chooses a point that is definitely too late (due to the rather large scattering of the data). When I enter 100 ms as start value for the fit (which is too low), python moves the collision time to ≈ 120 ms which makes sense
→ analysis works, but somewhat bigger errors

27.03.2015

C22_F3_P05: two collisions: each big-medium
→ analysis works nicely

C23_F3_P05: one collision: big-big, after collision one very small particle is visible, which might be a fragment or might come from the piston tube below the collision
→ analyse collision and later analyse possible fragment
→ analysis works nicely

probably fragment (flies not straight up, but sideways)

C24_F3_P06: one collision: big-medium, medium particle hard to track after collision in left view
→ analysis works ok

C25_F3_P06: one, maybe two collisions: a big and a medium-sized particle from top, a medium sized particle from the bottom. unclear whether top-medium particle is involved in collision. It can only be tracked in right view after collision. Ignore it for now.
→ analysis works nicely
small fragment chipped off
small particle from bottom might be sticking

H
→ 16.10.2015

27.03.2015

Continue with data analysis from 46th ESA campaign (Braunschweig 2007)

C26_F3_P07: two big and one medium sized particle collide almost at the same time. after the collision ≈ 5 very small fragments show up, flying away in all directions. the bigger particles seem to loose almost all of their translational energy but rotate strongly
→ analyse later

H
particles wobbling
residual gravity
→ up to which frame
can I use this video?

C27_F3_P07: one collision: big-medium, the big particle is surrounded by a cloud of small ones, but none of them seems to be involved in the collision. After the collision a very small fragment is showing up (flying away from the medium particle), but it can only be tracked in the left view
→ analyse trajectories ignoring the fragment for now
→ analysis works nicely

C28_F3_P08: one collision: medium-medium, after collision 4 very small fragments are visible, all can be tracked for at least 3 frames.
→ analyse collision now and fragment trajectories later
→ analysis works nicely

C29_F3_P08: several collisions: one big particle collides with the following particles: - small: bouncing, - small: cannot be tracked afterwards (sticking?) (can be tracked probably not collid[illegible]
- medium: bouncing, - very small, - very small: ~~of the last~~
fragment

two, only one can be seen after the collision, not clear which one (probably the first) both bounce
I could simply ignore the two last ones and the second one (~~possible~~ sticking), but how much sense does it make to get collisional data for the first one in this case, since the big particle collides with two similarly small ones within a very short time → any ~~any~~ velocity change might be due to either of these collisions.
→ analyse later

C30_F3_P08: probably three collisions: a big particle collides with a medium and a small one (most likely) at the same time, later it collides with another small one
~~→ for now, I will analyse the last collision and leave the other(s) for later~~
→ plotting the trajectories of all four particles shows little to no alteration in the path of particle three → ignore this possible collision for now and analyse the other two
→ analysis works nicely for those, plot shows that there is another particle
→ this might be a useful way of analysing multiple collisions, where one has significantly more influence than the other.

30.03.2015

C31_F3_P09: one collision, big-big, after the collision a very small fragment shows up on the right view only
.09.2015
isca = 52 px →
→ fragmentation but not trackable!
→ analyse big particles only for now
→ analysis works OK

on frame 14 (3d collision), two small particles collide with top particle (#2)
→ ignore

C32_F3_P09: probaby two collisions: first a big particles collides with a small one, after the collision the small one ~~flies~~ can be tracked only on two frames, then the big particle and probably also the small one collide with a medium ~~siz~~ sized particle, all bounce and can be tracked, but the big one only for two or three slides.
~> analyse later

C33_F3_P10: several medium sized particles ~~and~~ collide with a big one, after the collision, at least one, maybe two small fragments are visible. one can be tracked
~> analyse later

C34_F3_P10: two collisions, maybe three: 2x medium-medium, ~~one~~ first: at least ~~a~~ three fragments are chipped of in this glancing collision, can be tracked one frame after first collision, particle collides with another one, ~~to~~ 1 small (very) fragment appears. Maybe one or two fragments from the first collision collide with another small particle
~> analyse later

C35_F3_P12: several collisions, at least one fragmentation:
≈ frame 21: 3 or 4 small particles from the bottom hit a big one from the top. after the collision two particles fly away to the left, several smaller ones appear on top of big particle.
I can't track which particle / fragment after the collision was which one before.
~> analyse later (big particle positions already safed)

C36_F3_P12: one collision: big-medium, between frames 16 and 17 the smaller particle seems to "jump"
→ delete data points after frame 16
⇝ analysis works nicely

C37_F3_P12: several collisions: one big-medium, probably two big-small, after the big-medium collision at least two fragments appear, after the second big-small collision, the small particle seems to be carried away with the big one. When the big one hits the piston-tube, the small one and another fragment come off.
⇝ was it "loosly sticking" (the colliding one), or just moving in front of the big one? no, moving in front
→ try to track trajectories of all involved particles except the fragments from the first collision, to get a clearer picture.
→ not enough data points for good fit of the last two collisions → ignore them for now and fit only big-medium collision (although trajectory of big particle (#1) looks like it was altered by second collision a bit.
⇝ analysis works ok

C38_F3_P13: two collisions: one big-big, one big-small
in the big-big collision, at least ~~three~~ four fragments (3 very small) get chipped off (plus 1 small)
→ analyse fragments later and collisions now
→ analysis works ok

C39_F3_P13: one collision: big-big, from the top big particle, two medium and two small fragments get chipped off → analyse later

30.03.2015

Continue with data analysis from
46th ESA campaign (Braunschweig 2007)

C40_F3_P13: one collision: big-small, after the collision, the small particle fragments in two smaller ones, also 2 very small ones show up, unclear wheter they are from big or small particle, cannot be tracked properly
→ analyse later

C41_F3_P14: two collisions: 2x big-small
first: small particle splits in a least five fragments, not all can be tracked in both views
second: after collision, a smaller particle shows up under the big one, might be a fragment or a bad view of the original particle, can be tracked only on two frames
→ analyse later

C42_F3_P14: one collision, medium-small (#1 bottom, #2 top)
→ analysis works nicely

H C43_F3_P15: at least one collision: big-medium
the medium particle fragments into ≈20 pieces of various sizes, they fly away in all directions, into this cloud then fly two very small particles from the bottom and one small particle from the top (the latter probably collides with the biggest fragment), fragments hard to distinguisch → analyse later.

Hard to tell how many particles are coming from the bottom tube.

C44_F3_P17: two collisions: medium-medium, medium-small
in the first collision at least 3 very small fragments appear (unclear from which particle)
after frame ≈30 residual gravity seems to set in. → use only data points before
→ analyse fragments later and collision now.
→ fit for the particles that have only one collision (# 2, #3) works fine, but fit for particle 1, who has only 4 data points between collisions and wobbly trajectory (due to its size ~ center hard to determine), is rubbish
→ analyse again later.

C45_F3_P18: one collision, possible fragmentation: medium-medium
after collision a medium particle moves independent from top particle, hard to see, whether they were really attached in the beginning.
→ analyse later → they were not attached (07.05.2015)

C46_F3_P19: one collision: big-medium, after collision, two small fragments appear
→ analyse collision now and fragments later
→ analysis works nicely

C47_F3_P22: several collisions: one big particle from the top hits the following particles: frame 6-small (particle not visible after collision (→sticking?) | ~~frame 8 - very small particle not visible after collision (sticking?)~~ frame 11 - medium and very small (1sticking?) | frame 14 - small (fragmentation?) | frame 16 - 2small || ~~between frames 14 and 20 two particles are flying away from the big one (unclear which ones they ~~were~~ were originally)~~

fragment traceable only on right view

→ ignore?

two small particles come from the bottom hard to see, but left view shows they fly by

H

→ See 19.10.2015

→ analyse later

C48_F3_P22: one collision : big-medium , after collision several small fragments fly away , unclear whether they come from one of the particles , they cannot be tracked properly.
→ analyse collision now and fragments later
→ medium particle is hidden behind big one for several frames , shortly after collision it moves off (residual gravity? , other particle does not show this)
probably hits the ground →
→ trajectories probably not suited for analysis, only incoming velocities

C49_F3_P23: ~~several~~ two collisions: big-medium , big-big after both collisions several small fragments of unknown origin appear
→ ignore fragments for now
→ analysis works ok , but only two frames between collisions → bigger errors

C50_F3_P23: one collision : big-medium
→ analysis works nicely

C51_F3_P24: several collisions: one big particle collides with the following ones: frame 8: - very small (sticking?) / frame 9 - small (~~fragmentation~~ ?) / frame 10 - medium (bouncing) / frame 13 - medium + 2 small (bouncing)
→ analyse later
possible fragmentation

flying away → to the right side in left view on top of big particle (not visible) in right view!

(11.05.2015)

31.03.2015

Summary: I can analyse single and multiple collisions, that have enough data points before and after each collision (≈ 3).
The resulting errorbars for ε are ok, for everything else, they are huge.
When fragments are chipped off, or ~~small~~ minor collisions (low influence on trajectory of relevant particle) happen, I can still analyse the main collision ~~of~~ by ignoring the extra particles.

Future work: I need to get trajectories of all particles involved in any collision, including sticking particles and chipped off fragments.
That way, I can sum up all ~~kinetic~~ translational energies before and after the collision(s).
→ Write a fitroutine, that loops through all the particles and asks for breaking points in each particle's trajectory → give them manually and let python fit the different trajectory bits
→ write area to file and calculate volume of particle, to later convert it to mass via density.

?. **Question:** I would like to state how much of the original particle size was chipped off. In many cases I can't tell from which of the original particles the fragments come. What makes more sense?
- Giving total volume of particles before collision as reference.
- Separating in two datasets, giving the original particle size where identified and the sum where not.

combination of both: Generally state total mass of colliding particles, plus paragraph with more detailed information where available.

31.03.2015

Data Analysis (suggestion from group meeting)

COR: investigate dependence on momentum:

fragments: lot of particles with comparable velocities of very different sizes

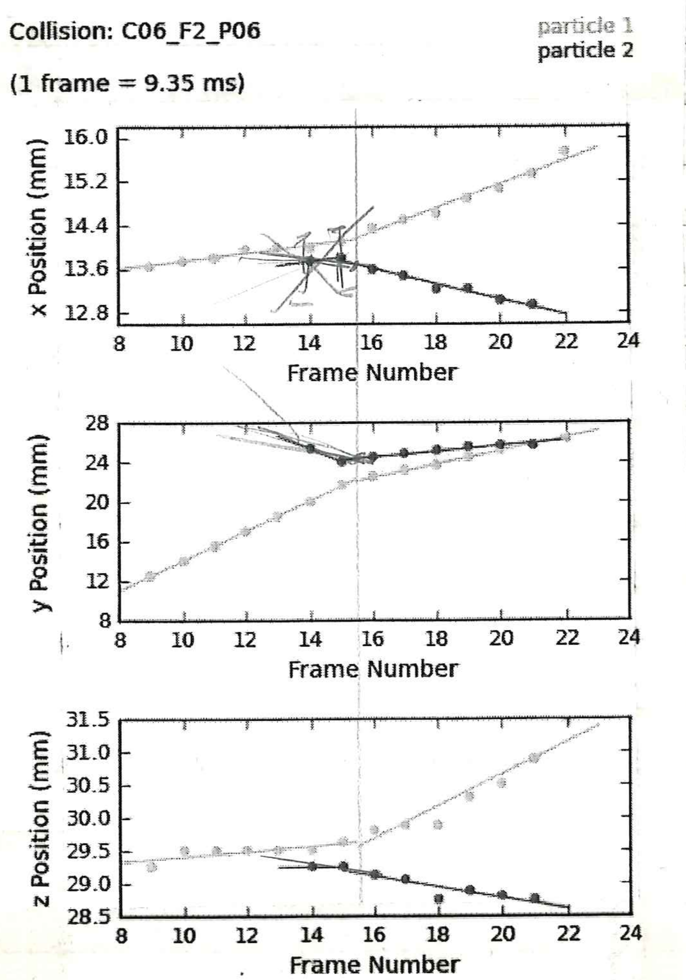
02.04.2015

? Question: When I have only 2 datapoints before (or after) a collision for one of the particles, does the following approach make sense?

Fit trajectories that have more than 2 points

→ calculate encounter time from the trajectories of the other particle

→ choose this time on the the trajectory of the "bad" particle that has enough points and use it as additional data point to fit the 2-point-trajectory.



→ try that

Test new python skript (for the analysis of difficult collisions):

C11_F2_P14: particle 1: coming from bottom tube (big)
particle 2: coming from top tube (big)
particle 3: coming from top tube (small)
collisions: after frame 10: particles 1 and 2
after frame 13: particles 2 and 3
after frame ~~14 or~~ 15: particles 1 and 2
⇒ particle breakpoints:
#1: 10 and 15
#2: 10, ~~13~~, 15 (ignore 13)
#3: 13

↖ plotted data suggest 15 rather than 14

H ✓

⇒ analysis works, but the collision with particle 3 does not seem to alter the trajectory of particle 2, maybe ignoring this collision would give a better starting point for the analysis of the second collision of #1 and #2.
→ try that → seems to work nicely

27.08.2015: when I do the energy maths, the collision system 1-2 II seems to gain trans. energy during the collision!
→ maybe from rotation

C04_F2_P06: particle 1: coming from top tube (big)
particle 2: coming from bottom tube (medium)
fragments between frames 9 and 10
particles 5, 6, 7: fragments of particle 2
(labelled top to bottom)
#5 cannot be tracked in right view
→ Is there any way to get a reasonable estimate of it's kinetics? It is hidden under particle 1, that could give a range for the movement. Try that → See 13.10.2015

H ✓

particle 3: coming from bottom tube (small) after #2 collides with #1 after frame 10
then I loose track of it. In frame 13 a particle of similar size appears above #1 but it's moving in the wrong direction
→ what's going on? → sticking

particle 4: coming from bottom tube after particle 3 (small)
colliding & bouncing with #1

for particle ~~no~~ 5 right view, I drew an ellipse having the same ~~and~~ height & ~~po~~ y-position as the particle shows in the left view, spanning all the range of the big particle #1 in width → get range in which particle could be moving → See 13.10.2015 for new approach

collisions: after frame 9: particles 1 and 2
after frame 13: particles 1 and ~~3~~ 4
after frame 10: particles 1 an 3

⇒ particle breakpoints: #1 : 9, ~~10~~, 13 (ignore 10)
~~#3: 10~~ (sticking)
#4: 13

Fit does not run for particles without break points
→ check that.

07.04.2015

↳ fixed

particle 1 cannot be fitted with collisions at frames 9 and 10 → ignore collision at frame 10 because particle 3 is very small.

try different approach for particle 5, which cannot be tracked in right view:
introduce particle ~~..~~8, which has the same coordinates in left view. use 5 and ~~..~~ 8 as limits for particle position in right view (particle 1 borders for x, ~~copy from left view for y~~) try to get y right from left view)
works better, but treat with a different fit routine for final analysis.
↳ See 13.10.2015 for new approach

C05-F2-P06: particle 1: from top tube (big)
fragments between frames 12 and 13
particle 2: from bottom tube (medium)
first particle from the left
particle 3: from bottom tube (small)
second particle from ~~the~~ the left, hard to
see on right view, probably fragmenting
between frames 12 and 13
particle 4: bottom (medium), third from left
fragmenting between 12 and 13
particle 5: bottom (medium), fourth from left
fragmenting between 12 and 13
particle 6: bottom (very small), coming after
#2-5, maybe bouncing, but cannot be
identified among fragments → track only
up to f.12

fragments:
particle 7: (small) chipped off #1
particle 8: (medium) either fragment of / or whole particle 4
flying towards camera on left view (creating shadow
on particle 1)
particle 9: (small) fragment of particle 3 or 4, flying
towards bottom tube | judging from plots fragment
of particle 3.
particles 10 and 11: fragments of particle 5, flying towards
bottom-right, ~~in~~ #11 hard to see on left view
(hidden behind other particles.

all other fragments are not properly traceable
→ estimate their sizes and velocities later as
far as possible → 13.10.2015: take average velocity of all other fragments
and mass of #10 to account for E_trans of these
fragments. ⇒ "#12"

see screenshot of frame 16 for particle numbers

⇒ particle breakpoints: particle 1: 12
particle 2: 12

! when there are more than 9 particles, they have to be
numbered 01, 02, ..., 09, 10, ..., otherwise python sorts them wrong !

C07_F2_P08: particle 1: top (big), first particle from top
particle 2: top (big), second particle from top
not hitting anything → particle 3: bottom (small), first particle from bo
particle 4: bottom (small), second particle from b.
particle 5: bottom (medium) a little bit above #6
particle 6: bottom (medium) a little bit below #5
particle 7: bottom (small) immediately below #6
(there is another small one, visible only in right view)
both bounce, but only #7 can be tracked
⇝ similar size and velocities ⇝ use translational energy of #7 twice for final analysis
particle 8: bottom (very small), topmost of #8,9,10
can ~~be~~ be tracked only before collision
particle 9: bottom (small), ~~second~~ second of #8,9,10
particle 10: bottom (medium), third of #8,9,10
probably not hitting anything. plot & check trajectory to be sure → no clear collision, but bent trajectory. weird
~~particle 11: bottom (small)~~)

collisions: frame 18: particles 1,5,6 1,5 / 1,6 fragments: 11 13 -18
frame 17: particles 1,4 fragment #12
frame 20: particles 6,7 fragment #19 not tracable
frame 28: particles 2,8 sticking
frame 21: particles 2,1,5,6 1,2 / 1,6 / 2,5, 5,6
frame 30: particles 2,9

⇒ particle breakpoints: particle 1: ~~17~~,18,21 (ignore 17)
particle 2: 21, 28, 30, particle 4: 17
particle 5: 18, ~~21~~ (no data points at 21), particle 6: 18,~~20~~,21 (ignore 20)
particle 7: 20, ~~particle 8: 28~~
particle 9: 30

fragments after collisions: particle 11: flying off to top left from frame 24 on (small long)
~~particle 11: showing up above particle 4 on frame 21~~ can't be traced
Only none of them can be tracked in right view
→ estimate sizes and velocities for final analysis.

14.10.2015

some trajectories (especially z component) look very bent after frame 32
⇝ I'll ignore the later datapoints for particles 1,2,5
for particles 6,9 I have to take the late datapoints because I don't have early ones.
10 is not colliding.
→ run fit again

#12 to #19 not tracable → take masses only
velocities: #12 double as fast as #4 after col.
#13-18: half as fast as #11
#19: double as fast as 7 after col.

H

C08_F2_P09: After checking the video again and again, I'm
→ pretty sure, that there is no sticking or fragmentation.

frame 35 in the original video looks like particle 2 fragmented

particle 1 might be two particles close to each other

However, most of the particles are hard to track because they rarely show on both views and cannot be identified before-to-after collision.

particle 1: top (big)
particle 2: bottom (medium), first from bottom
particle 3: bottom (small), smallest of the group of four coming after #2, flying to the left in left view (almost straight in left view after) collision and to the right in right view
particle 4: bottom (medium-small), uppermost of group of four, flying to the left and slightly downwards after collision
→ probably wrong identified in right view
→ redo tomorrow.

10.04.2015

↳ redo right view of particles 3 and 4 after collision

15.10.2015

collisions:
1,2 : 33
1,4 : 34/35
1,5 : 35
1,6 : 35
1,3 : 35/36
1,7 : 37
1,8 : 37

particle 5: bottom (medium), second upmost of the group of four, to the right of particle 4 in both views
= 12
I cannot identify it after the collision
→ track unidentified particles after the collision separately and see wheter plotted trajectories help with identification.
particle 6: bottom (medium-small), last of the group of four, left view on the very right, right view on the very left. can't be identified after col.
= 10
particle 7: bottom (small), coming after group of ~~four~~ four
can't be tracked in right view after collision
↳ moves almost like #8 → take this velocity
particle 8: bottom (medium), after #7
after collision: ~~on~~ left view: rightmost particle
right view: on top of #1 but visible
now: particles after collision that are not identified

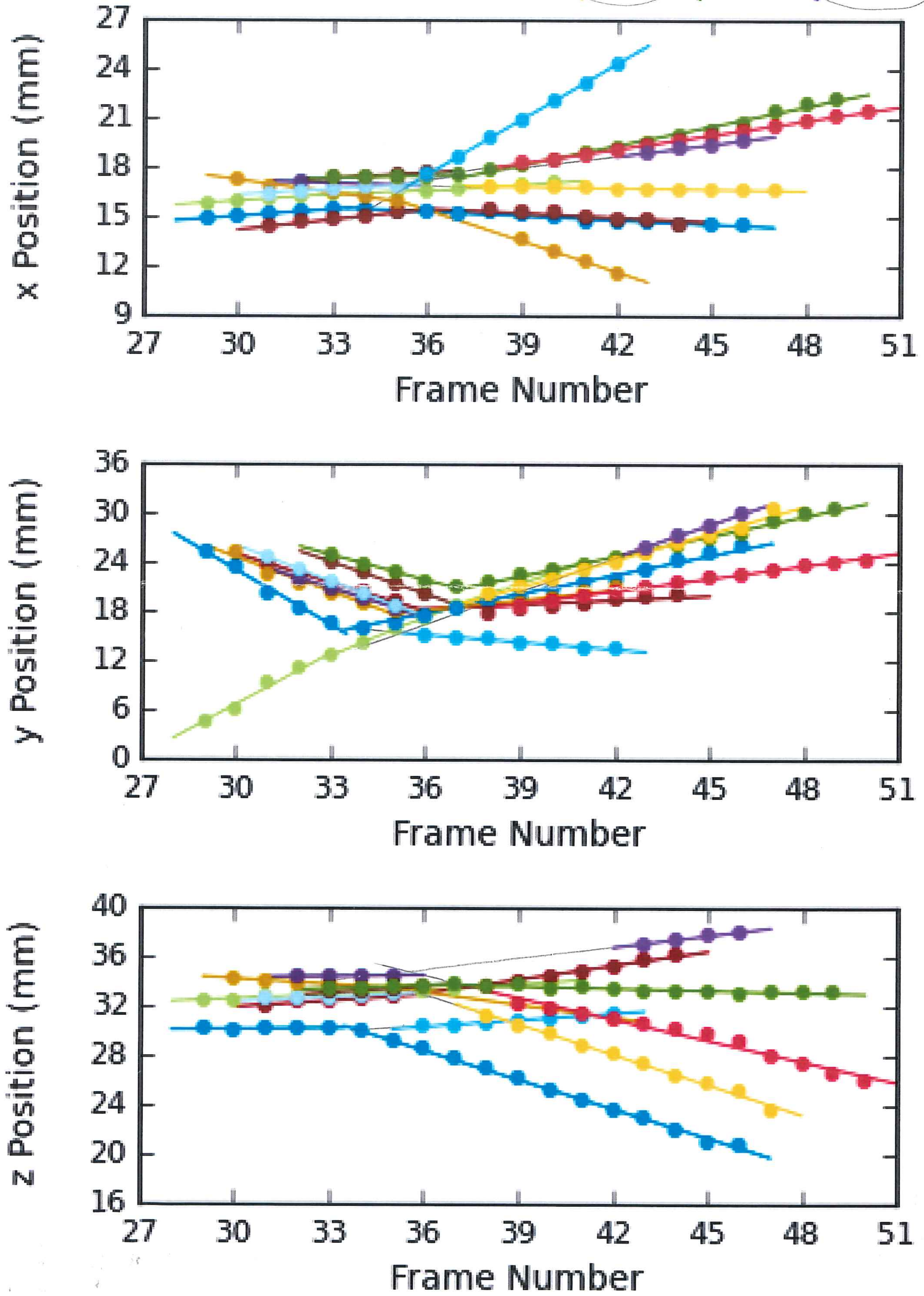
for the identification problems: I'll treat encounter 1,3,4,5,6 as multiple anyways and take ~~the~~ the doubly tracked particles as best guess.

Collision: C08_F2_P09

before: 8 particles, after: 10 (9 plotted)

(1 frame = 9.35 ms)

part 1 part 5 part 9
part 2 part 6 part 10
part 3 part 7 part 11 fragm. of #2
part 4 part 8 part 12



particle 9: small, flying to the top
left view moving to right (fast), right ~~m~~ view:
moving more or less straight up, barely visible
particle 10: small, flying more ~~..~~ or less horizontally
left view flying to the right (~~under top~~ topmost
under #9), right view, flying to the left
(appearing at the tip of #1), flying slightly
downwards.
misidentification: I tracked the same
particle in the right view for #10 and
#4. Problem: I don't see any other
particle moving at the same height in
right view and can't identify whether it
is #4 or #10. Plot positions and see
if that helps
(medium-small)
particle 11: potential fragment of #2. appearing on top
of #1 in left view (frame 36), flying to the
bottom right. right view flying fast to the
left.
particle 12: appearing at frame 43 after #1 was stopped
by piston ~~at~~ to the right of ~~a~~ tube (medium)
moving down and right in both views
particle break points: #1: 33, 35, 37
#2: 33
#3: 35
#4: 35
#8: 37
plot: #9 must be fragment from collision #1/#2 as well
#11 behaves as if it was #5, but video shows that it can't be
#12 is ~~it~~ most likely #5 ↳ fragment of #2
#10 would then be #6
plot does not help in identifying whether z-component
(right view) of doubly tracked particle belongs to
#4 or #10

22.09.2025

C13_F2_P18: particle 1: bottom (~~medium~~-big) uppermost of big particles (left in both views)

Collisions:
1-4: 8 1
3-4: 10 3
1-5: 10 2
2-7: 18 7
2-5: 11 4
2-6: 12 5
2-8: 16 6
7-8: 19 8

particle 2: bottom (big-medium) lowest of big particles (middle in both views)

particle 3: bottom (small) under #2
collides with #4 after frame 10

particle 4: top (medium-small), first particle from top

particle 5: top (medium), coming together with #6
left view on the left of #6, overtaking it before collision with #1 (and #2?)

particle 6: top (medium), see #5, might be colliding at frame 10 or 11, but hard to tell -> check plotted trajectory. #2 - #6 after 12 (very glancing, is more for #2)

Analysis of collision 1-4 shows gain in translational energy -> video looks like loss of rot energy

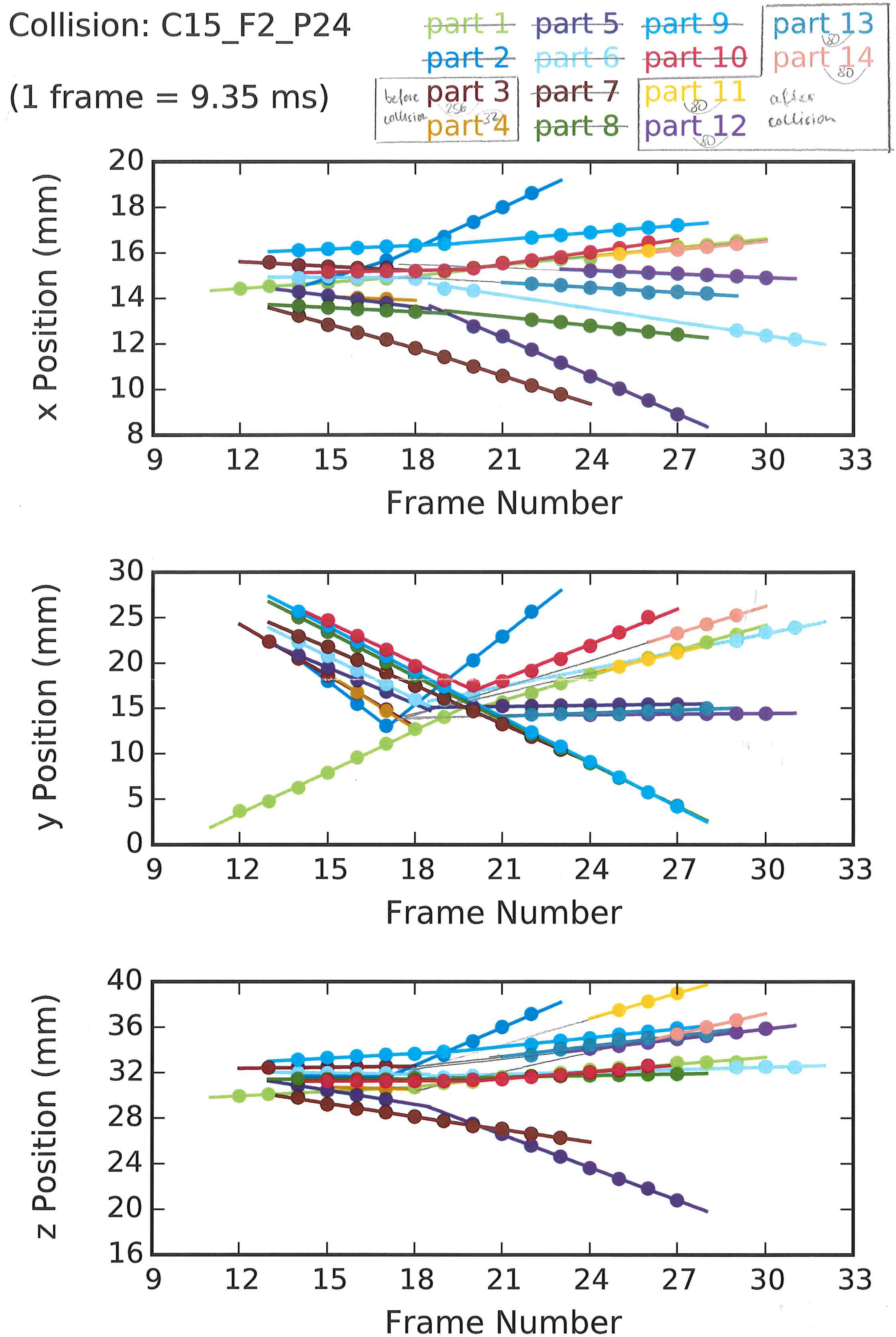
particle 7: top (medium), fully out of tube on frame 9
colliding with #2 after frame 18

particle 8: top (small), fully out of tube on frame 6
colliding with #2 after frame 15 or 16
and maybe with #7 ~~or #10~~ after frame ~~18~~ or 19

~~particle 9: bottom (small). first traceable point: frame 9~~
~~left view: between #2 and third big particle~~
~~right view: between #1 and #2~~
~~wrong identification. #9 is not really trackable and probably does not hit anything.~~

particle 9: (named 10 in screenshot)
top (medium); coming out in front of #7
might be colliding with somthing between frames 16 and 20. -> no

particle breakpoints: #1: 8 ~~9 (or 10)~~
#2: 11, 16, 18, #3: 10
#4: 8, 10, #5: 10 ~~(12?)~~
#6: ~~10 or 11?~~ 12, #7: 18
#8: ~~15 or 16~~, ~~18 or 19~~, #9: ~~3~~ ~~18~~ ~~9~~
no data -> use 16



Collision: C15_F2_P24
(1 frame = 9.35 ms)
~~part 1~~
~~part 2~~
before collision
part 3 256
part 4 32
~~part 5~~
~~part 6~~
~~part 7~~
~~part 8~~
~~part 9~~
~~part 10~~
part 11 80
part 12 80
part 13 80
part 14 80
after collision
x Position (mm)
y Position (mm)
z Position (mm)
Frame Number
Frame Number
Frame Number

~~[illegible]~~ 13.04.2015

H C15_F2_P24: particle 1: top (big), collisions:

15.10.2015 — frame: ~~[illegible]~~ 17 17 18 19 20

treat particles — particle: 2 3,4 5,6 8,9 10

11,12,13,14 — particle 2: ~~sm~~ bottom (small), uppermost from bottom

as fragments of 3 — particle 3: bottom (small), under #2

treat #4 as — can't be tracked after collision. might be

sticking — ~~sticking~~ or fragmenting → check number of particles after collision

particle 4: bottom (very small) next to #3

H → can't be identified after collision — might be 14 or sticking

particle 5: bottom (medium-small), after #2,3,4

collisions: — (do not track before frame 14, because it comes

1,2 : 17 — originally from top and collides with ~~#6~~)

1,3 : 17 — colliding with #1 at frame 18 and with #7 at 19

1,4 : 17 — no data points for 18 and 19 on left view

1,5 : 18 — particle 6: bottom (medium), hidden under #1

1,6 : 18 — after collision, small corner becomes visible

1,8 : 19 — on frames 29-31

1,9 : 19 — particle 7: bottom (very small), might be colliding

1,10 : 20 — with #5 at frame 19

5,7 : 19 — particle 8: bottom (small), partly hidden under #10 in right view. might be colliding with #1 at f19

particle 9: bottom (medium-small), next to #10

particle 10: bottom (medium) last particle

particles after collision:

particle 11: small same height as #1

particle 12 and 13: very small, ~~above~~ on top of target holder

12 above 13, 13 hits target holder and sticks at frame ~~[illegible]~~ 28

particle 14: very small, below #1

particle break points: #1: ~~[illegible]~~ 17, 19 | #2: ~~18~~ 17

~~#3: 17~~ | ~~#4: 17~~ | #5: 18 | #6: 18

#7: 19 | #8: 19 | #9: 19 | #10: 20

C01-F2-P04: particle 1: bottom (medium), second in
the group of three medium particles
collides with #2 after frame 10
particle 2: top (medium), bigger of the two
particles appearing on frame 5
fragments in collision with #1
after collision: particle 3: smaller fragment of #2
particle 4: bigger fragment of #2, can
only be tracked (blurry) for a few late
frames, because it is on top of particles #1
most of the time in right view.
particle break points: #1: 10
→ analysis works that way

C03-F2_P06: particle 1: top (big)
particles 2 and 3: bottom (very small)
(uppermost and lowest of the group of ~~three~~ four similar
particles), collide with #1 after frame 5
seem to be pushed along by #1 at
the same ~~spe~~ speed, but do not stick (visible
slightly below #1 on several frames, but
not trackable) → use velocity of #1 after collision and average of 4 and 5 before.
particle 4 → 2: bottom (small), coming after group
of three, collides with #1 after frame 6
not visible after that, might be sticking.
particle break points: #1: 6
particle 5: bottom (very small) second of group of four
can't be tracked after collision → potential sticking
I can't track #2 and #5 → rename for fit: 4 to 2
→ to estimate velocities of #2 and #5, use average
of the other two small particles, as they move
more or less at the same speed and direction

14.04.2015

Continue with data analysis from 46th ESA campaign (Braunschweig 2007)

Summary of Flight 2 - analysis so far:

Fitted trajectories and encounter times: (got ε and b/R)

C02, C09, C10, ~~C11~~, C12, C14

Fitted trajectories (no other analysis so far):

C01, C03, C05, C07, C11, C13, C15

Analyse later with specialised fit routine:

C04, C06

Talk to Helen:

C08

Flight 3:

C16_F3_P01: At very close look, the three fragments can be tracked on at least two frames, each.

→ copy ImageJ-results and rerun fit for split trajectories, use both fits for final analysis

particle 1: bottom (big) colliding with #2 after frame 8 ~~or 9~~

particle 2: top (medium)

particle 3: fragment (very small) flying downwards

particle 4: fragment (very small) flying upwards (faster)

particle 5: fragment (very small) flying upwards (slower)

particle break points: #1: 8, #2: 8

→ analysis works

C19_F3_P03: particle 1: top (medium), left of two particles in both views. Collides with #4 (and #3) after frame 10. Between frames ~~8~~ 7 and 9, #1 and #2 are probably touching each other at the edges.

particle 2: top (medium), right on both views collides with #5 after frame ~~10~~ 11 and potentially #4 after frame 11

H

particle 3: bottom (small), collides with #1 and #4 after frame 10. I don't see it after that and the fragments showing up do ~~no~~ seem to have enough mass to make up for #3. It looks like it might be sticking to the right bottom edge of #1, though! ⇒ compare #1 on frames 8 and 31 (right view).

particle 4: bottom (medium), left in both views, collides with #1 and #3 after frame 10 and potentially with #2 and #5 after frame 11. ~~collides with #6 after frame 15 or 16~~

particle 5: bottom (medium), right in both views, hidden partially under #4 in left view. colliding with #2 and potentially #4 after frame 11. collides with #6 after frame 15 or 16

particle 6: bottom (small), coming after #5, colliding with #5 after frame 15 or 16

fragments:

particle 7: showing up to the left of #4 (very small) moving down and left in both views

particles 8 and 9: showing up to the right of #1 ~~mo~~ (very small) moving up and right in both views, #9 is the lower one

particle 10: flying in the same direction as #9 but faster (rather small) partially on some frames hidden by #9

several other fragments cannot be tracked → ~~double~~ increase (≈ x1.5) amount of their kinetic energy for analysis

particle 11: showing up to the right of #1, faster ~~to~~ than 8 and 9 but moving in roughly same directions

particle break points: #1: 10, #2: ~~10~~ 11 ~~#3:~~
#4: 10, #5: ~~10~~/11, 15 , #6: 15/~~16~~

16.10.2015: I'll treat the collisions of 1,3,4 as follows:
3,4 bouncing → 1,3 sticking → 1,4 fragmenting

15.04.2015

H

C20_F3_P04: particle 1: bottom (big), colliding with #2 after frame 8 and probably with ~~#3 after 10/11~~, #4: 11
particle 2: top (big), colliding with #1 after 8
particles 3 and 4: top (small), 3 coming first, probably colliding with #1 after frames 10/11 → #3 no, #4 yes

It flies off to the side, so probably fragment, right?

particle 5: either fragment of #1 or carried along by it (small)
particle 6: probably ~~fragment of #1~~, carried along by #1, might be fragment of it. (small)

16.10.2015 I'll treat #5 and #6 as fragments of #1

I'll take its positions before the collision of #1 and #2 to see whether it changes direction. it does

particle breakpoints: #1: 8, 11, #2: 8, #3: ~~10/11~~
#4: 11, #6: 8

→ plotted trajectory suggests that #3 is not colliding

~~C26_F3_P07~~:

C27_F3_P07: trajectories and encounter times already fitted
now copy data of particles 1 (big) and 2 (medium) and trace particle 3 (fragment, very small) (on top of #2 in right view)
break points: #1: 11, #2: 11

C28_F3_P08: trajectories and encounter times already fitted
now copy data of particles 1 (medium) and 2 (big) and trace fragments.
particle 3: close to to top of #2 (very small), moving down and left
particle 4: below #1 (small), moving right, wobbling up and down
particles 5 and 6: (very small) moving down from #2
#6 is faster and bigger
break points: #1 and #2: 8

~~[illegible]~~ C29_F3_P08: particle 1: top (big), collisions:

frame:	3	6 7/8	~~9~~10	10	11	14
particle:	2	3	4	5	6/7	not traceable

particle 2: (small) bottom, first from bottom
particle 3: (small) second from bottom
particle 4: (medium) third from bottom
particle 5: (very small) 4th from bottom | #6 (v-small) 5th from bot.
| #7: (medium) 6th from bot.

break points: #1: ~~[illegible]~~ 3, 6, 9, 11
#2: 3, #3: 6, #4: ~~8~~10 ← fit works better
#5: 10, #6: 11, #7: 11

particle 8: fragment from collision of #1 and #4

C30_F3_P08: particles 1, 2 and 4 already analysed with fitted encounter times. To analyse particle 3, I copy the data and run trajectory-only-analysis.

particle break points: #1: 10, 15, #2: 10, #3: 11
#4: 15

trajectory of #3 is still almost straight, only x-coordinate shows tiny bend.

C32-F3_P0~~8~~9: particle 1: bottom (big), collisions:

frame	5	6	12
particle	2	3	4 ~~#3~~

| particle 2: top (very small) seems to stick

particle 3: top (small), collides with #1 after 6 and with #4 (and ~~maybe~~ #1) after 12

particle 4: top (medium) collides with #1 and #3 after 12

break points: #1: 6, 12, ~~#2: 5~~ #3: 6, 12, #4: 12

→ trajectories of particle 3 before and after frame 12 do not meet. → probably it was hitting particles #1 and #4 not at the same time, but bounces from one to the other

21.04.2015

03.09.2015
collisions:
1-2: 11 [1]
1-5: 12 [2]
2-4: 12 [3]

C33_F3_P10: particle 1: top (big), collides with # ~~1~~2
after frame 11 and with #5 after 11 or 12
particle 2: bottom (medium) first one from bottom
collides with #1 after 11 ~~and maybe with #3~~ no
and #4 after 12 ~~or 13~~
particle 3: bottom (small) second from bottom
particle 4: bottom (small) ~~[illegible]~~ on the left side in both views
~~maybe~~ colliding with #2 after 12 ~~/13~~
particle 5: bottom (medium ~~)~~ - large) right side in both views
collides with # ~~2~~ 1 after ~~11~~/12
particle 6: fragment from #1/2 (very small) flying to the bottom
particle 7: fragment from #1/5 (very small) flying upwards
particle break points: #1: 11 ~~/12~~, #2: 11, ~~12/13~~
#4: 12 ~~/13~~, #5: ~~11~~/12

C34_F3_P10:

22.04.2015

particle 1: top (medium), collides with 3 after frame
9 ~~/10~~, with 2 after 11, with 8 after 14
particle 2: bottom (medium) second from bottom tube
collides with #1 only, after collision partially hidden
underneath #1 ~> larger errors for position
particle 3: first from bottom (medium), collides with #1 only
particle 4: fragment (very small) from collision #1/3
flying upwards
particle 5: fragment (very small) from collision #1/3
flying down (above #6), ~~might be~~ colliding
with #7 after 14
particle 6: fragment (small) from collision #1/3
flying down (below #5)
particle 7: third from bottom (small) ~~maybe~~ colliding
with #5
particle 8: fourth from bottom (small), collides with #1 only
particle 9: fragment of collision #1/2 (very small)

can be tracked only on ~~two~~ three frames

particle break points: # 1: 9, 11, 14 | 03.09.2015 # 5: 12

2: 11 | # 3: 9 ~~10~~ | # 7: 14 | # 8: 14

23.04.2015

C35_F3_P12: particle 1: first from top (after frame 14) (medium-big), collisions:

particle	5	7
frame	20	20

particle 2: second from top (after frame 14) (medium-small), colliding with # 4 after frame 21 and # 9 after 23

particle 3: third from top (after frame 14) (small), collides with # 4 after frame 21, probably fragments ~~into~~ that collision partially hidden behind # 2 in right view → larger errors

particle 4: first from bottom (small), collides with # 2 and # 3 after frame 21

particle 5: second from bottom (small), very bright, collides with # 1 after 20, seems to split into one big and several small pieces → track big ~~bi~~ piece as #5 after collision, fragments not tracked, → 13

particle 6: third from bottom (small), left in left view, right in right view, collides probably with nothing → check ✓

particle 7: fourth from bottom (small), in the middle between # 5 and 6, collides with # 1 after frame 20

particle 8: fifth from bottom (very small), right in left view and left in right view, probably not colliding with anything → check ✓

particle 9: sixth from bottom (very small), left in left view and right in right view, collides with # 2 after 23 in this collision a small fragment appears flying roughly in the original direction of # 9.

particle break points: # 1: 20, # 2: 21, 23

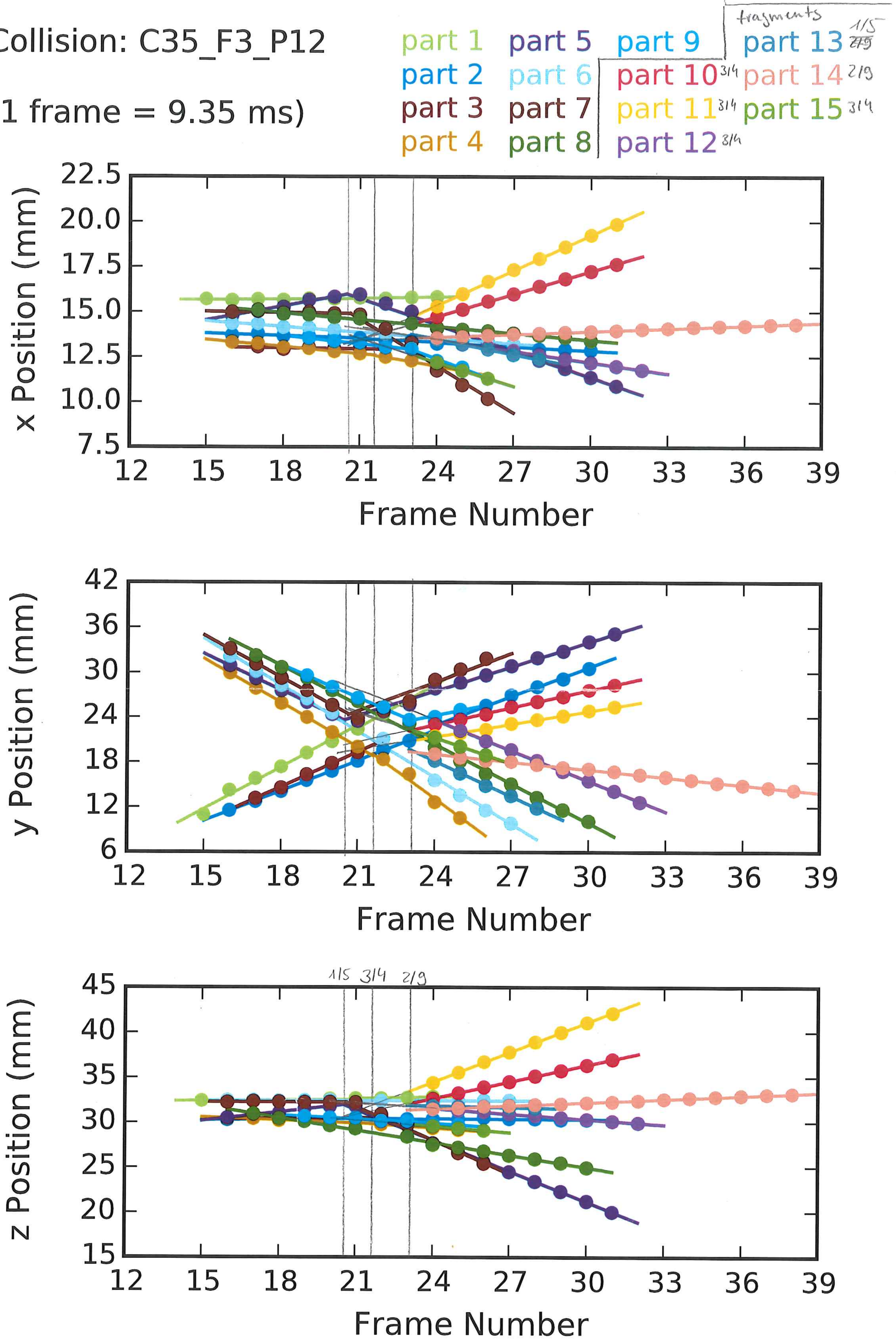
~~#1: 20~~ # 4: 21, # 5: 20, # 7: 20, # 9: 23

04.09.2015

collisions:	1-5	1-7	2-4	3-4	2-9
	20	20	21	21	23

Collision: C35_F3_P12

(1 frame = 9.35 ms)



24.04.2015

fragments:

particle 10: (very small) ~~appearing~~ (in left view) on frame 24, right of #2 moving down (from 3-4 collision)

particle 11: (very small) appearing (in left view) on frame 24 right and top of #2 (far right), moving slightly down (3-4)

particle 12: (very small) appearing on frame 25 (left view) on top of #2, slightly below 11 (left of it), moving almost straight up (from 3-4)

particle 13: (very small) from ~~#2/9~~ 15 appearing on frame 24 in a group of ~~three~~ similar particles (top left in that group) moving up (from 1-5 collision)

particle 14: (very small) from #2/9 same group as #13 on frame 24 (lowest particle), moving up more slowly than #13 (2-9)

particle 15: (very small) showing up on top (left) of #2 at frame 24, flying in direction of #9 before collision (3-4)

H C38_F3_P13: particles 1 to 3 already analysed and encounter times fitted. → copy data and run trajectory-only fit for particles and fragments:

particle 1: bottom (big), collides with #2 after 11 and #3 after 20

particle 2: first from top (medium)

particle 3: second from top (~~very~~ small)

fragments: (of collision #1/2)

particle 4: (very small) uppermost of group of ~~three~~ three

particle 5: (very small) center of group of three (almost as high as #4) ~~the~~

particle 6: (very small) lowest of group of three

H particle 7: (small) might be fragment of #1 or just carried along by it before collision (appears on top of it around frame 16) 16.10.2015: I'll treat it as fragment

particle break points: #1: 11, 20, #2: 11, #3: 20

C39-F3-P13: particle 1: (big) bottom, colliding with #2 after frame ~~...~~ 10, particle has a weird shape and is partially hidden in the tube ~~...~~ for most frames before the collision → large errors

particle 2: top (medium), fragmenting in collision with #1

~~particles~~: fragments of #2:

particle 3: (medium-small), second largest fragment flying up and left

particle 4: (~~sm~~ very small), second smallest fragment flying up, left in left and right in right view

particle 5: (small), middle sized of fragments, flying up

particle 6: (very small), third smallest of fragments, flying straight up in left view and a bit to the right in right view

particle 7: (medium), main fragment, flying left

particle 8: (very small), smallest fragment, flying up (highest)

particle break points: #1: 10

plotted trajectories suggest that particles #4 and #8 might be fragments of #1 instead of #2.

But maybe, they were just chipped off the surface of #2 (very small particles → center of mass ~~≈~~ border)

C40-F3-P13: particle 1: top (big), colliding with #2 after 12

particle 2: bottom (very small), splits in ~~two~~ three in collision with #1

particle 3: topmost fragment of #2 (very small)

particle 4: middle fragment (very small)

particle 5: lowest and smallest fragment (very small) hard to track → larger errors

break point: #1: 12

26.04.2015

C41_F3_P14: particle 1: top (big), collides with #2 and 3 after 5
after frame 6
particle 2: second from bottom (small), fragments in collision with #1
particle 3: third from bottom (very small), fragments in collision with #1
probably not

04.09.2015 treat #4 as #3 → use data from 4 but size of 3

fragments:
particle 4: (very small), below #1 (in curve of #1) = #3 or fragment of #3
counting expanding group from top to bottom:
particle 5: (very small) second largest
particles 6 and 7: (very small) hard to see in right view
particle 8: (small)
larger errors
particle 9: (very small) hard to see in right view ← errors
break points: #1: 5

H C44_F3_P17: 07.05.2015

trajectories of particles 1-3 have already been analysed and encounter times fitted. (Analysis for #1 works better without fitting encounter time.)
→ copy positions and analyse fragments
particle 1: bottom (big), collides with #2 after frame 11 and with #3 after frame 17
particle 2: top (big)
particle 3: top (small)
fragments: (from collision of #1 and 2)
particle 4: (very small) lowest, flying down
particle 5: (very small) middle, flying up, right view on top of #2 and not visible before frame 51
→ problem: residual gravity after frame ≈ 30
→ what to do with #5? ignore / larger errors?
particle 6: (very small) uppermost, flying slightly up
break points: #1: 11, 17 | #2: 11 | #3: 17

17.10.2015: I'll take the datapoints of #5 after frame 30 as best guess.

C45_F3_P18: particle 1: bottom (big) colliding with #3 and maybe #2 after frame 13/~~14~~ and with #4 after 20
particle 2: first from top (medium-small), maybe colliding with #1[3] after frame 13
particle 3: second from top (big), colliding with #~~1~~2 after frame 13/~~14~~
particle 4: third from top (very small), colliding with #1 after frame 20
break points: #1: 13, 20 / #2: 13 / #3: 13
#4: 20
comment: trajectory of #2 looks like it has a slight collision. but actually the video shows that #1 and #2 do not touch. If any, #2 touches #3 when #3 collides with #1.
comment: trajectory of #1 is a bit bent in the end
→ maybe residual gravity → rerun analysis with less data points. (only until frame 35)
→ looks better

C46_F3_P19: collision of particles 1 ~~[illegible]~~ (medium) and 2 (big) already analysed and encounter times fitted
→ copy data and analyse fragments:
particle 3: (very small) smaller fragment from collision, is between #1 and #4
particle 4: (very small) bigger of the two small fragments lowest of group #1, 3, 4.
break points: #1: 20, #2: 20
comment: all trajectories look like there is at least one frame missing between 28 and 29 (particle 2 tracked until f27 only, all other particles: rename frames after 28: 29→30, 30→31 etc.)
→ new fit works much better
→ rerun trajectory fitting with new particle 1 data aswell → works nicely

08.05.2015

M

C48_F3_P22: particle 1: top (big), collides with #2 after frame 11/~~12~~
particle 2: bottom (medium), after collision partially hidden under #1 in right view, hits the bottom after frame 20 → bigger errors
particle 3: fragment (small) flying left and slightly up in both views
particle 4: fragment (very small) flying left and a bit down in both views
break points: #1: 11 | #2: 11
comments: fits work, but all trajectories are a bit wobbly. #3's is especially bent after frame 28 → deleted all data points after that frame, but it might have been a bad parabola

use this data or ignore it?

17.10.2015: I'll use the data and see how much centre of mass velocity deviation I get before and after collision

C49_F3_P23: particle 1: top (big)
particle 2: bottom (big)
particle 3: bottom (medium)
} already analysed and encounter times fitted → copy data and analyse
fragments: (from collision #1/3)
particles 4/5/6: (small (6))/(very small (4/5)) moving down
#5 hard to track in left view, on frames 14/15 it is on top of #1/2
break points: #1: 11, 13 | #2: 11 | #3: 13
→ analysis works ok

11.05.2015

M C51_F3_P24: missing frame between 9 and 10?
particle 1: top (big), collisions: and 16 and 17?

frame	7	9	~~9~~/10	12	→ yes
particle	2(=3)	4	5	6,7,8	

particle 2/3: first from bottom (very small), collides with #1 after frame 7, after collision it is hidden by #1 in right view → get left border of #1 as #2 and right border as #3 to have ~~a~~ margins for the position of #2

17.10.2015
In Excel sheet take average of #3 and #2 → #10

particle ~~#~~4: second from bottom (small)
particle 5: third from bottom (medium)
particle 6: fourth from bottom (small)
particle 7: fith from bottom (small)
particle 8: sixth from bottom (medium) 17.10.2015: treat #9 as independent particle
H particle 9: either seventh from bottom or ~~fragment of~~
collision #1/8 (very small) → plot shows that is has
break points: #1: 7, ~~9~~10, 12 | #2/3: 7
#4: 9 | #5: ~~9~~10 | #6/7/8: 12
comment: plotted data show jumps between frames
9 and 10 and 16 and 17 → rename frames
in data files and plot again
→ new break points: #1: 7, 11, 13, #2/3: 7
#4: 9 | #5: 11 | #6/7/8: 13
→ plots look much better now
→ rerun fit for particle 2/3 with same kind of routine as
C04.

neither significant x or z velocity → unlikely fragment

C23_F3_P05: particles 1 (top, big) and 2 (bottom, medium)
have already been analysed and ~~m~~ encounter times fitted
H → copy data and analyse fragment:
particle 3: (very small) → might be fragment, might be
break points: #1/2: 13 independent particle plotted
trajectory is not clear.
16.10.2015 I'll treat #3 as fragment

11.05.2015

continue with data analysis from 46th ESA campaign (Braunschweig 2007)

C37_F3_P12: particle 1: bottom (big), collisions: #2 after frame 9, #3 after frame 13/14, #4 after frame 15
particle 2: top (medium), first from top
particle 3: second from top (small)
particle 4: third from top (small)
} counting only the colliding particles
fragments of collision #1/2:
particle 5: (very small), left above #2
particle 6: (small), right above #2 (partially hidden by #2 in ~~a~~ left view)
particle 7: (very small) flying almost straight right in ~~left~~ both views (hard to see in right view) (below #2)
particle 8: (very small) flying slightly up and to the left in both views (below #2)
break points: #1: 9, 13~~/14~~, 15 | #2: 9
#3: 13~~/14~~, #4: 15
comment: on frame 18 in the right view another particle (#9) shows up close to the bottom left of #1
→ not trackable in left view, origin unclear
→ ~~ignore for now~~ → ~~following the trajectory shows, that it likely is another fragment of the collision of #1 and 2 → get margins for position in left view and analyse with the same routine as C04 and C51.~~
→ particle 9~~/10:~~ found it on top of #1 in original video and on top of tube in median-background-substr.

Summary of Flight 3 - analysis so far:

Fitted trajectories and encounter times: (got ε and b/R)

C18, C21, C22, C24, C36, C42, C50 (C31)

Fitted trajectories (no other analysis so far):

C16, C27, C28, C29, C30, C32, C33, C34, C35, C37, C39, C40, C41, C45, C49

Analyse later with specialised fit routine

C51

Talk to Helen:

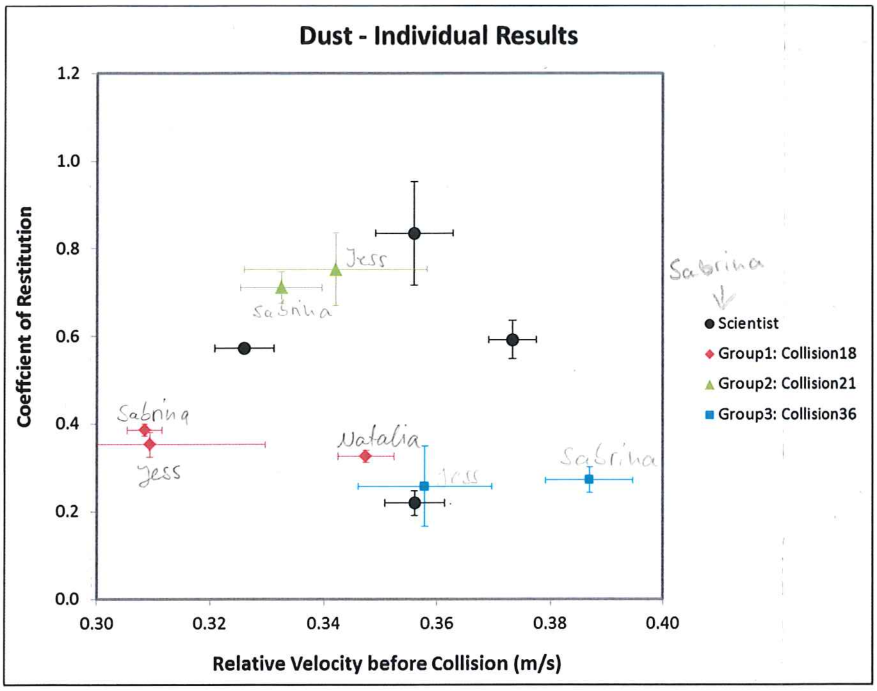
C17, C19, C20, C23, C25, C26, C38, C43, C44, C46, C47, C48, C51

24.07.2015

Comparison of parabolic flight results, when the same video is analysed by several people

Our work-experience student Jessica (and me) analysed three ice-sphere videos and three dust videos (following the procedures developed for the Ogden outreach event on July 2nd).
Also Natalia and Sergio analysed one collision each.

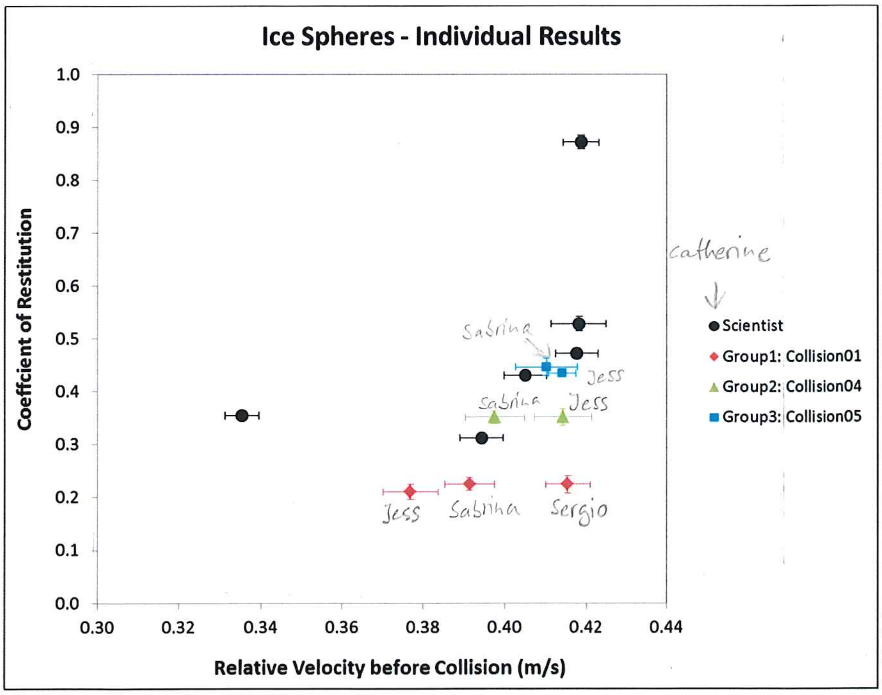
comment:
I used the same piston diameter for all 3 collisions, Jess measured it for every collision.



ε-values match ok

V_b values don't match

→ pixel to mm calib.



S: Sabrina P: Python E: Excel

S **Number of Encounters included in Analysis**
P **Volume Particle 1 before Encounter(s)**
Uncertainty
P **Volume Particle 2 before Encounter(s)**
Uncertainty
P **Velocity Particle 1 before Encounter(s)**
Uncertainty
P **Velocity Particle 1 after Encounter(s)**
Uncertainty
P **Velocity Particle 2 before Encounter(s)**
Uncertainty
P **Velocity Particle 2 after Encounter(s)**
Uncertainty
E **total Translational Energy before Encounter(s)**
Uncertainty
E **total Translational Energy after Encounter(s)**
Uncertainty
S **Number of Particles Rotating before Encounter**
S **Number of Particles Rotating after Encounter**
P **Distance of Centres of Mass at Encounter**
Uncertainty
P **Impact Parameter**
Uncertainty
P **Normalized Impact Parameter**
Uncertainty
P **Parallel Component**
Uncertainty
P **Perpendicular Component**
Uncertainty

add more particles

modify python scripts to read out particle volumes

for already analysed collisions read out volumes manually

S **Volume of larger sticking particle**
Uncertainty
S **Volume of smaller sticking particle**
Uncertainty

P **Coefficient of Restitution**
Uncertainty
P **Parallel Component**
Uncertainty
P **Perpendicular Component**
Uncertainty

S **Number of Particles after Collision** **(= Fragments + main Particles)**
P **Volume of original Particles**
Uncertainty
P **Volume of Fragments**
Uncertainty
E **Fraction of Particle Volume**
Uncertainty

26.08.2015

Continue with analysis of collisions from 46th ESA campaign (data from Braunschweig)

<u>ToDo:</u> modify python script to read out particle volumes

For the already analysed collisions its probabey faster to get the volumes manually than to re-run python scripts.

How to get velocity-results that are compareable to the relative velocities from bouncing collisions for sticking/fragmenting collisions?
→ It makes more sense to take absolute velocities for kinetic energy calculations for all collision types.
convert them to centre of mass system.

Each particle i has velocity components $v_{i\alpha}$ in Lab and $\tilde{v}_{i\alpha}$ in centre of mass system, and mass m_i
centre of mass has velocity components $v_{M\alpha}$ in Lab and 0 in centre of mass system, and mass M

$$M = \sum_i m_i \quad , \quad \tilde{v}_{i\alpha} = v_{i\alpha} - v_{M\alpha} \quad , \quad v_{M\alpha} = \frac{\sum_i m_i v_{i\alpha}}{M}$$

$$\Rightarrow \tilde{v}_{i\alpha} = v_{i\alpha} - \frac{\sum_k m_k v_{k\alpha}}{\sum_k m_k}$$

Mass of particles is determined by their volume V_i (Radius R_i, Area A_i)

Circle: $A_i = \pi R_i^2 \quad \Rightarrow \quad R_i = \sqrt{\frac{A_i}{\pi}}$

Sphere: $V_i = \frac{4}{3}\pi R_i^3 = \frac{4}{3}\pi \left(\frac{A_i}{\pi}\right)^{3/2} = \frac{4}{3}\sqrt{\frac{A_i^3}{\pi}}$

→ Calculate these velocities in Excel

28.09.2015

Problem: Plot of ~~Loss~~-of-translational-energy vs translational-energy-before-encounter is not suited for compariso with previous plots. E_{trans} varies a lot because of the variations in particle size (mass).

Idea: take individual encounters from multiples whereever possible and calculate relative velocities (before encounter) as usual

~~⇝ average them~~

~~for ε use $\sqrt{\frac{E_{trans}^{after}}{E_{trans}^{before}}}$~~

⇓

Problem: This formula for ε neglects the number of collisions.

Energy Loss: $\Delta E = E_{before} - E_{after} \Rightarrow \frac{\Delta E}{E_{before}} = -\frac{E_{after}}{E_{before}} + 1$

$\Rightarrow \sqrt{\frac{E_{after}}{E_{before}}} = \sqrt{1 - \frac{\Delta E}{E_{before}}} = \varepsilon$

I can calculate $\frac{\Delta E_{after}}{E_{before}} \cdot \frac{1}{\#\,encounters}$

⇝ ε per encounter $= \sqrt{1 - \frac{\Delta E}{E_{before} \cdot N}}$

01.10.2015

Problem: neither this, nor $\varepsilon = \sqrt{\frac{E_a}{E_b}}$ for single encounters gives the right result ($\varepsilon = \frac{V_a}{V_b}$)

⇝ The origin of this problem seems to be that the formula works only for perfect centre of mass frame which I apparently don't have after the collision.

Question: does it make any sense to use a different centre of mass velocity before and after encounter?

→ see 06.10.2015

Help file: SFOEUH11.HLP
Driver version: 1.00
Environment: Windows NT x86
Additional files used by this driver:

general case

$$E_{trans} = \frac{1}{2} \sum_i m_i \tilde{v}_i^2 = \frac{1}{2} \sum_i m_i \cdot \sum_\alpha \left(v_{i\alpha} - \frac{\sum_k m_k v_{k\alpha}}{\sum_k m_k} \right)^2$$

E_{trans} ↑ centre of mass frame; i ↑ particles; m_i ↑ mass; $\tilde{v}_i$ ↑ velocity w.r.t. centre of mass; α ↑ components; $v_{i\alpha}$ ← absolute velocities (w.r.t. camera)

bouncing, single collision:

$$v_{rel} = \sqrt{\sum_\alpha (v_{1\alpha} - v_{2\alpha})^2}$$

$$\varepsilon = \frac{v_{rel}^{after}}{v_{rel}^{before}}$$

$$E_{trans} = \frac{1}{2} \left[m_1 \cdot \sum_\alpha \left(v_{1\alpha} - \frac{m_1 v_{1\alpha} + m_2 v_{2\alpha}}{m_1 + m_2} \right)^2 + m_2 \sum_\alpha \left(v_{2\alpha} - \frac{m_1 v_{1\alpha} + m_2 v_{2\alpha}}{m_1 + m_2} \right)^2 \right]$$

E_{trans} ↑ centre of mass frame

$m_1 + m_2 = M$

$$\Rightarrow M^2 \cdot E_{trans} = \frac{1}{2} \left[m_1 \cdot \sum_\alpha \left(\cancel{m_1 v_{1\alpha}} + m_2 v_{1\alpha} - \cancel{m_1 v_{1\alpha}} - m_2 v_{2\alpha} \right)^2 + m_2 \sum_\alpha \left(m_1 v_{2\alpha} + \cancel{m_2 v_{2\alpha}} - m_1 v_{1\alpha} - \cancel{m_2 v_{2\alpha}} \right)^2 \right]$$

$$= \frac{1}{2} \left[m_1 \cdot \sum_\alpha \left(m_2 (v_{1\alpha} - v_{2\alpha}) \right)^2 + m_2 \sum_\alpha \left(m_1 (v_{2\alpha} - v_{1\alpha}) \right)^2 \right]$$

$$= \frac{1}{2} \left[m_1 m_2^2 \cdot \sum_\alpha (v_{1\alpha} - v_{2\alpha})^2 + m_2 m_1^2 \sum_\alpha (v_{1\alpha} - v_{2\alpha})^2 \right]$$

$$= \frac{1}{2} \left[m_1 m_2 \cdot m_2 \cdot v_{rel}^2 + m_1 m_2 m_1 \cdot v_{rel}^2 \right]$$

$$= \frac{1}{2} m_1 \cdot m_2 \cdot M v_{rel}^2$$

$$\Rightarrow E_{trans} = \frac{1}{2} \frac{m_1 \cdot m_2}{M} v_{rel}^2$$

28.09.2015

Problem: Plot of Loss-of-translational-energy vs translational-energy-before-encounter is not suited for compariso with previous plots.
E_{trans} varies a lot because of the variations in particle size (mass).

2d general case:

$E_{trans} = \frac{1}{2}$

↑ centre of mass frame

↑ par

bouncing, single coll

Pro $v_{rel} = \sqrt{\sum_\alpha (v_{1\alpha} - v_{2\alpha}}$

$\varepsilon = \frac{v_{rel}^{after}}{v_{rel}^{before}}$

$E_{trans} = \frac{1}{2}\Big[m_1$

↑ centre of mass frame

$m_1 + m_2 = M$

$\Rightarrow \quad M^2 \cdot E_{tran}$

01.

Pr

=

=

=

$\Rightarrow E_{trans} = \frac{1}{2}$

2u

$$\Rightarrow v_{rel} = \sqrt{\frac{2M}{m_1 \cdot m_2} E_{trans}}$$

$$\Rightarrow \varepsilon^2 = \frac{E_{trans}^{after}}{E_{trans}^{before}}$$

velocity w.r.t. centre of mass:

$$\tilde{v}_{1\alpha} = v_{1\alpha} - \frac{m_1 v_{1\alpha} + m_2 v_{2\alpha}}{M}$$

$$= \frac{m_1 v_{1\alpha} + m_2 v_{1\alpha} - m_1 v_{1\alpha} - m_2 v_{2\alpha}}{M}$$

$$= \frac{m_2 (v_{1\alpha} - v_{2\alpha})}{M}$$

$$\tilde{v}_{2\alpha} = \frac{m_1 v_{2\alpha} + m_2 v_{2\alpha} - m_1 v_{1\alpha} - m_2 v_{2\alpha}}{M}$$

$$= \frac{m_1 (v_{2\alpha} - v_{1\alpha})}{M}$$

centre of mass velocity before and after encounter:

→ see 06.10.2015

30.09.2015

Continue with analysis of collisions from 46th ESA campaign (data from Braunschweig)

Calculate Uncertainties:

Centre-of-Mass-velocity: $$v_{M\alpha} = \frac{\sum_i m_i v_{i\alpha}}{\sum_i m_i}$$

i: particles, α: components, m_i: particle mass
v_i: particle velocity in lab-frame

$$\Delta V_{M\alpha} = \left[\sum_i \left(\Delta v_i \cdot \frac{m_i}{\sum_k m_k} \right)^2 + \sum_i \left(\Delta m_i \cdot \frac{v_{i\alpha} \cdot \sum_k m_k - \sum_k m_k v_{k\alpha} \cdot 1}{\left(\sum_k m_k\right)^2} \right)^2 \right]^{0.5}$$

$$= \left[\frac{1}{\left(\sum_k m_k\right)^2} \cdot \left\{ \sum_i \left(\Delta v_i \cdot m_i \right)^2 + \sum_i \left(\Delta m_i \cdot \left(v_{i\alpha} - \frac{\sum_k m_k v_{k\alpha}}{\sum_k m_k} \right) \right)^2 \right\} \right]^{1/2}$$

$$= \frac{1}{\sum_k m_k} \cdot \left[\sum_i \left(\Delta v_i \cdot m_i \right)^2 + \sum_i \left(\Delta m_i \cdot \left(v_{i\alpha} - v_{M\alpha} \right) \right)^2 \right]^{1/2}$$

Particle velocity in centre of mass frame: $\tilde{v}_{i\alpha} = v_{i\alpha} - v_{M\alpha}$

$$\Delta \tilde{v}_{i\alpha} = \sqrt{\left(\Delta v_{i\alpha}\right)^2 + \left(\Delta v_{M\alpha}\right)^2}$$

Today I found a mistake in the calculation of the velocities in the excel sheet. The calibration factor was missing for the original particle velocities.
→ ~~use~~ delete older versions of spreadsheet.

Translational Energy: $E = \sum_i m_i \cancel{\cdot} \sum_\alpha \left(\tilde{v}_{i\alpha}\right)^2$

$$\Delta E = \left[\sum_i \left(\Delta m_i \cdot \sum_\alpha \left(\tilde{v}_{i\alpha}\right)^2 \right)^2 + \sum_i \sum_\alpha \left(2 m_i \tilde{v}_{i\alpha} \Delta \tilde{v}_{i\alpha} \right)^2 \right]^{1/2}$$

Loss of translational energy: $\frac{\Delta E}{E_{before}} = 1 - \frac{E_{after}}{E_{before}}$

$$\Delta\left(\frac{\Delta E}{E_{before}}\right) = \sqrt{\left(\frac{\Delta E_{after}}{E_{before}}\right)^2 + \left(\Delta E_{before} \cdot \frac{E_{after}}{E_{before}^2}\right)^2}$$

relative velocity: $v_{rel,\alpha} = \sqrt{\sum_\alpha (v_{1\alpha} - v_{2\alpha})^2}$

$$\Delta v_{rel} = \frac{1}{2} \cdot v_{rel}^{-1} \cdot \sqrt{\sum_\alpha \left(2 \cdot (v_{1\alpha} - v_{2\alpha})\right)^2 \cdot \left(\Delta v_{1\alpha}^2 + \Delta v_{2\alpha}^2\right)}$$

$$= \frac{\sqrt{\sum_\alpha (v_{1\alpha} - v_{2\alpha})^2 \cdot (\Delta v_{1\alpha}^2 + \Delta v_{2\alpha}^2)}}{v_{rel}}$$

coefficient of restitution: (multiple encounters)

$$\varepsilon = \sqrt{1 - \frac{\Delta E}{E_{before} \cdot N}} = \sqrt{1 - \frac{E_{before} - E_{after}}{E_{before} \cdot N}}$$

$$\Delta\varepsilon = \frac{1}{2} \cdot \frac{1}{\varepsilon} \cdot \sqrt{\left(\Delta E_{before} \cdot \frac{(E_{before} - E_{after}) \cdot N - E_{before} \cdot N}{(E_{before} \cdot N)^2}\right)^2 + \left(\frac{\Delta E_{after}}{E_{before} \cdot N}\right)^2}$$

$$= \frac{1}{2 \cdot \varepsilon} \cdot \sqrt{\left(\frac{\Delta E_{before}}{E_{before} \cdot N} \cdot \frac{E_{after}}{E_{before}}\right)^2 + \left(\frac{\Delta E_{after}}{E_{before} \cdot N}\right)^2}$$

$$= \frac{\sqrt{\left(\Delta E_{before} \cdot \frac{E_{after}}{E_{before}}\right)^2 + (\Delta E_{after})^2}}{2 \cdot \varepsilon \cdot E_{before} \cdot N}$$

06.10.2015

Change in centre-of-mass velocities:

- it makes the most sense to treat all data the same i.e. use different v_M before and after collision, as this is how $\varepsilon = \frac{v_a}{v_b}$ is usually calculated.
- ✓ check which videos have the strongest deviation (each component of v_M), maybe something is wrong with those.

- do a quick calculation, how much apparent change in velocity would be caused by small wing-to-wing angle changes of the plane (1° over 5-10s)
  → compare with changes we see.

vector componenb:

strongest deviation ~~[illegible]~~

v_x	v_y	v_z
C13	C13	C13
C34	C34	C32
C41	C03	C49
C49	C16	C29
C34	C37	C30
C49	C14	C42

biggest error bars ~~[illegible]~~

v_x	v_y	v_z
C13	C49	C13
C37	C49	C50
C50	C03	C42
C02	C13	C29
C37	C35	C03
C42	C37	C32

C13: ~~||||~~ |
C34: |||
C32: ||
C41: |
C03: |||
C49: ~~||||~~
C16: |
C29: ||
C37: ||||
C30: |

C14: |
C42: |||
C50: ||
C02: |
C35: |

Most suspicious:
C13, C49, C37,
C34, C03, C42

C13_F2_P18: Many particles, 8 encounters in total
2 × single encounters, 2× ~~a~~ triple encounters
few ~~poor~~ data for the last triple (particle #8)

C~~45~~49_F3_P23: colliding particles and fragments fitted with different rolltimes. One of the fragments (#5) partially on top of other particle ? hard to track, 2× single encounter (1 fragmentation)

C37_F3_P12: Many particles, 3 × single encounter (1 fragmentation)
Some of the fragments hard to track (#6, 7, 9)

C34_F3_P10: 4 single encounters (2 × fragmentation)
fragment #9 (2. encounter) hard to trace, fragment #5 (1. encounter) collides with particle #7

C03_F2_P06: 4 encounters analysed together, 2× potential sticking, two particles (#2, 5) could not be tracked properly → velocities estimated from comparison with other particles

C42_F3_P14: I didn't note down anything special, 1 × bouncing.
→ watched video again → from the bottom 2 medium particles are coming and moving + rotating very closely together. Maybe they do touch at some point.

Compare ε-results when using either different c.o.m velocity after collision or the same as before

→ some data points don't shift at all
→ some data points shift a lot.
→ strange: they all shift in the same direction
(lower ε if $v_{M\,after}$ is used)

Strongest changes: C34 (3) #1+8 single bounce, C37 (3) #1+4 single bounce, C45 (3) single bounce #1+4
Strong (far less than ↑): C37 (2), C32 (2), C32 (3, 4), C29 (1) ~~[illegible]~~
Medium changes: C13 (6, 7, 8), C13 (1), C30 (3), C40 (1), C34 (2)
C11 (1), C16 (1), C03 (1, 2)

Small changes: c11(2), c49(2), c31(1), c34(4), c35(5)
c30(1), c30(2), c39(1), c35(1), c35(2)
c27(1), c41(2), c41(1), c28(1)

No change: c45(1,2), c22(1), c22(2), c12(2), c12(1), c33(3)
c13(2,4,5), c02(2), c02(1), c24(1), c18(1)
c13(3), c33(1,2), ...

07/10/2015

Re-watch videos:

c34 encounter 3 : particle 8 is very small and hard to track after the collision (tracking "shadow for two out of three frames)
that collision has big changes in centre-of-mass velocity for x ~~and y~~ component

c37 encounter 3: particle 4 is hard to track/identify after the collision
big change in z component of centre-of-mass velocity
particle 1 (big) only tracked for two frames after the collision (then hitting the guide tube)

c45 encounter 3: when I watched the video again, I first could not find #4 after the collision. The particle I apparently tracked as #4 afterwards might actually coming from the bottom tube (#4 is coming from top) and colliding with #1 after #4.
(medium change in v_{xy})
Also I noted earlier that this video showed wobbly trajectories (residual gravity) for late times for #1.
-> take out this collision out or treat it as potential sliding

Idea: Maybe the change of ε w.r.t to centre-of-mass velocity before/after encounter could be a good uncertainty esti~~m~~mate. Likewise for velocities.

Estimate apparent velocity changes caused by small tilt of aircraft during collisions:

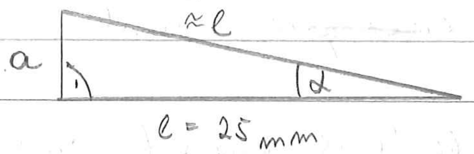
collision volume ~ 650 pixel Ø $\hat{=}$ 25 mm

typical velocity (y-direction): $\frac{1}{2} \cdot 300 \, \frac{mm}{s}$

collision "duration": time it takes to travel 25 mm with $150 \, \frac{mm}{s}$

$t = \frac{25 \, mm \cdot s}{150 \, mm} = \frac{1}{6} s$ ($\approx$ 18 frames → makes sense as upper limit)

tilt:



$a \approx l \cdot \sin \alpha$

$\alpha = 1°$ $\Rightarrow a \approx 0{,}44 \, mm$

apparent velocity by tilt: $v = \frac{a}{t} = \frac{0{,}44 \, mm \cdot 6}{1 \, s} \approx 2{,}6 \, \frac{mm}{s}$

→ $0{,}0026 \, \frac{m}{s}$

If biggest tilt can be in y-direction, biggest apparent velocity will be in x/z-direction

x and z velocities around $0{,}01$ to $0{,}02 \, \frac{m}{s}$

⇝ apparent velocity would cause ~ 10 to 20 % change

for y-velocities it would cause ~ 0,5 % change

The observed changes in centre-of-mass velocities are often much bigger than that ⇝ probably rather due to tracking problems.

Calculate encounter time (where not fitted):

For each trajectory component (x, y, z / before, after):

$$r_{0,1} + V_1 \cdot t_e = r_{0,2} + V_2 \cdot t_e$$

$$\Rightarrow r_{0,1} - r_{0,2} = t_e \cdot (V_2 - V_1)$$

$$\Rightarrow$$

$$t_e = \frac{r_{0,1} - r_{0,2}}{V_2 - V_1}$$

calculate those + average

⚠ for multiple encounters, sticking + fragmentation use only data before encounter.

⚠ look at trajectories, some vector components need to be ignored.

08.10.2015

That does not work !!! Particle trajectories won't meet
I would need the time where each trajectory bends.
⤳ Problem how should I do that best for multiple encounters. They don't happen at exactly the same time but Python routine fits them as if they did.

~~For now I'll do only the single encounters~~.

For each particle and component:

$$r_{0,b} + V_b \cdot t_e = r_{0,a} + V_a + t_e$$

$$\Rightarrow t_e = \frac{r_{0,a} - r_{0,b}}{V_b - V_a}$$

I'll treat multiple encounters with the same encounter time and think about a better way of doing it later.
→ That seems to work ok, since each trajectory (particle) results in a slightly different encounter time

12.10.2015

When I compare the results for the translational energies after the encounter (from COR vs V_{rel} plot), the deviation always goes in the same direction:

ε is lower when related to the centre-of-mass after the the encounter.

$$E_{trans}^{com} = \frac{1}{2} \sum_i m_i \sum_\alpha (v_{i\alpha} - V_{M\alpha})^2$$

i: particles, α: coordinates, $V_{M\alpha}$: centre-of-mass velocity

$$= \frac{1}{2} \sum_i m_i \sum_\alpha (v_{i\alpha}^2 - 2 v_{i\alpha} V_{M\alpha} + V_{M\alpha}^2)$$

$$= E_{trans}^{lab} + \frac{1}{2} \sum_i m_i \sum_\alpha V_{M\alpha}^2 - 2 \cdot \frac{1}{2} \sum_\alpha V_{M\alpha} \sum_i m_i v_{i\alpha}$$

$$= E_{trans}^{lab} + \frac{1}{2} M \cdot \sum_\alpha V_{M\alpha}^2 - \sum_\alpha V_{M\alpha} \cdot M \cdot V_{M\alpha}$$

$$= E_{trans}^{lab} - \frac{1}{2} M \sum_\alpha V_{M\alpha}^2$$

$$= E_{trans}^{lab} - E_{trans,\,com}^{lab}$$

$\Rightarrow$ In the lab frame the energy of the centre of mass after the encounter must be higher in all cases.

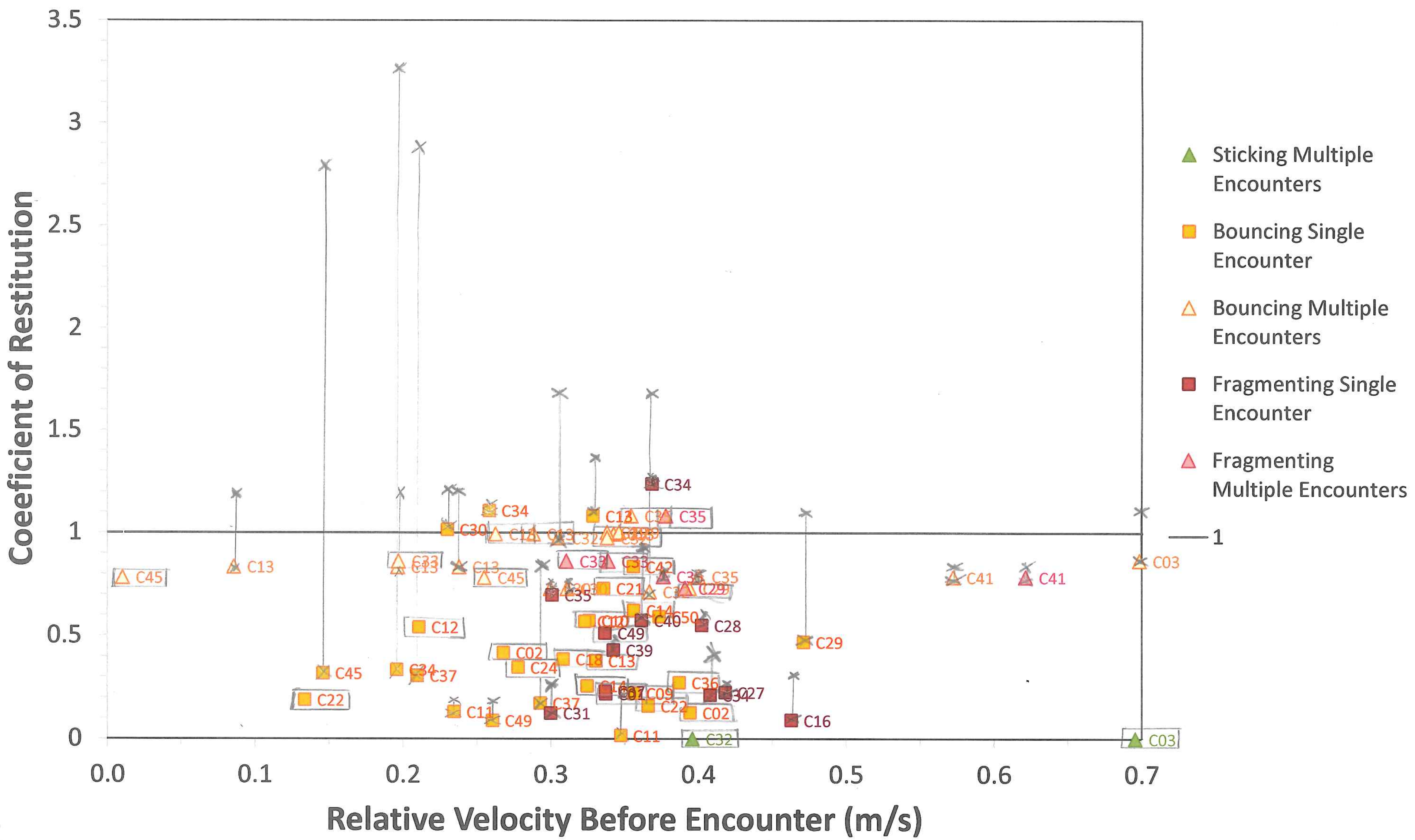
The only source to gain energy from would be residual gravity (rotational energy might change the relative velocities of the particles, but only forces can change the translational energy of the whole system).

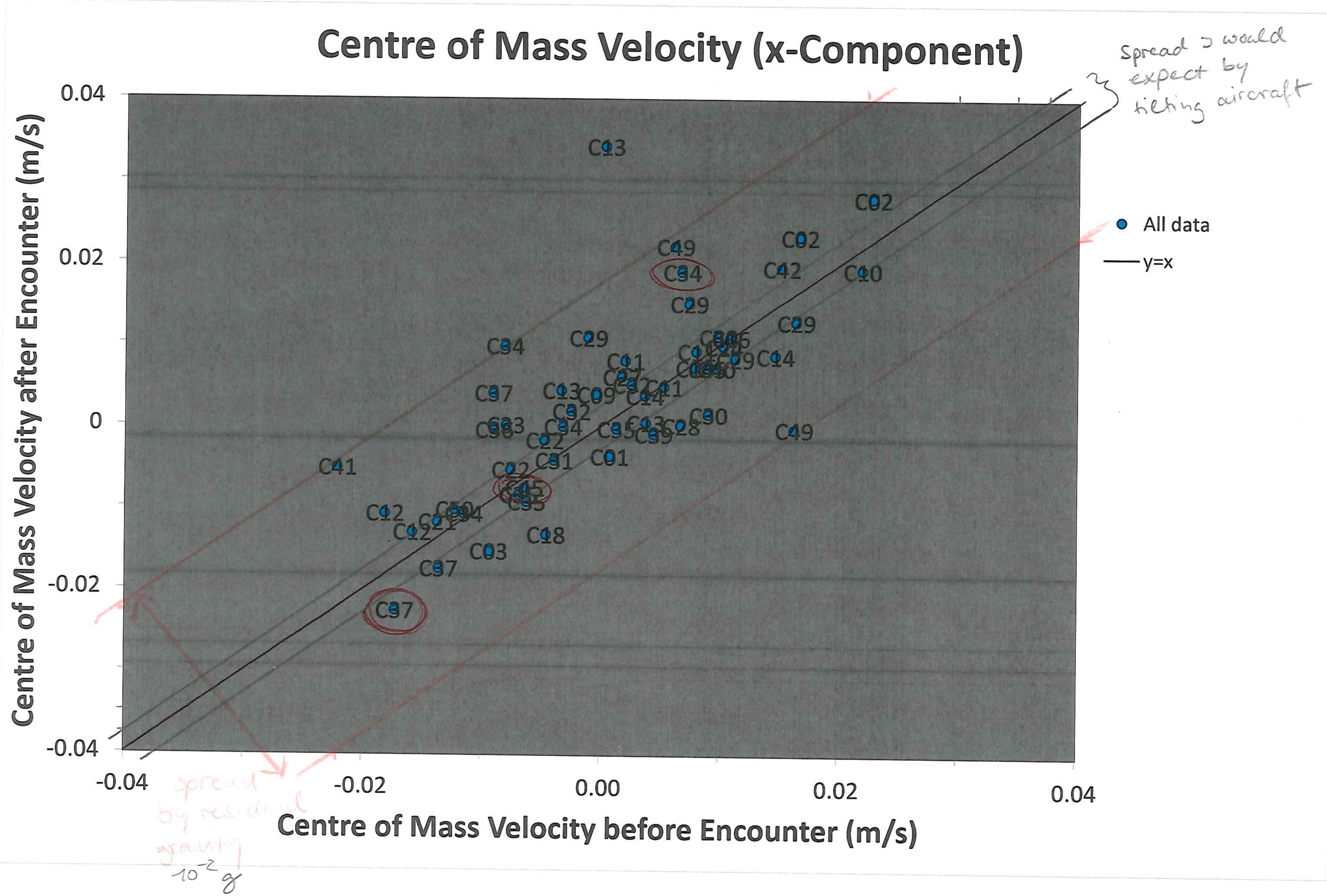
<u>Estimate how much change in velocity the typical residual gravity values would cause:</u>

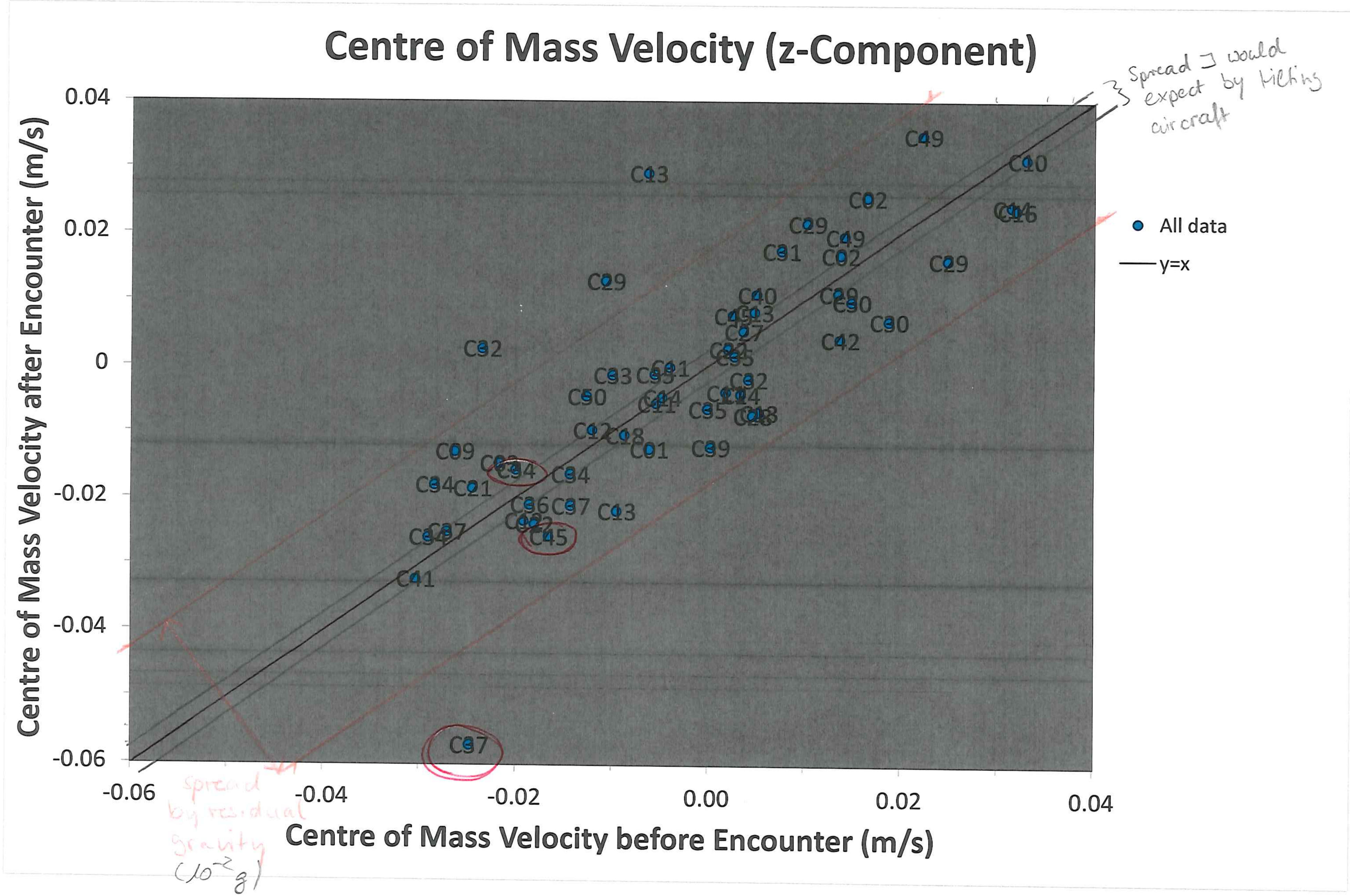
E_{before} → centre of mass velocity before collision

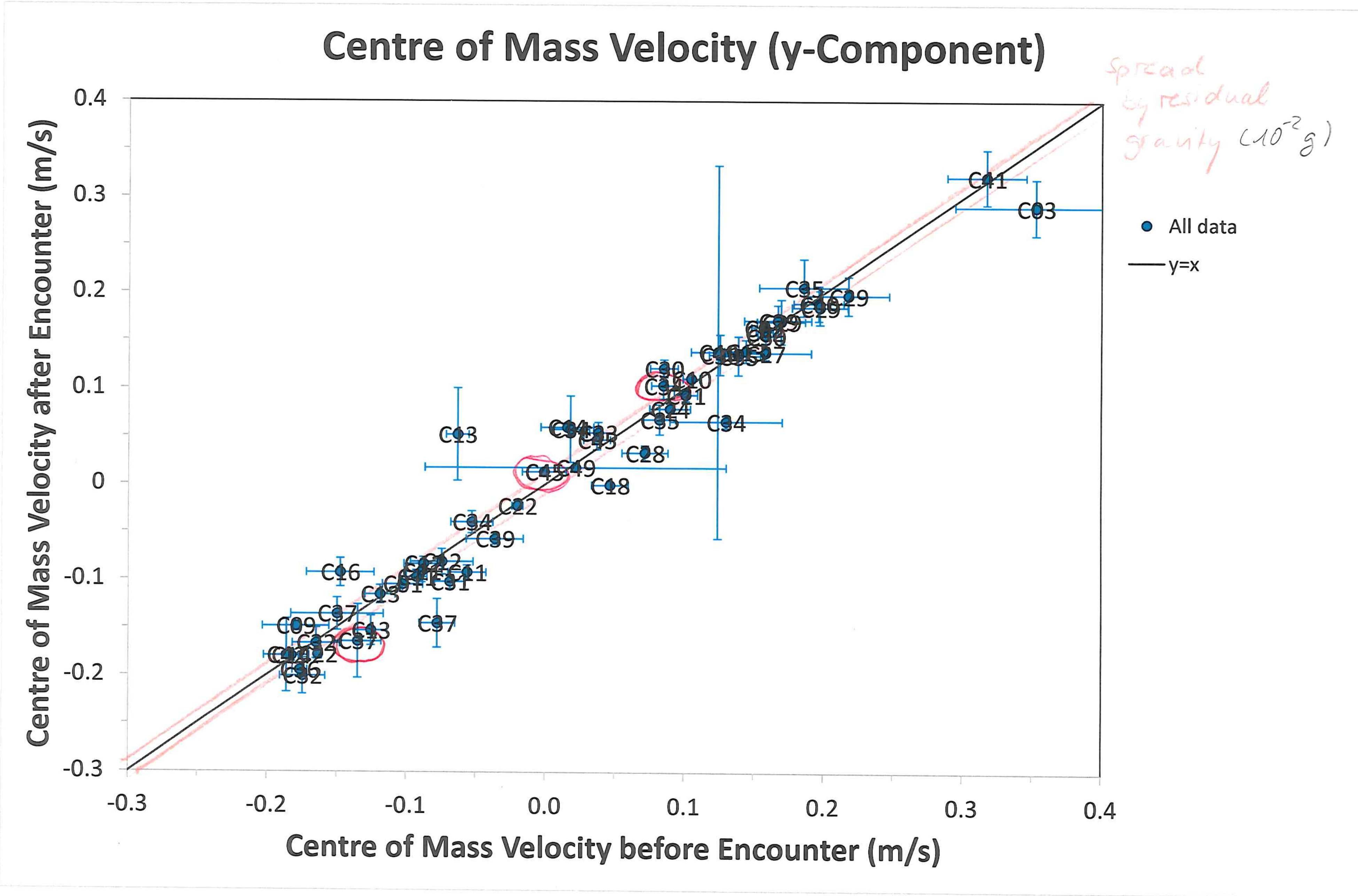
E_{after} → centre of mass velocity after collision

Coefficient of Restitution (vs Velocity)




Centre of Mass Velocity (x-Component)
Centre of Mass Velocity after Encounter (m/s)
Centre of Mass Velocity before Encounter (m/s)
0.04
0.02
0
-0.02
-0.04
0.00
All data
y=x
C13
C02
C49
C34
C42
C10
C29
C41
C12
C37
C03
C18
C01
C31
C22
C14
C30
C09
C28
spread ⊃ would expect by tilting aircraft
spread by residual gravity
10^{-2} g


Centre of Mass Velocity (z-Component)
Centre of Mass Velocity after Encounter (m/s)
Centre of Mass Velocity before Encounter (m/s)
All data
y=x
0.04
0.02
0
-0.02
-0.04
-0.06
0.00
Spread I would expect by Hiltings aircraft
spread by residual gravity (10^{-2} g)



Centre of Mass Velocity (y-Component)
Centre of Mass Velocity after Encounter (m/s)
Centre of Mass Velocity before Encounter (m/s)
All data
y=x
C41
C03
C35
C29
C34
C13
C28
C45
C49
C18
C22
C39
C16
C97
C09
C32
Spread by residual gravity (10^{-2}g)

$\Delta v = \tilde{g} \cdot \Delta t$ $\qquad \Delta t \approx \frac{1}{6} s$ $\qquad , \tilde{g} \approx 10^{-2} \cdot 10 \frac{m}{s^2}$

$= \frac{1}{6} \cdot \frac{1}{10} \frac{m}{s} \approx 0{,}017 \frac{m}{s}$

$\Rightarrow$ This covers almost all changes in centre-of-mass velocities I oberved (within uncertainties).

$\Rightarrow$ It does not only make sense to calculate E w.r.t. to centre-of-mass-velocity before (E_b) + after (E_a) collision, it is the only way to observe the changes that are caused by the collision and exclude those that are caused by the aircraft.

Volume to mass conversion:

Volume of a sphere: $\quad V = \frac{4}{3} \pi r^3 \qquad V = \frac{4}{3} \sqrt{\frac{A}{\pi}}^3$

Measured area: $\quad A = \pi r^2 \qquad \Rightarrow r = \sqrt{\frac{A}{\pi}}$

Uncertainties: I assume an uncertainty of 10% for V

Mass of the samples: $\quad m = x \cdot \rho \cdot V$

ρ: density of SiO_2 ($2{,}65 \frac{g}{cm^3}$)
x: volume filling factor ($1 - 85\% = 0{,}15$)

$\Rightarrow \frac{\Delta m}{m} = \frac{\Delta V}{V}$ (10%)

Reduced Mass:

$\mu = \frac{m_1 \cdot m_2}{m_1 + m_2}$, $\Delta\mu = \left(\left(\Delta m_1 \cdot \frac{m_2 (m_1 + m_2) - m_1 \cdot m_2}{(m_1+m_2)^2} \right)^2 + \left(\Delta m_2 \cdot \frac{m_1^2}{(m_1+m_2)^2} \right)^2 \right)^{1/2}$

$\Rightarrow \Delta\mu = \frac{1}{M^2} \cdot \sqrt{(\Delta m_1 \cdot m_2^2)^2 + (\Delta m_2 \cdot m_1^2)^2}$

$m_1 + m_2$

Normalized Reduced mass:

μ can range from m_2 to $\frac{1}{2} m_2$. m_2 is the smaller mass, $m_1 \gg m_2 \leadsto \mu \approx m_2$, $m_1 = m_2 \leadsto \mu = \frac{1}{2} m_2$

normalise by $m_2 \Rightarrow \hat{\mu} \in [0{,}5, 1]$

$\hat{\mu} = \frac{\mu}{m_2}$ $\quad \cancel{\Delta\hat{\mu} = \sqrt{\left(\frac{\Delta\mu}{m_2}\right)^2 + \left(\frac{\Delta m_2 \cdot \mu}{m_2^2}\right)^2}}$

$\cancel{\Delta\hat{\mu} = \frac{\mu}{m_2} \cdot \sqrt{\left(\frac{\Delta\mu}{\mu}\right)^2 + \left(\frac{\Delta m_2}{m_2}\right)^2}}$ See 05.11.2015

$\cancel{\Rightarrow \frac{\Delta\hat{\mu}}{\hat{\mu}} = \sqrt{\left(\frac{\Delta\mu}{\mu}\right)^2 + \left(\frac{\Delta m_2}{m_2}\right)^2}}$

13.10.2015

C04_F2_P06: I'll track particle 5 in the left view and ~~taken~~ calculate right view as follows:
y-movement: from left view with offset
x-movement: from particle 1:

16.10.2015

C17_F3_P01: particle 1: first from top (medium)
particle 2: second of the medium particles from bottom
particle 3: second of the two very small particles from bottom after #2
particle 4: first of the two very small particles from bottom after #2
particle 5: second from top (medium)

collisions:			
frame	8	~~9~~10	10/~~11~~ 11
particles	1,2	2,4	3,5

It looks like there's a frame missing between 8 and 9
→ plot and check trajectories. → yes → rename frames by +1 after 8

particle breakpoints: #1: 8, #2: 8, #3: ~~10~~ 11
#4: ~~9~~10, #5: ~~10~~ 11

C25_F3_P06: particles 1 (top big) and 2 (bottom medium) have already been analysed and encounter times fitted
⇝ copy data and rerun analysis to get results for all particles
particle 3: top (medium) partially hidden behind #1 on many frames, after collision only trackable in right view ⇝ for left view take positions of #1
particle 4: bottom (very small) catching up with #2 (sticking)
particle 5: (very small) fragment from collision #1,2
collisions: frame: 11 12
particles: 2,3 1,2 / 2,4
particle break points: #1: 12, #2: 12, #3: 11

18.10.2015

Estimate Uncertainties:

~~Positions~~ and velocities:

I'll calculate the change of centre-of-mass velocity before and after collision for each vector component. The magnitude of this vector will be the uncertainty for the rel. velocity before the encounter. The ratio of CoM velocity change (magnitude) to CoM velocity before collision (magnitude) will be used as relative uncertainty for the positions.
Problem: for very small CoM velocities I'll obviously get big relative uncertainties. → Use CoM velocity change directly as uncertainty for relative velocity before encounter.

19.10.2015

Coefficient of restitution:

$$\frac{\Delta\varepsilon}{\varepsilon} = \sqrt{2} \cdot \frac{\Delta v_{rel}}{v_{rel}}$$

C47_F3_P22: particle 1: big from top
particle 2: medium from bottom
particle 3: bottom (very small) left from #2
next to top of #2
particle 4: bottom (very small) originally next to
#3 but much slower → not colliding
particle 5: bottom (small) out of tube on frame 8
fragmenting in collision with #1
particle 6: bottom (small) appearing at tube
on frame 9
particle 7: fragment of #5 trackable only in
right view → copy + offset y-components
for left view and take x-component of
#1 for left view (hiding #5)

collisions:					
	frame	10	~~12~~	13	14
	particles	1,2 | 1,3	~~1,4?~~	1,5	1,6

particle break points: #1: 10, 13 , #2: 10
#3: 10 , ~~#4: 12~~ , #5: 13 , #6: 14

05.11.2015

Uncertanties for normalised reduced mass:

$$\hat{\mu} = \frac{\mu}{m_2} = \frac{m_1 \cdot m_2}{m_1 + m_2} \cdot \frac{1}{m_2} = \frac{m_1}{m_1 + m_2}$$

$$\Delta\hat{\mu} = \sqrt{\left(\Delta m_1 \cdot \frac{m_1 + m_2 - m_1}{(m_1 + m_2)^2}\right)^2 + \left(\Delta m_2 \cdot \frac{m_1}{(m_1+m_2)^2}\right)^2}$$

$$= \frac{1}{(m_1 + m_2)^2} \cdot \sqrt{(\Delta m_1 \cdot m_2)^2 + (\Delta m_2 \cdot m_1)^2}$$

19. 11. 2015

Topics:

✓ - usb 1 to usb adapter

~~- ISIS risk assessment~~

~~- Jes form for 60s adventures~~

✓ - paper (collisions) draft after ISIS

✓ - Tom Headen's mail (put our research on ISIS webpage)
↳ yes

✓ - Meetings / Conferences / Trainings:

y 22.01. UK planetary Early Career (Leicester) 05.01.16 registered

y 7.-9.03. planet formation (Duisburg)

STFC bursary y 14.-15.06. Cometary Science after Rosetta (London)

y 14.-15.03. Media & communications training (Buckinghamshire)

08.01.16 registered + abstract submitted

y 1-2.02. water in the inner Solar System (Newport pagnell)

decide in spring 16.-21.10. DPS (Pasadena) with EPSC

~~- practise talk for EClPs meeting~~

✓ - bullet points for cell biology episode → Peter Taylor UC

- Look at modified plots for COR

Nate (Nathiel Nottingham)

Wednesday: Robert Marchbanks

Ian McDonald

thermal engineering: Marco Marengo (Brighton)

→ Nathaniel Szewczyk

1. 12. 2015

my todo list:

Priorities:

- cold dust analysis + paper — after ISIS dec (maybe split in two papers if it takes too long)
- ISIS June analysis + paper — together with second ISIS run on deposited ice
- ISIS Dec analysis + paper — paper out before easter
- warm dust analysis — Is there a difference cold dust to warm dust that is in the literature if not → ignore it.
- 60s adventures
- teaching
- PF experiment preparation — more important than all paper

05.11.2015

Continue with data analysis for 46th ESA campaign

Plot of Coefficient of Restitution:

Problem: With the formula I used so far

$$\varepsilon = \sqrt{1 - \frac{\Delta E}{E_{before} \cdot N}}$$

I get the "average" over N encounters, but ε can only take values between $1-\frac{1}{N}$ and 1 instead of $[0,1]$.

Additional plot: $\tilde{\varepsilon} = \sqrt{1 - \frac{\Delta E}{E_{before}}}$

This ignores the number of encounters, but is $\in [0,1]$.

$$\Delta\tilde{\varepsilon} = \frac{1}{2\tilde{\varepsilon} \cdot E_{before}} \cdot \sqrt{\left(\Delta E_{before} \cdot \frac{E_{after}}{E_{before}}\right)^2 + \left(\Delta E_{after}\right)^2}$$

useless, I do this by change of center-of-mass velocity anyways.

Meet Jürgen Blum at DPS conference

12.11.2015

potential Sticking videos rumschicken
gleichverteilung erwartet für b_R^2
Fragmentationswahrscheinlichkeitsanalyse
  Fragmentationsgrenze bestimmen: Verhältnis Fragment / Gesamtstößen (evtl. mit schmalen Intervallen)
plot aufsplitten in viel / wenig Rotation (COR plot)
all cumulative number (COR vs V_{rel}) plot
eher auf Einzelstöße beschränken

26.11.2015

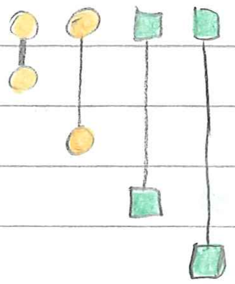
Mixed outcome analysis:

stick: ■
bounce: ●
fragment: ★

C03_F2_P06

Particle	Mass(g)
1	$2\cdot10^{-1}$
2	$6\cdot10^{-5}$
3	$6\cdot10^{-5}$
4	$8\cdot10^{-4}$
5	$6\cdot10^{-5}$

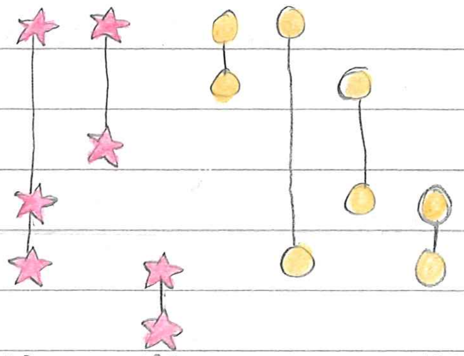
Events



encounter time (ms) 50 50 50 50

C07_F2_P08

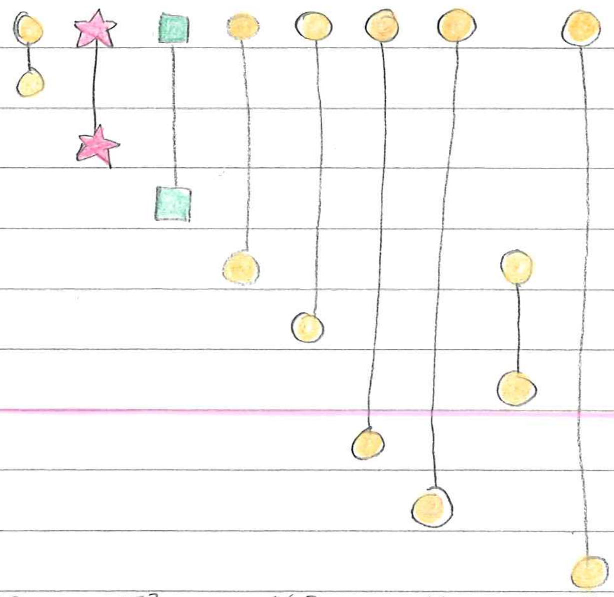
Particle	Mass(g)
1	$2\cdot10^{-1}$
2	$2\cdot10^{-1}$
4	$5\cdot10^{-4}$
5	$6\cdot10^{-2}$
6	$6\cdot10^{-2}$
7	$8\cdot10^{-5}$



172 167 180 182 174 183 173

C15_F2_P24

Particle	Mass(g)
1	$1\cdot10^{-1}$
2	$3\cdot10^{-4}$
3	$3\cdot10^{-4}$
4	$2\cdot10^{-5}$
5	$3\cdot10^{-3}$
6	$3\cdot10^{-2}$
7	$3\cdot10^{-5}$
8	$5\cdot10^{-4}$
9	$2\cdot10^{-3}$
10	$6\cdot10^{-3}$

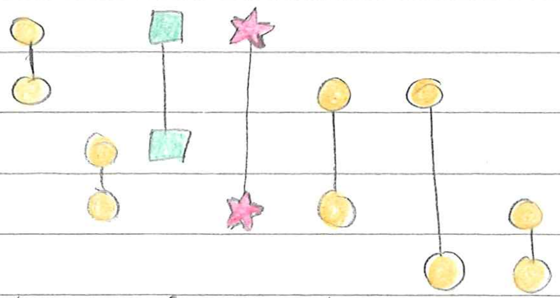


157 153 153 163 163 166 167 168 170

C19_F3_P03

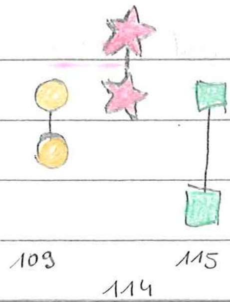
This is the collision where I think, I see sticking

Particle	Mass(g)
1	$1\cdot10^{-1}$
2	$1\cdot10^{-1}$
3	$\boxed{2\cdot10^{-3}}$
4	$2\cdot10^{-1}$
5	$4\cdot10^{-2}$



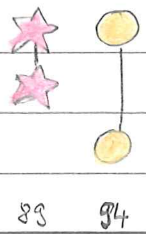
106 102 103 102 106 108 104

C25_F3_P06



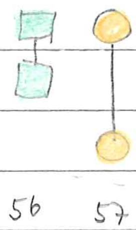
1	$1\cdot10^{-1}$
2	$6\cdot10^{-2}$
3	$9\cdot10^{-3}$
4	$3\cdot10^{-5}$

C29_F3_P08



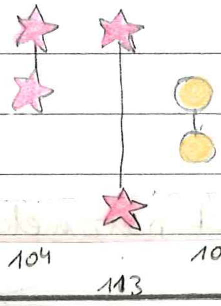
1	$1\cdot10^{-1}$
4	$6\cdot10^{-3}$
5	$7\cdot10^{-5}$

C32_F3_P09



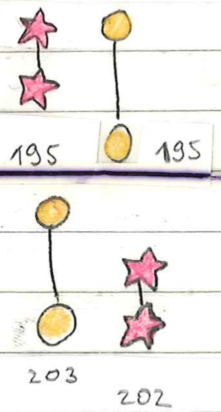
1	$1\cdot10^{-1}$
2	$5\cdot10^{-6}$
3	$2\cdot10^{4}$

C33_F3_P10



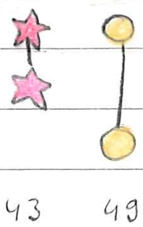
1	$2\cdot10^{-1}$
2	$1\cdot10^{-2}$
4	$4\cdot10^{-3}$
5	$8\cdot10^{-2}$

C35_F3_P12



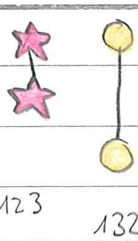
1	$1\cdot10^{-1}$
5	$1\cdot10^{-3}$
7	$2\cdot10^{-3}$
2	$1\cdot10^{-2}$
3	$5\cdot10^{-4}$
4	$2\cdot10^{-3}$

C41_F3_P14



1	$2\cdot10^{-1}$
2	$5\cdot10^{-4}$
3	$2\cdot10^{-4}$

C47_F3_P22



1	$2\cdot10^{-1}$
5	$2\cdot10^{-3}$
6	$5\cdot10^{-4}$

All of the particles on these two pages originally come from the guiding tubes. None is the result of a fragmenting collision.

Uncertainties for normalised impact parameter:

$$b_R = \frac{|\vec{b}|}{|\vec{R}|} = \frac{1}{|\vec{R}|} \cdot \left| \vec{R} - \frac{\vec{R}^T \vec{V}_{\pi b}}{V_{\pi b}^2} \cdot \vec{V}_{\pi b} \right|$$

Doing a proper error propagation here will be extremely complicated and probably not very precise any ways, since the uncertainties for $\vec{R}$, $\vec{v}_{\pi b}$, te will be rough estimates themselves.
Another problem is that these uncertainties are not independent (for bad $\vec{v}, \vec{r}$ results t will be bad aswell because it is determined from those).
→ Question: Does it make sense to use the same method as for ε? → Use relative uncertainty of v_π?
Test that: Looks useful.

Square of normalised impact parameter:

$$\Delta b_R^2 = |\Delta b_R \cdot b_R|$$