How Discrete Element Method code can model dynamical phenomena such as saltation transport, multiple collision process and granular avalanches

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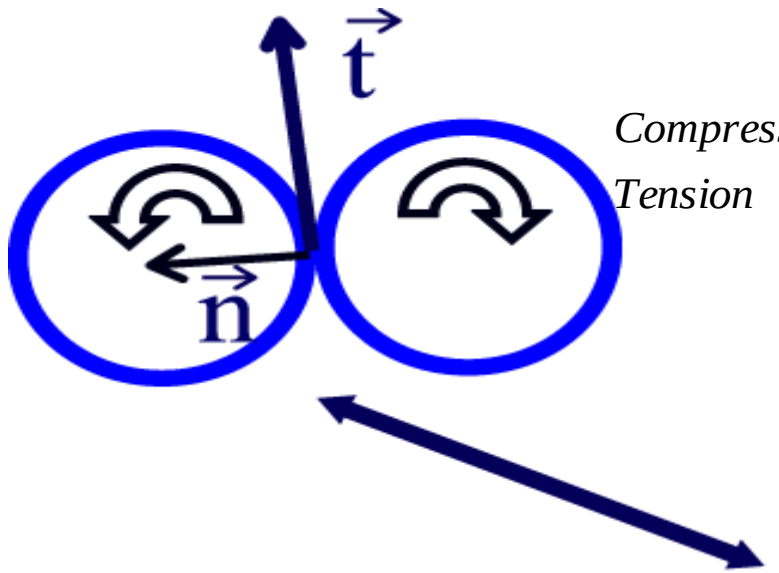
Schedule

1. General information for DEM
2. 3D grains interaction with humidity (avalanche)
3. 3D mono shot for Splash function
4. Multi shots for splash function
5. 2D saltation with wind interaction
6. Conclusion

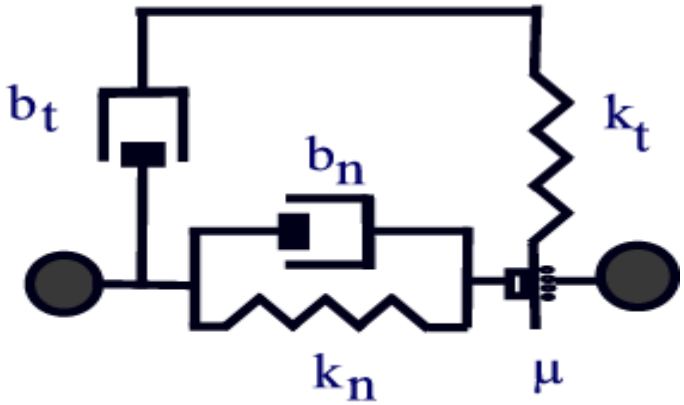
§1: General characteristics of DEM: Molecular Dynamics simulation (soft model)



$$Compression : F_n = K_n \delta - b_n v_n \quad (\delta \text{ is the positive overlap})$$

$$Tension \quad : F_n = 0 \quad (\text{if } \delta \text{ is negative})$$

+ external forces : wind, humidity, Electrostatic, …
+ shape factor : rolling resistance

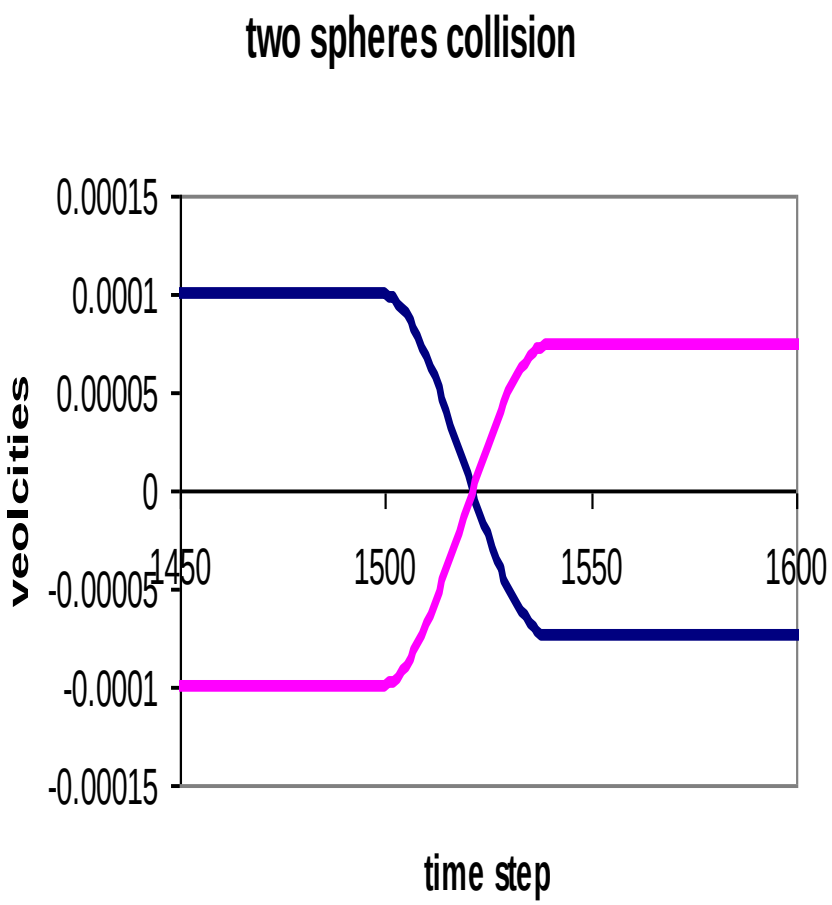


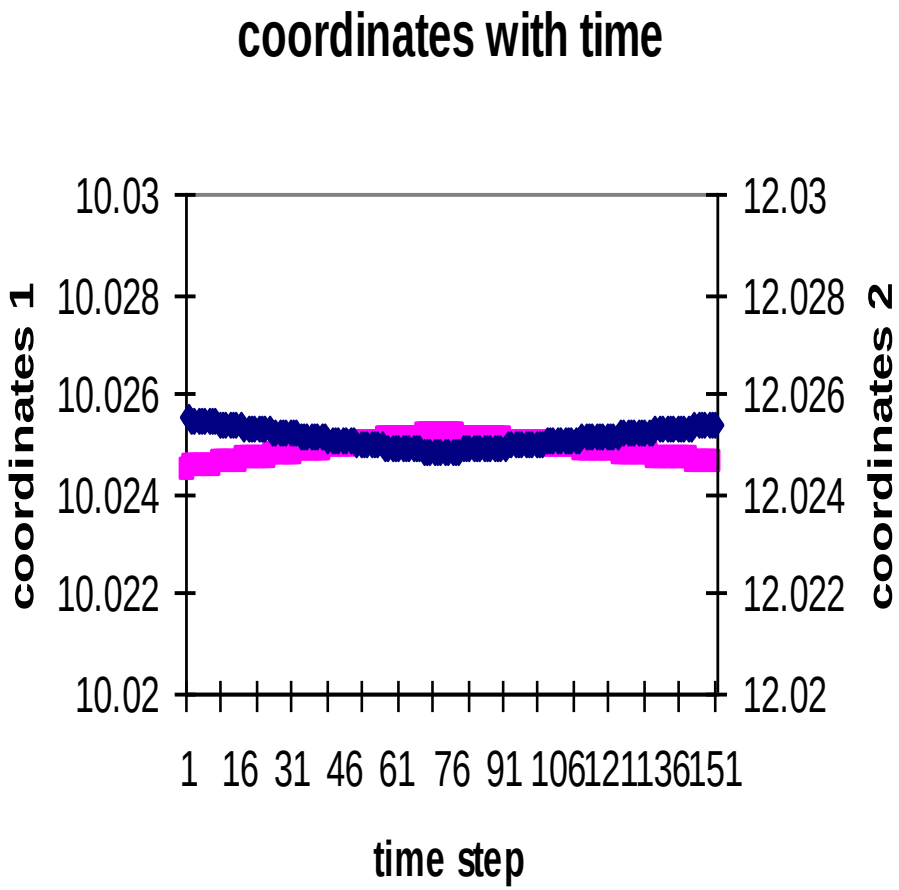
$$F_t = K_t \delta_t - b_t v_t$$

$$and\ F_t\ is\ controled\ by:$$

$$F_t = \mu_i F_n$$

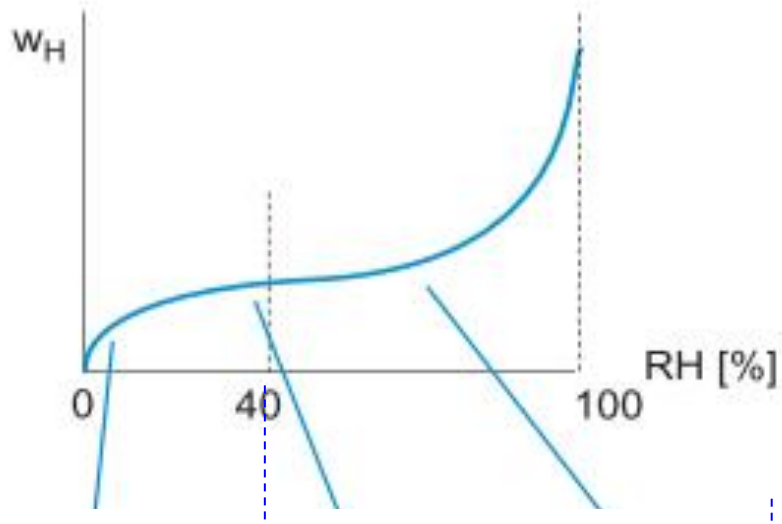
Soft sphere interaction

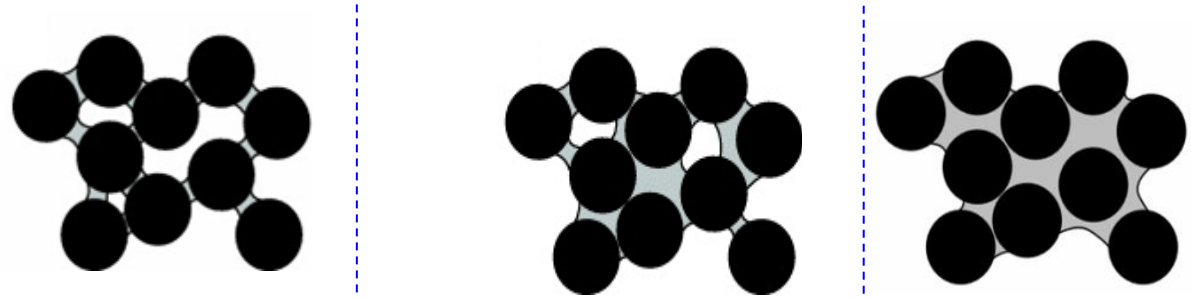




§2: 3D Avalanche with humidity

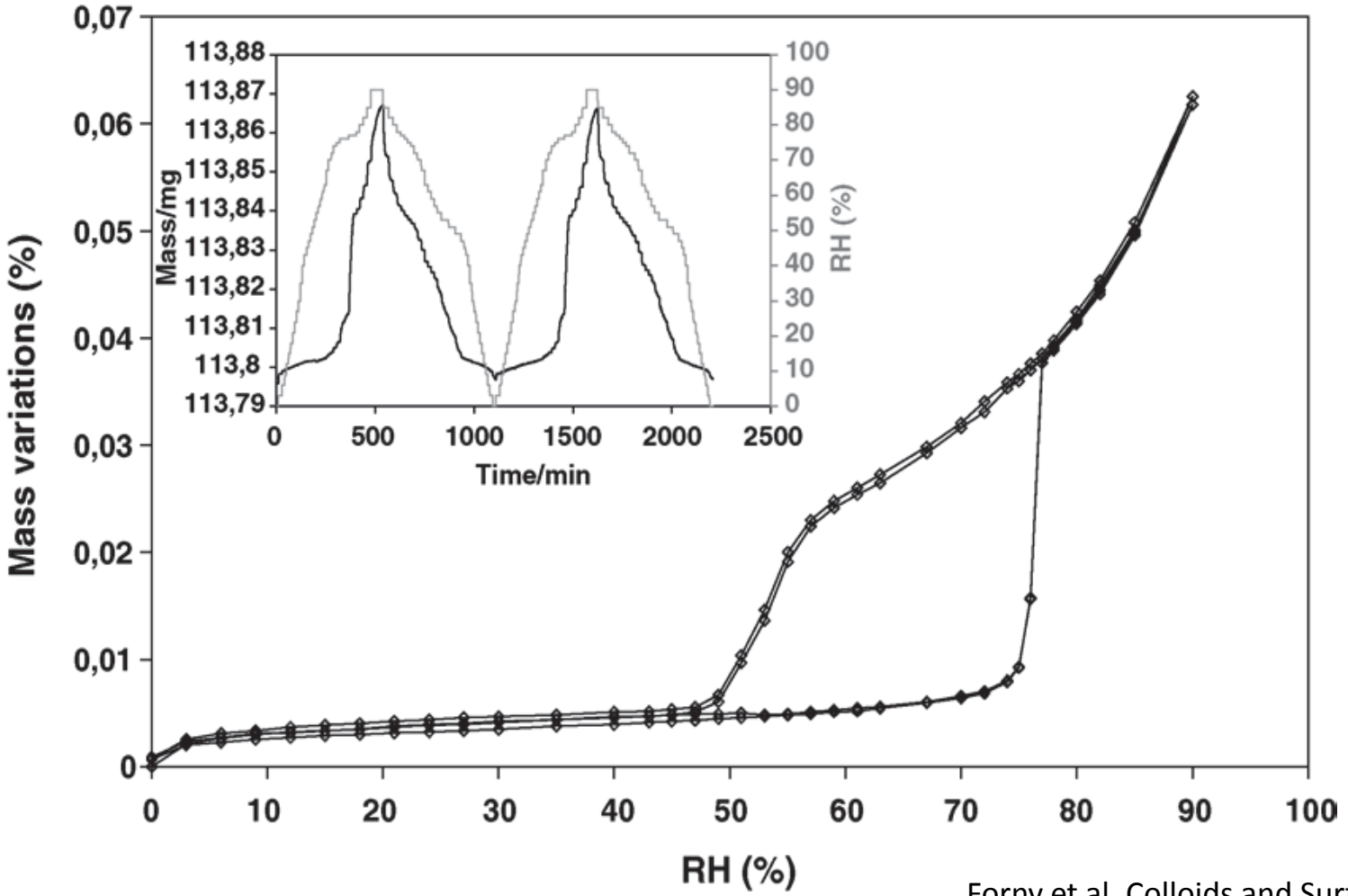
(present everywhere!)





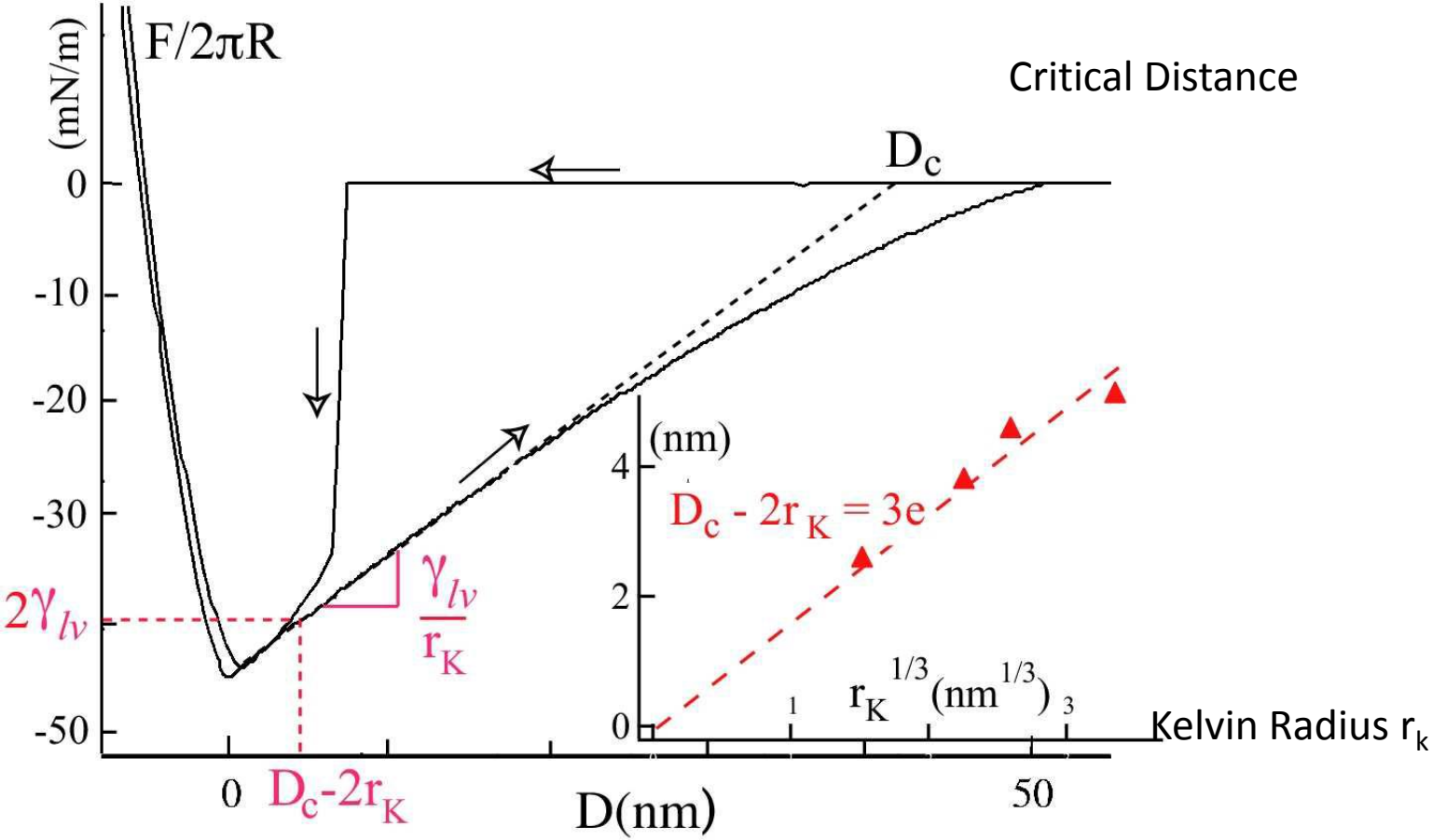
Pendular **Funicular** **Capillary**

85 µm glass beads



Forny et al. Colloids and Surfaces A (2005)

Force at the contact

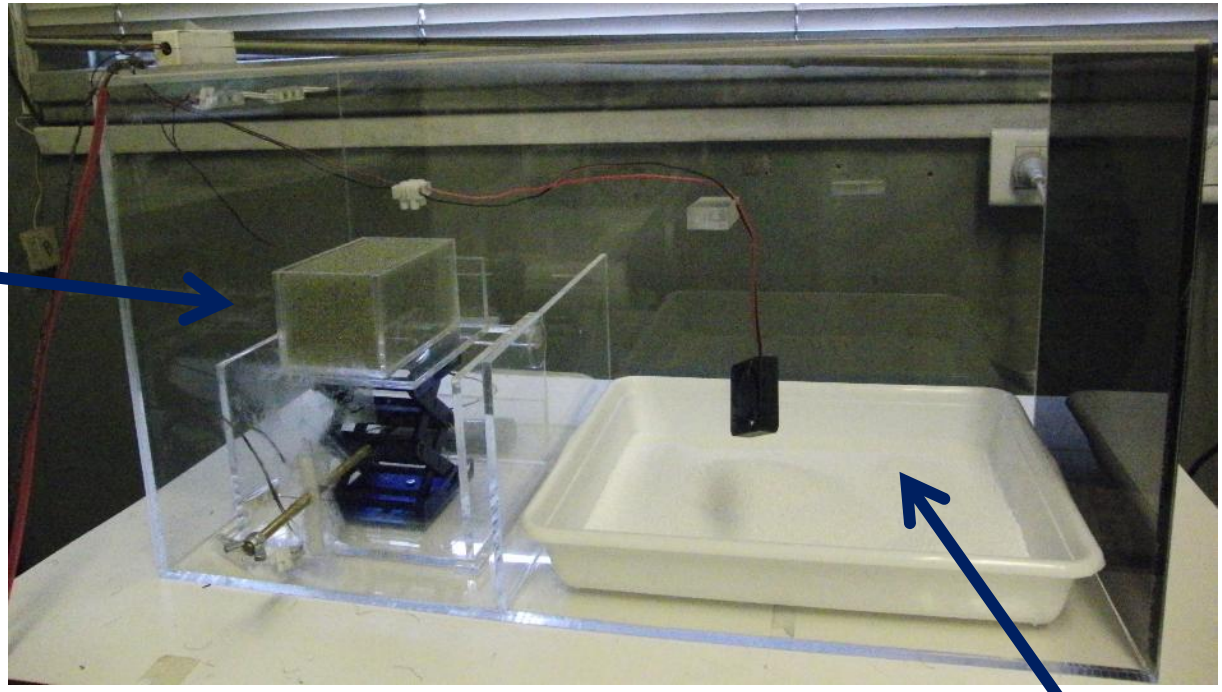


Charlaix et al. Handbook of Nanophysics (2010)

Experimental results at FI-UBA

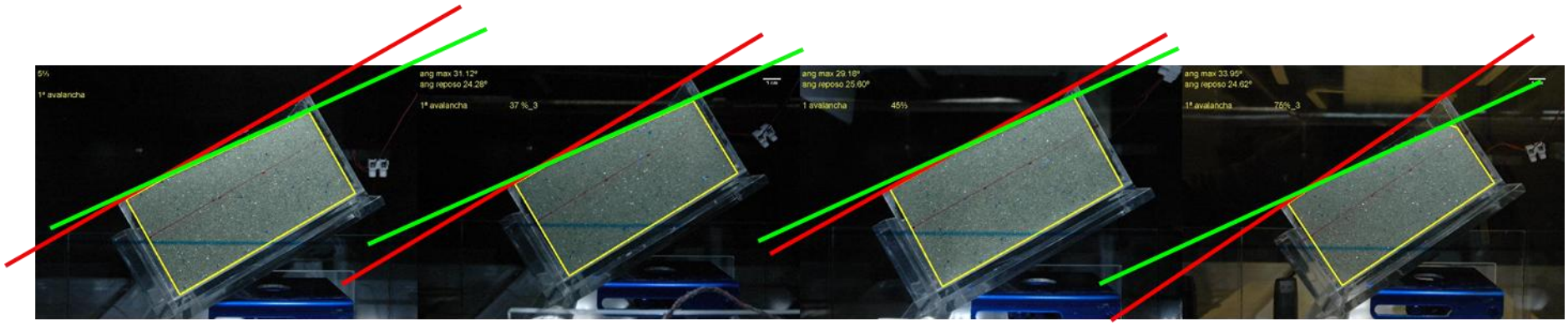
I. Arriarn & I. Ippolito

Tilt box

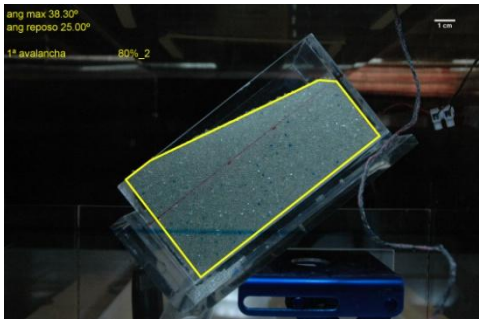


For humidity control

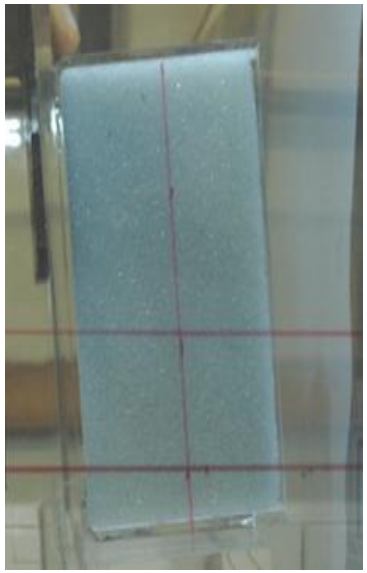
500 µm beads

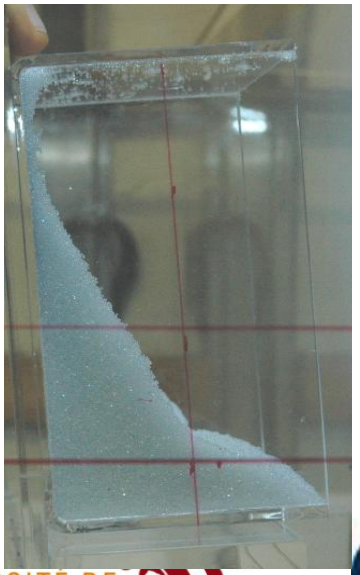


5% 37% 45% 75%



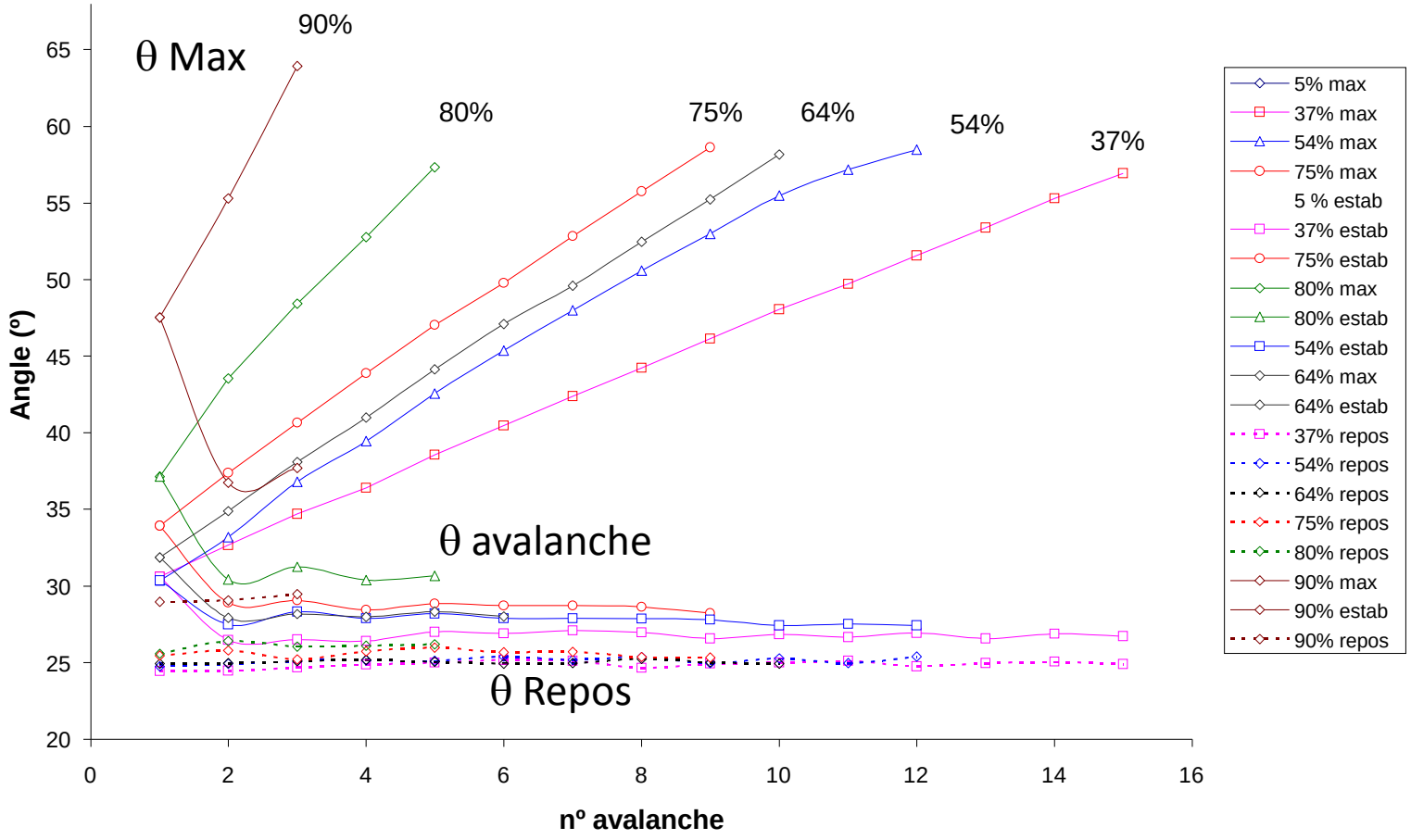
80%





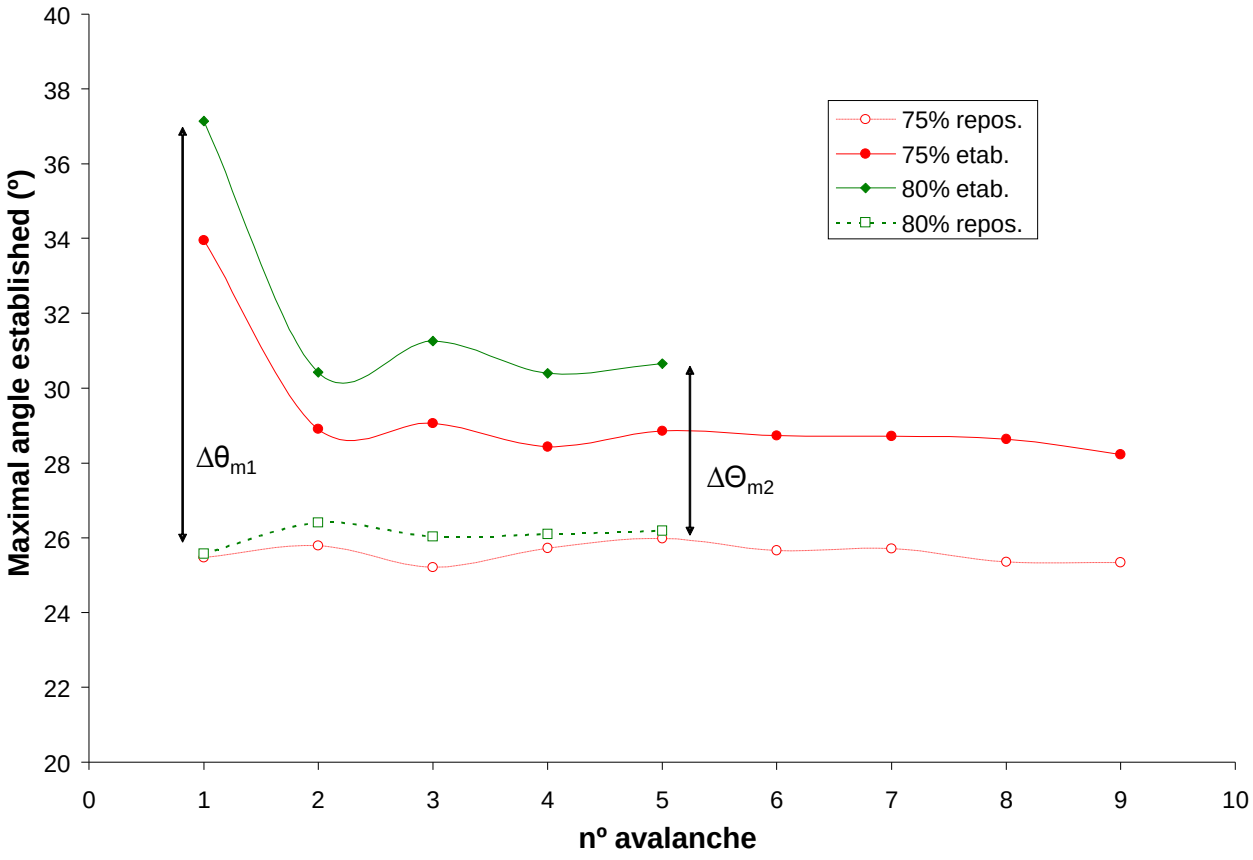
90% init final

Maximal angle and repose one
(grains 1 mm)



Différence between angles 1st avalanche & following

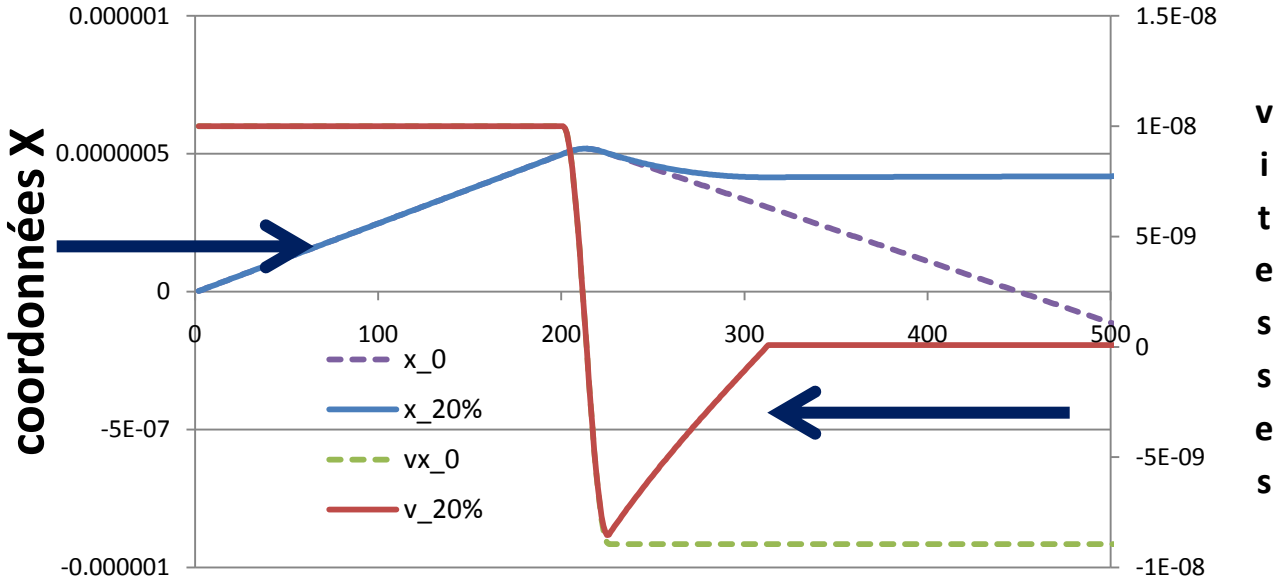
grains de 1mm

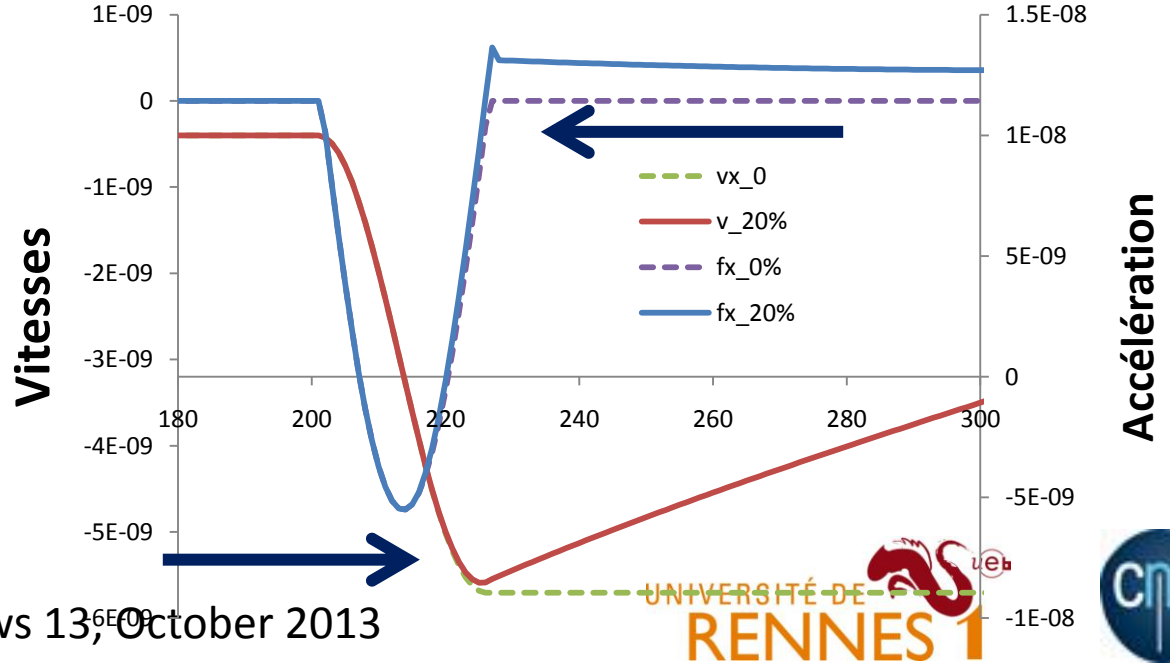


Numerical model

- Spring-Dashpot DEM 3D
- non periodic box
- 16000 monosize spheres
- Pré-consolidation des empilements
- Charlaix 's adhesion force
- Rotation by gravity vector
- Measures of angles in box directions

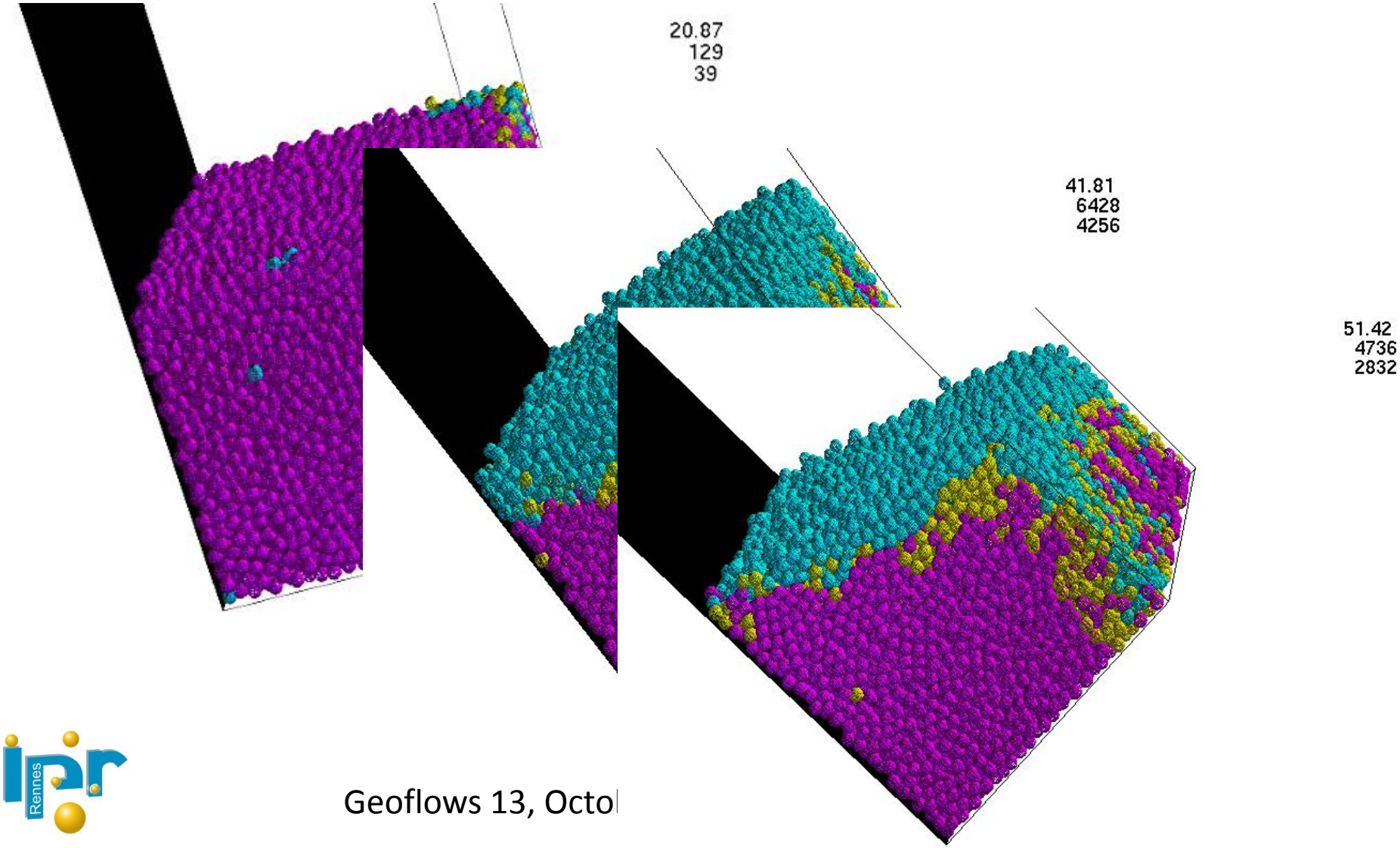
Comparaison déplacement, vitesse, accélération avec ou sans RH



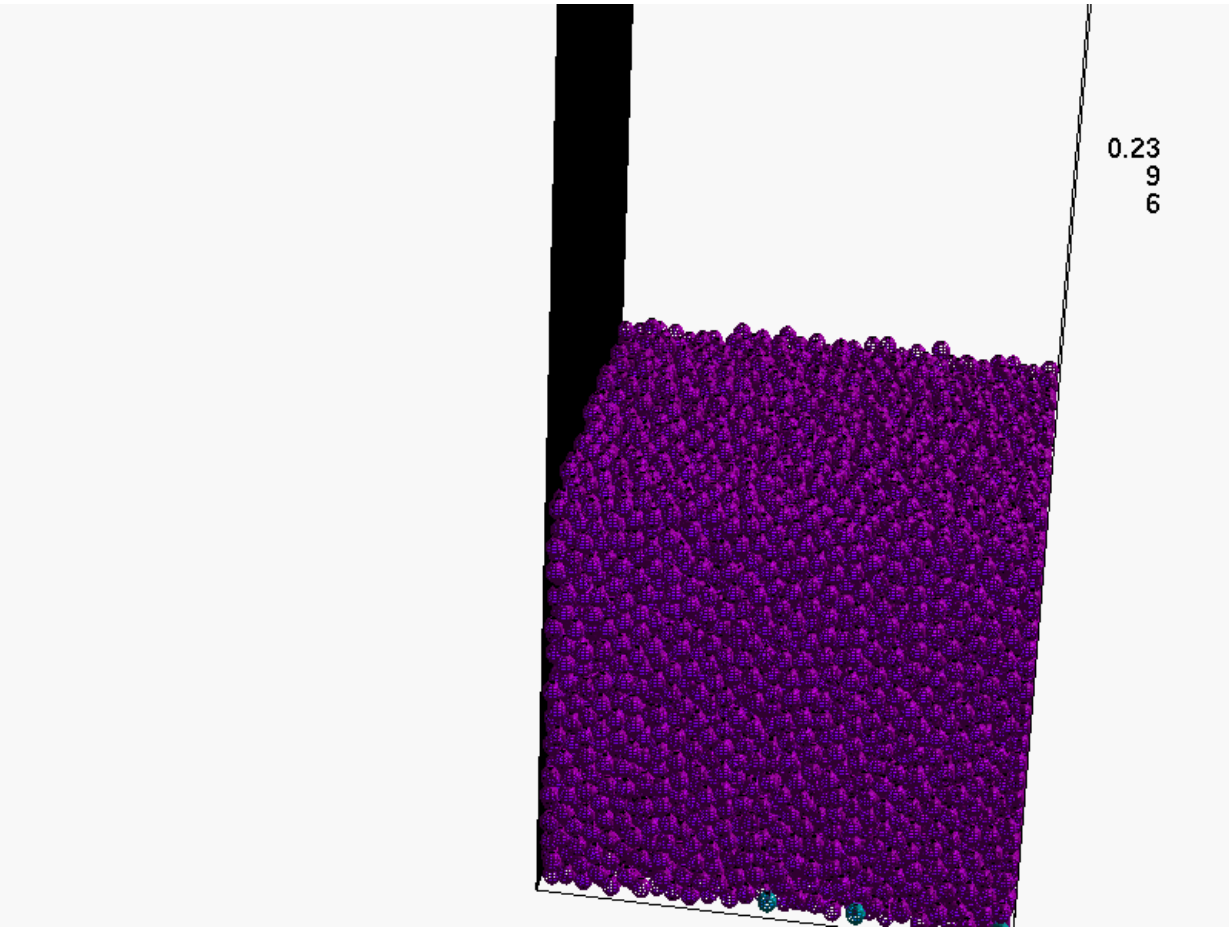


Evolution of velocities

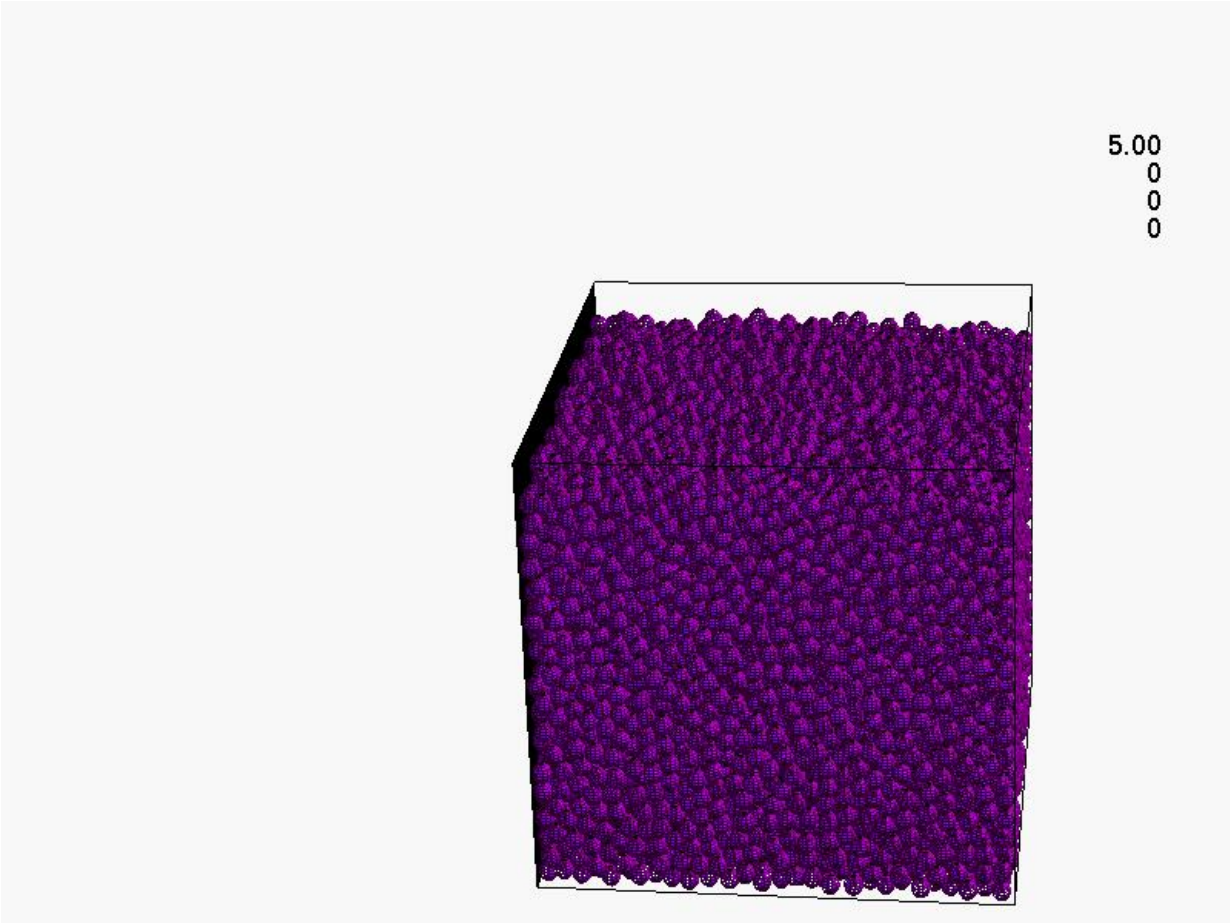
(2 vel. thresholds : 2colors : θ+2indications)



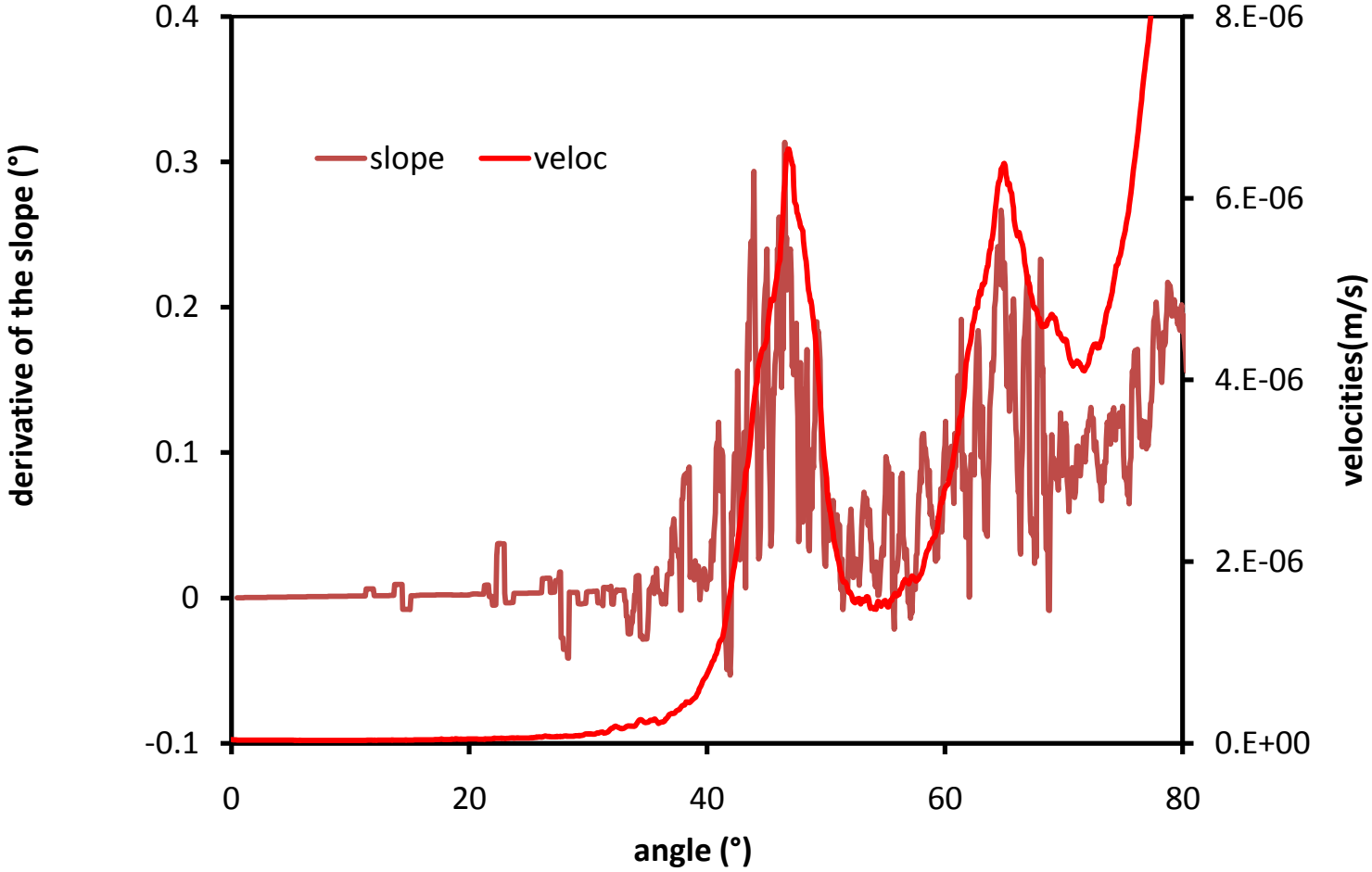
Movie of full sequence



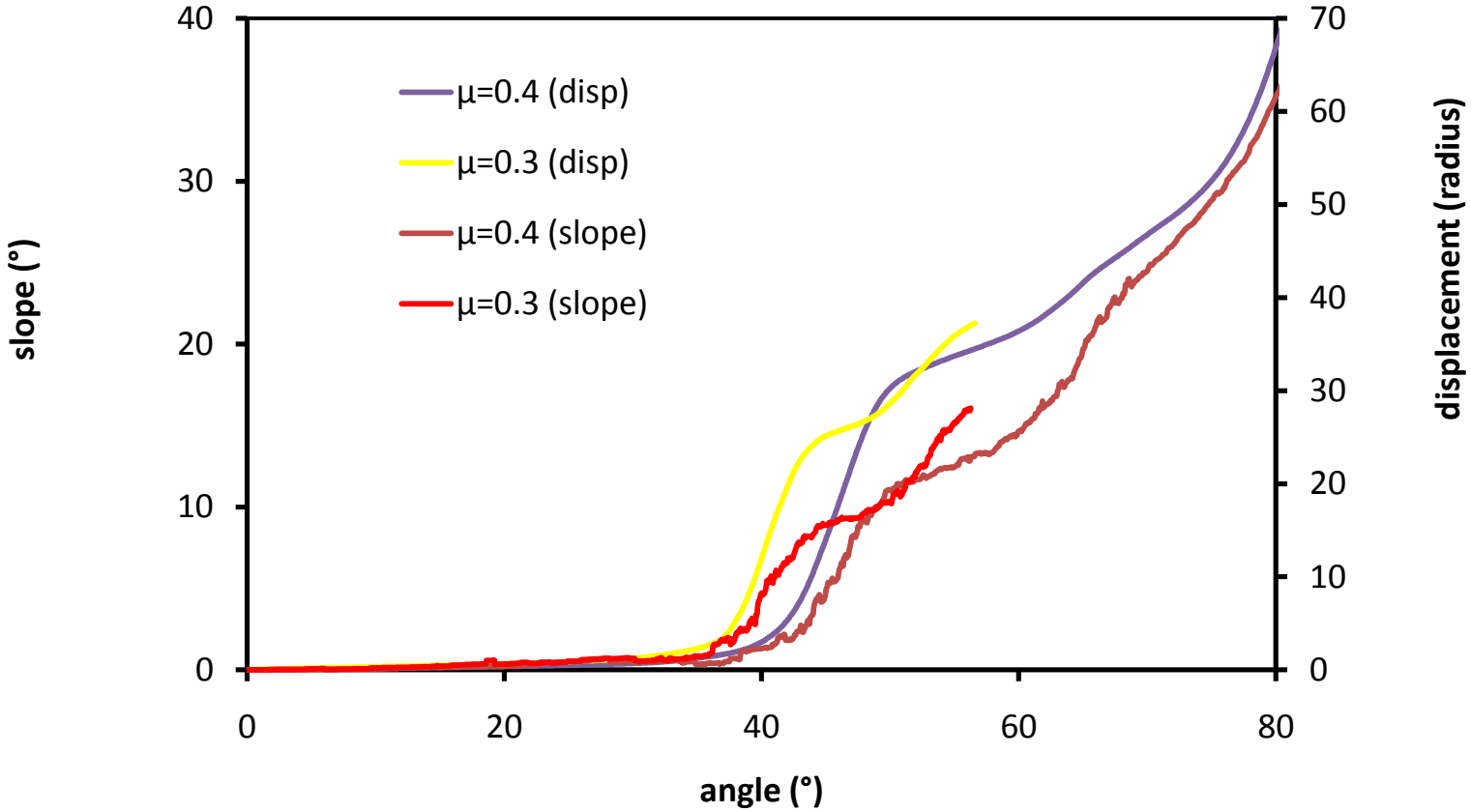
With sphere output



Evolution slopes velocities

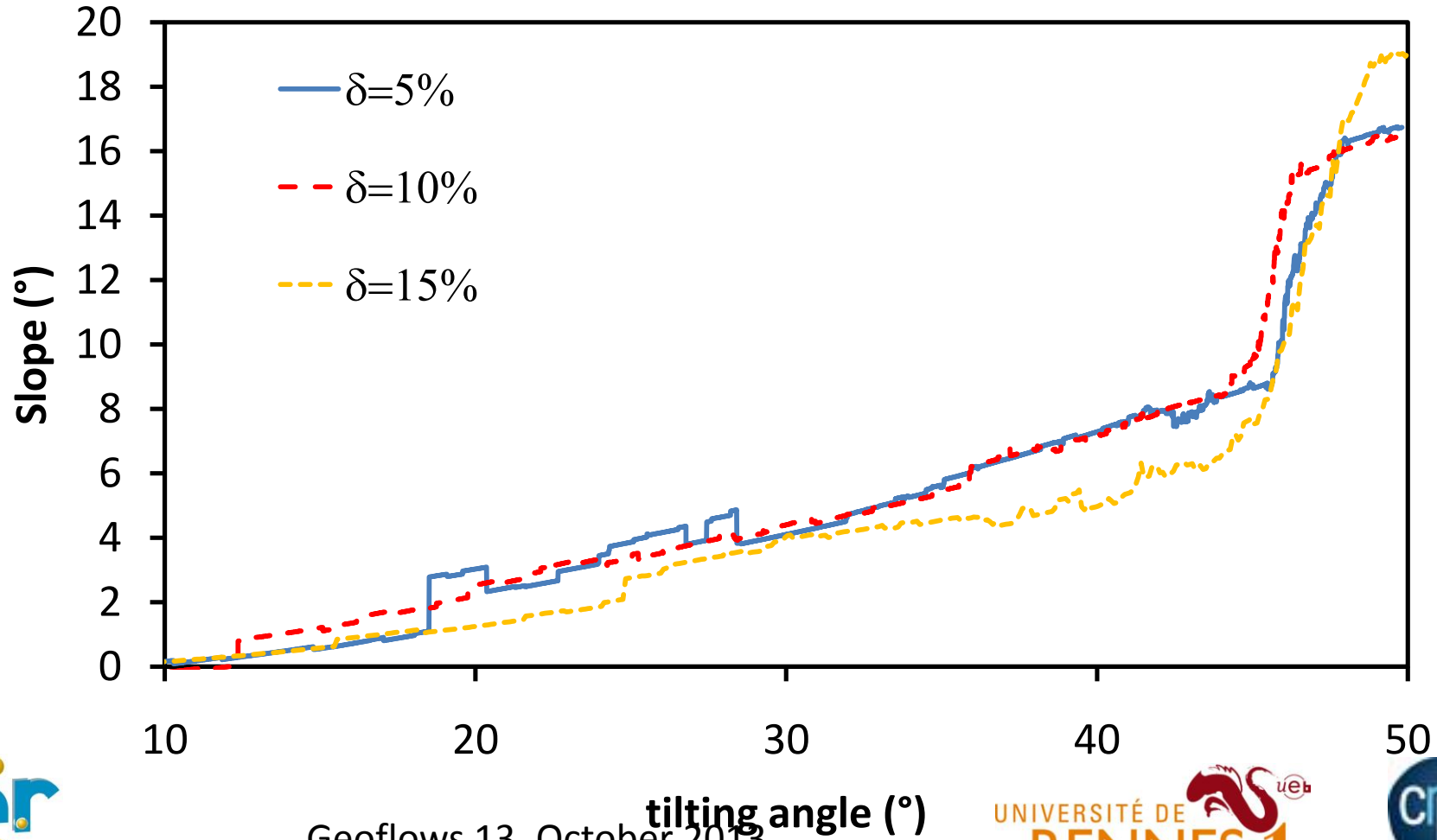


Evolution slopes & displacement
(2 friction coefficients)

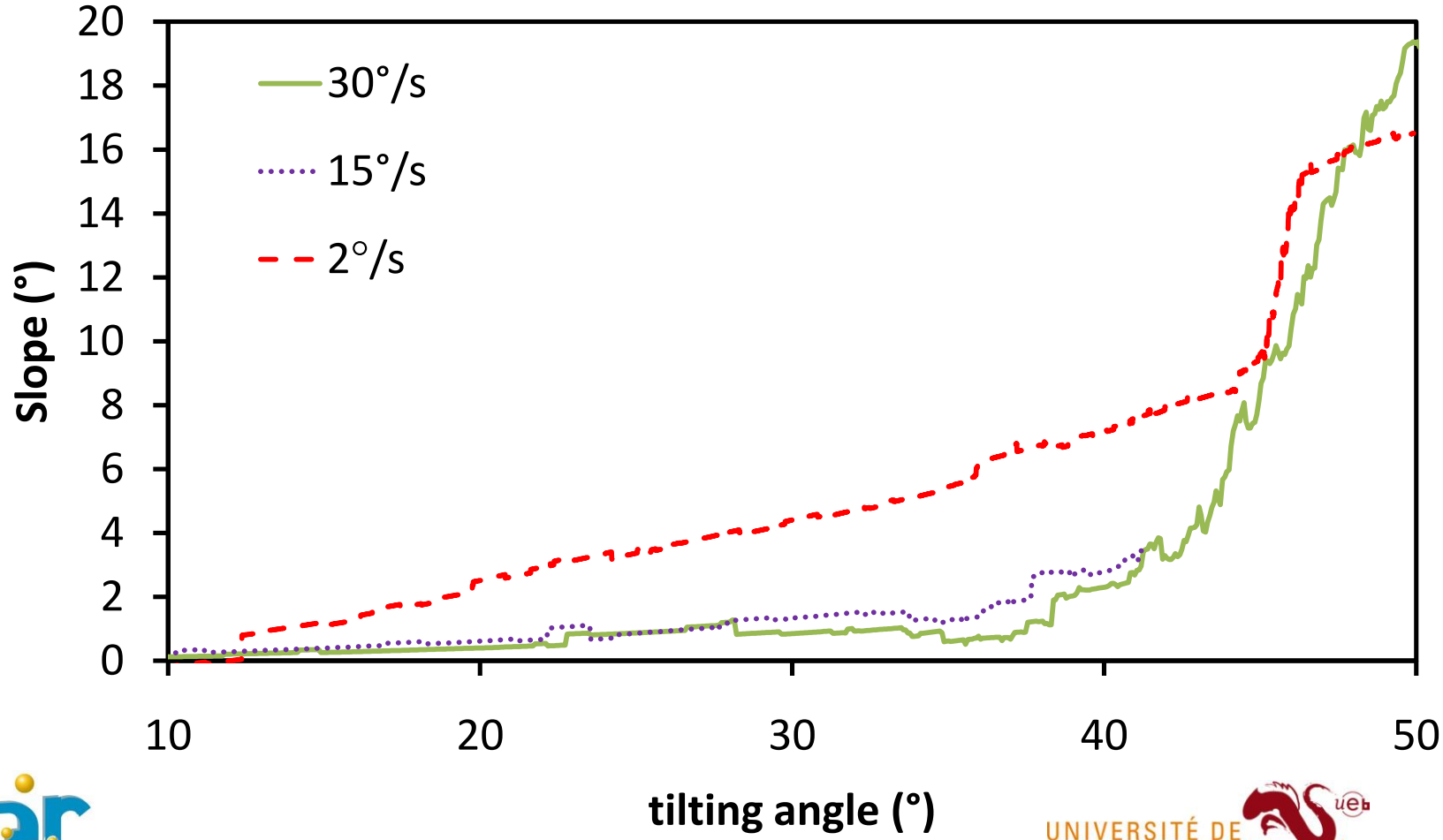


Sphere disorder effect

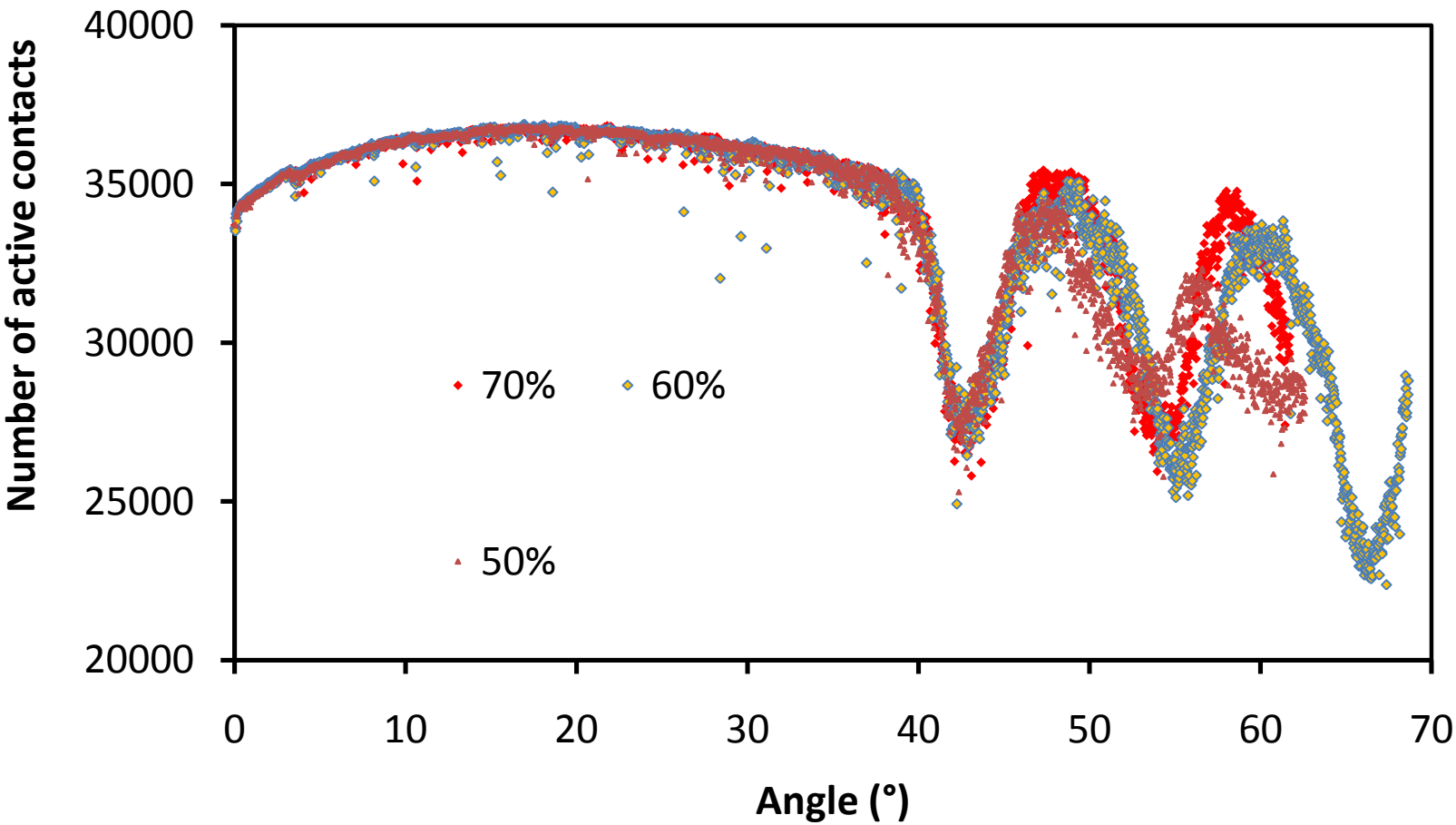
Different if higher than 10%



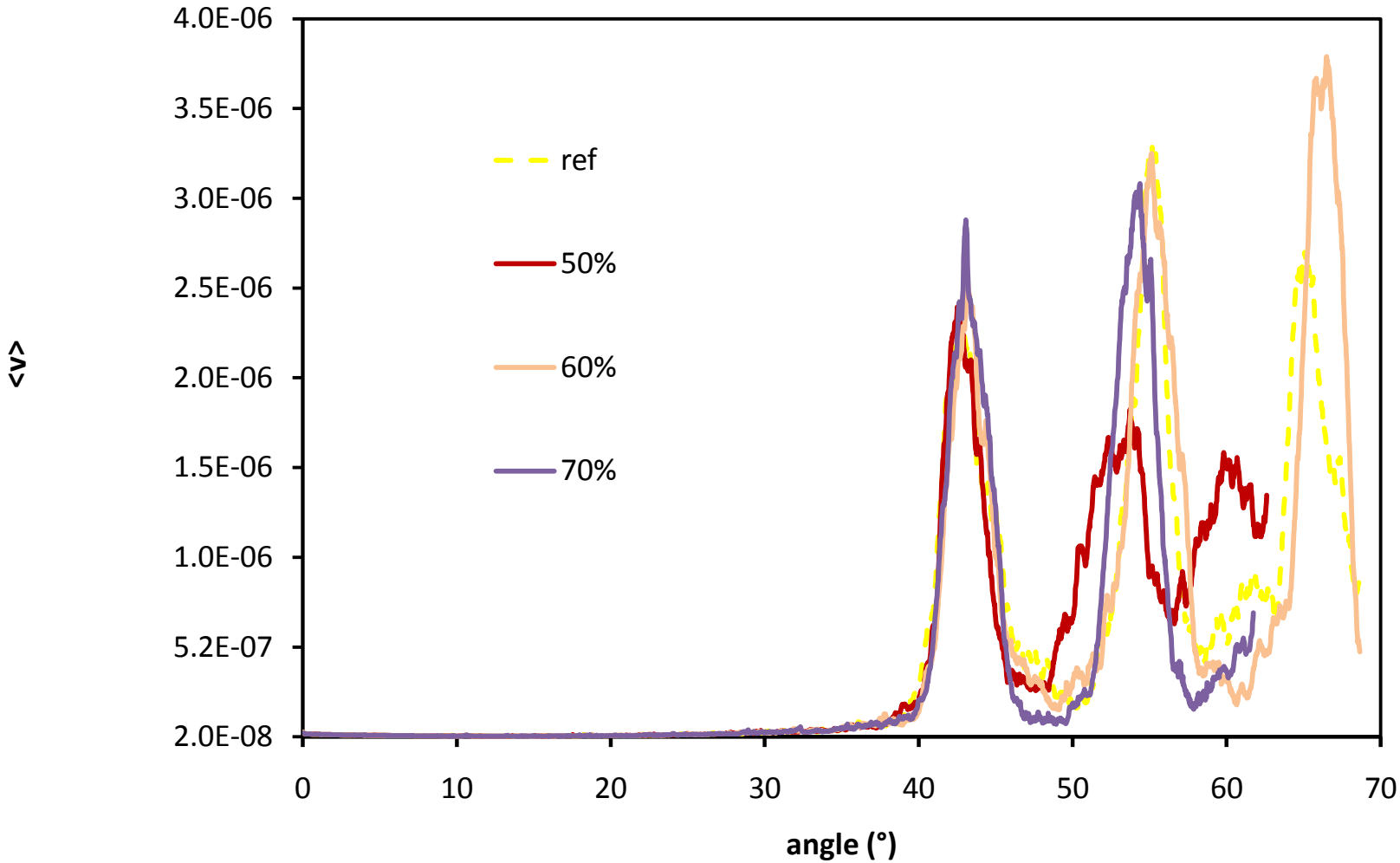
Effects of inclination speed

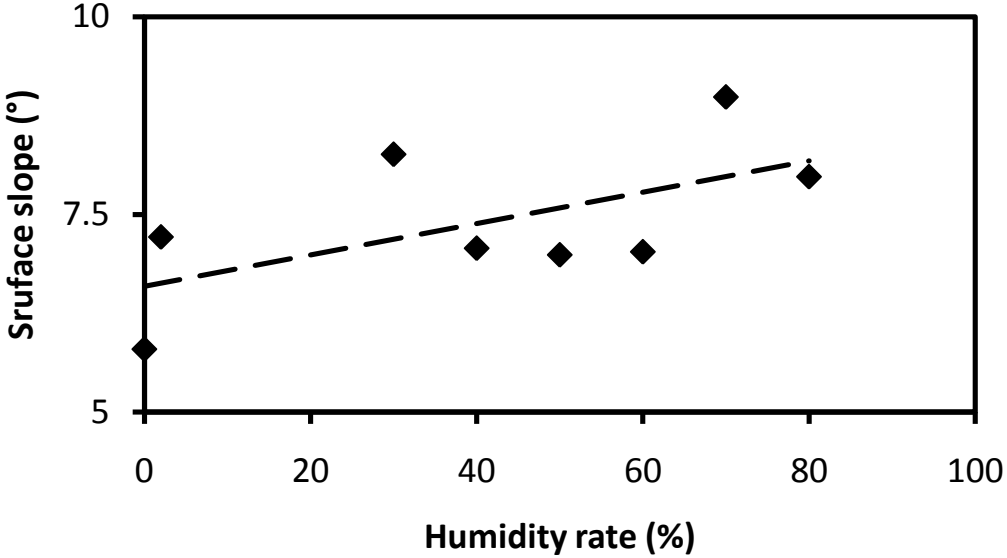


Evolution of active contacts

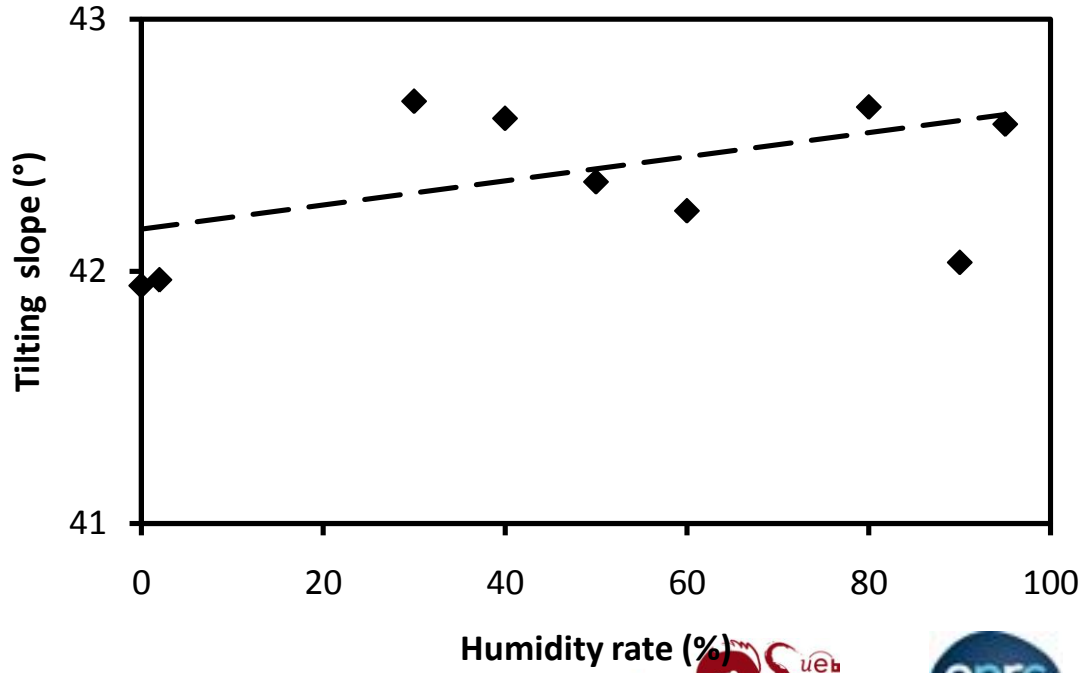


Evolution velocities = f(RH)




10
7.5
5
Sruface slope (°)
0
20
40
60
80
100
Humidity rate (%)

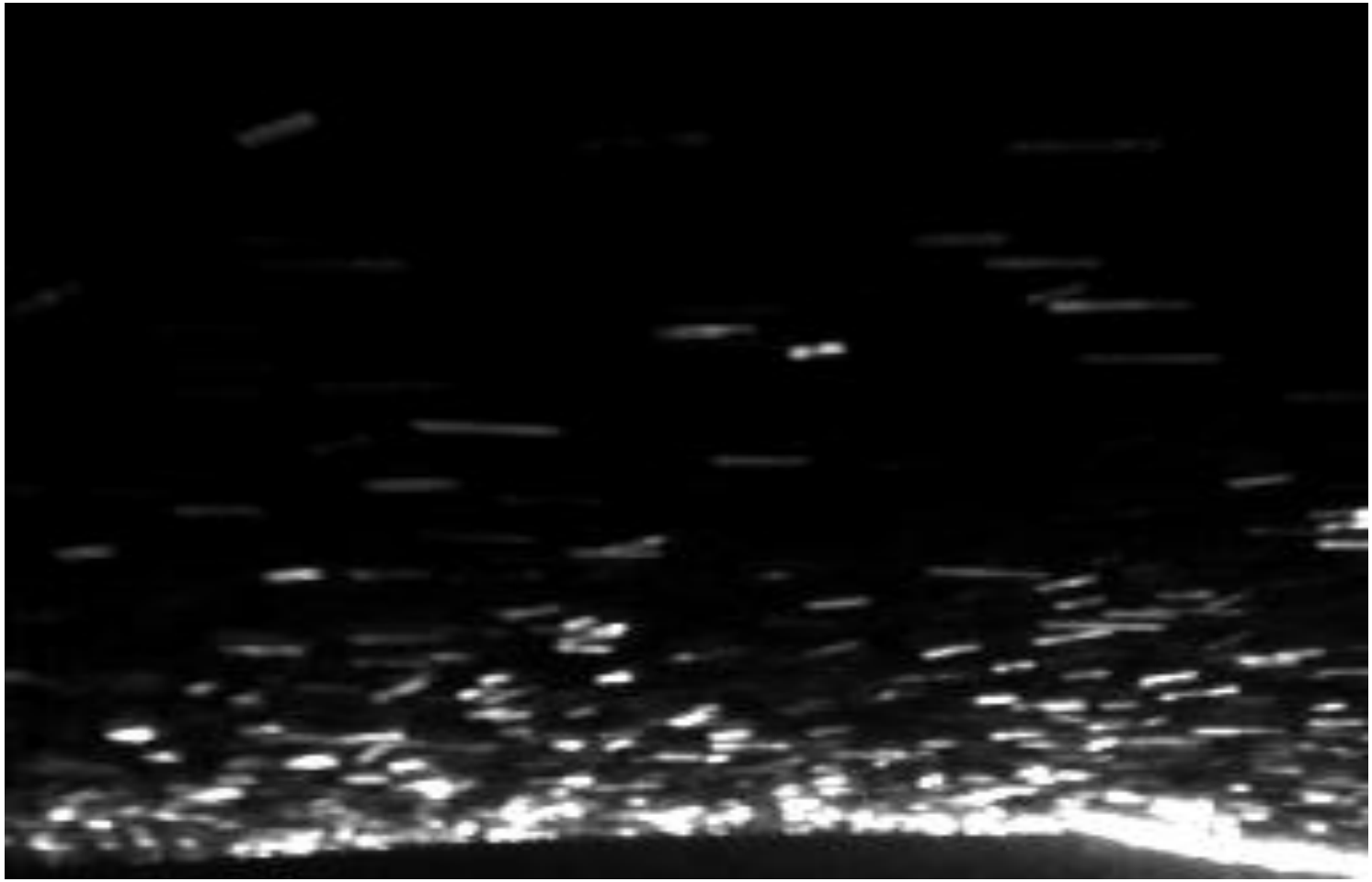
Results


43
42
41
Tilting slope (°)
0
20
40
60
80
100
Humidity rate (%)

§2:Conclusions

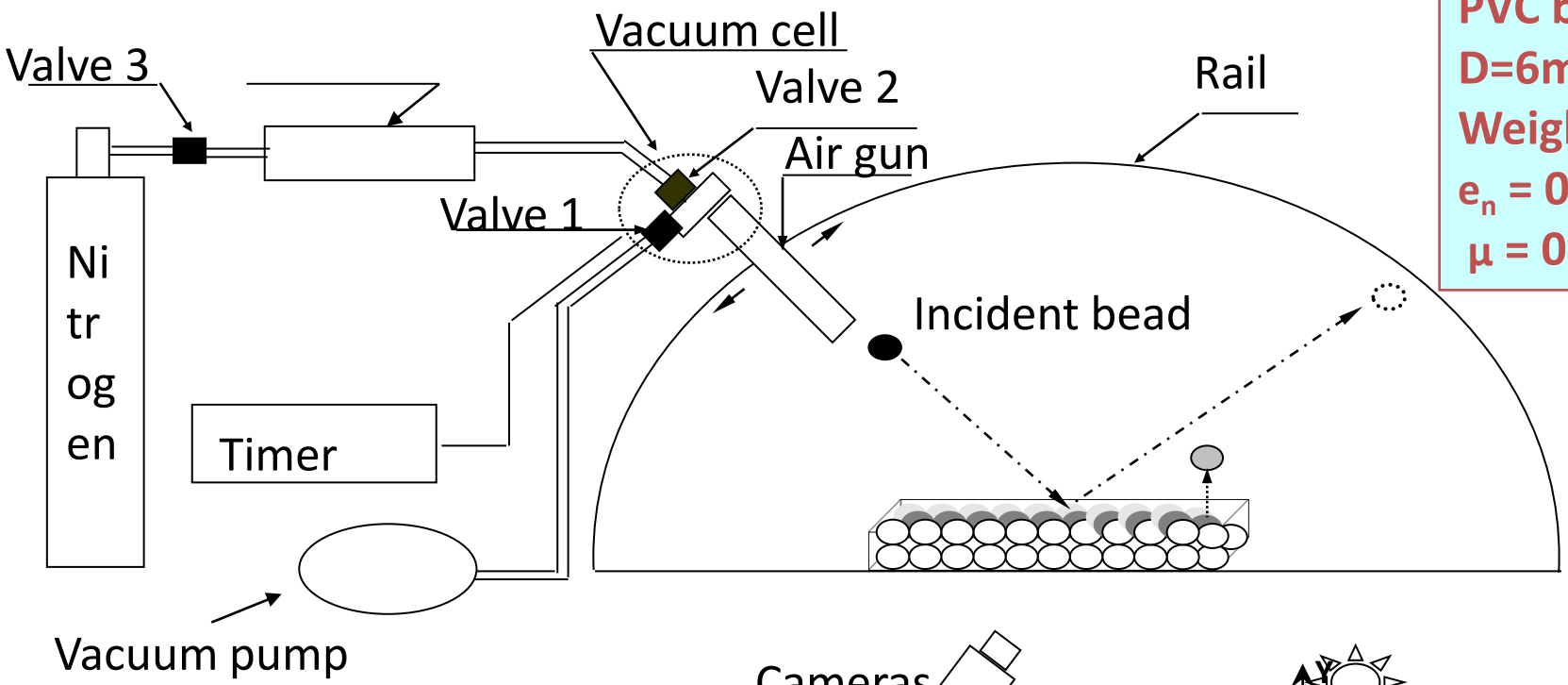
- Humidity is crucial to understand grains transport
- Humidity is difficult to model
- Correct results up to 70% RH
- Progress:
  - For high humidity rate!!!
  - Multiple capillary bridges!!

§3-4-5 issue: sand transport by saltation

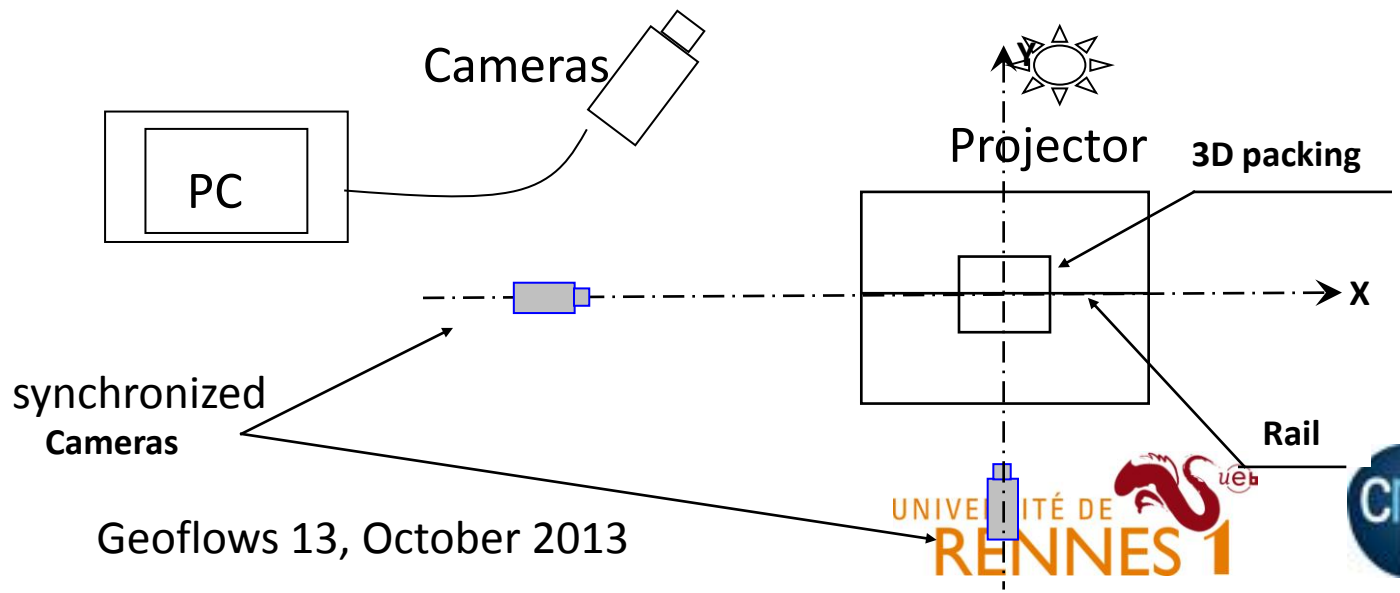


2D LASER slice of 3D sand flow inside a large wind Tunnel

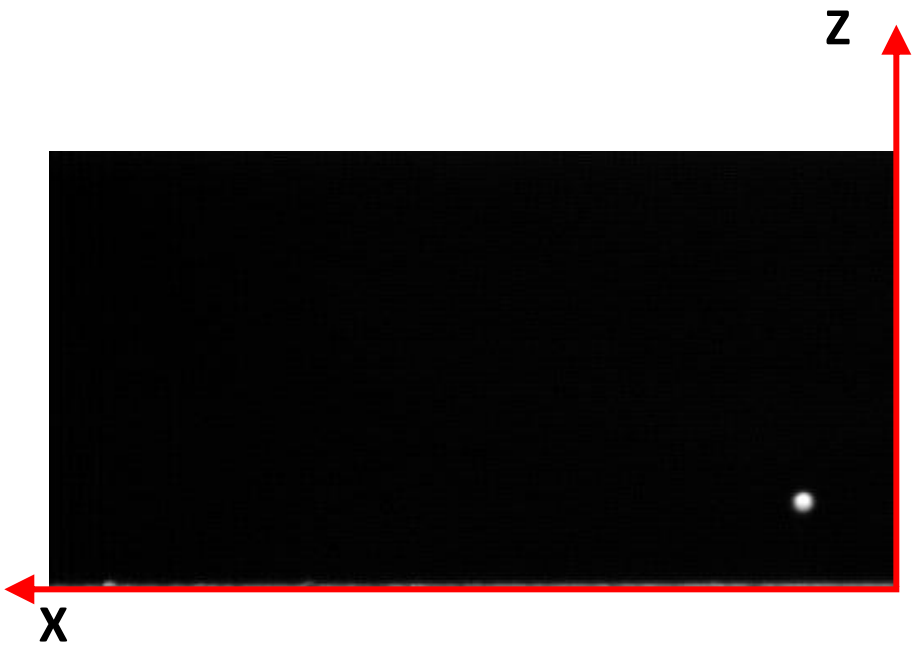
Experimental Setup



PVC beads
D=6mm
Weight = 0.2g
e_n = 0.91
μ = 0.19



Synchronized 3D Film



Possibility to detect the real 3D trajectories

Control Parameters

Froude Number= *1000*

Sand diameter ~ *100 µm*

Impact velocities : few m/s

→ **Impact speed ~ *10m/s***

Diameter = *6mm*

$$\text{Froude number} = \frac{\text{Impact kinetic energy}}{\text{Potential energy to reach One diameter high}} = \frac{V_i^2}{gd}$$

Incident angle effect :

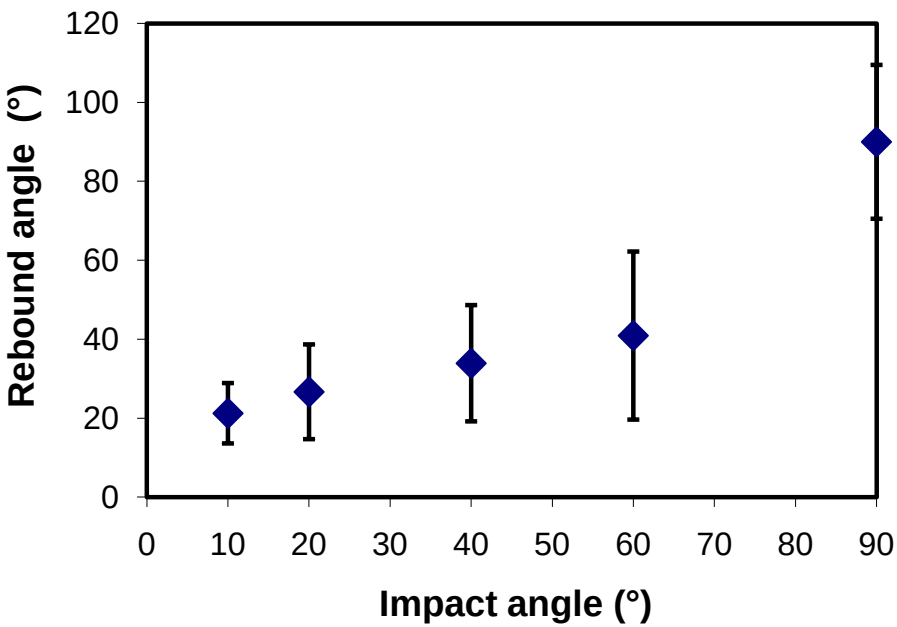
- **Constant speed: *26 m/s***
- **Variable angle: *0°* to *90°***

Incident speed effect:

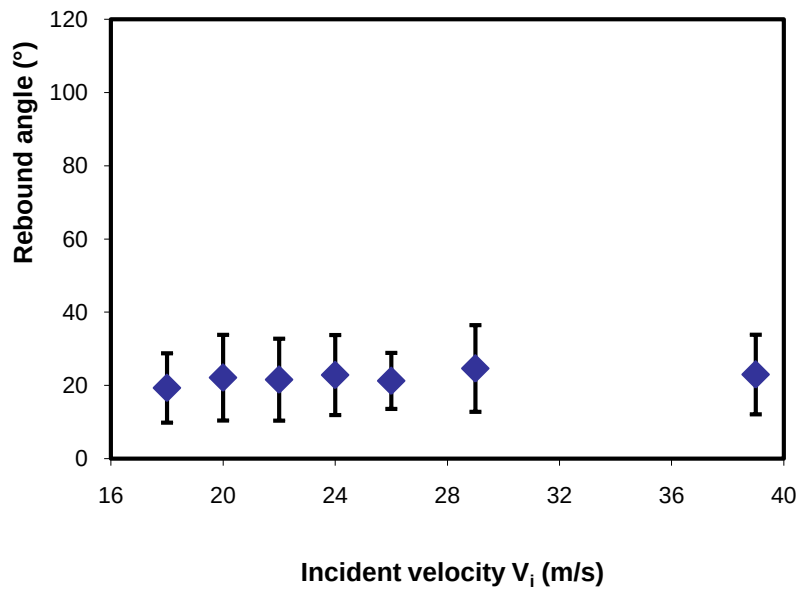
- **Constant Angle: 10° (Natural angle for saltation)**
- **Variable incident speed: *18 m/s et 39 m/s*.**

Variation of the rebound angle

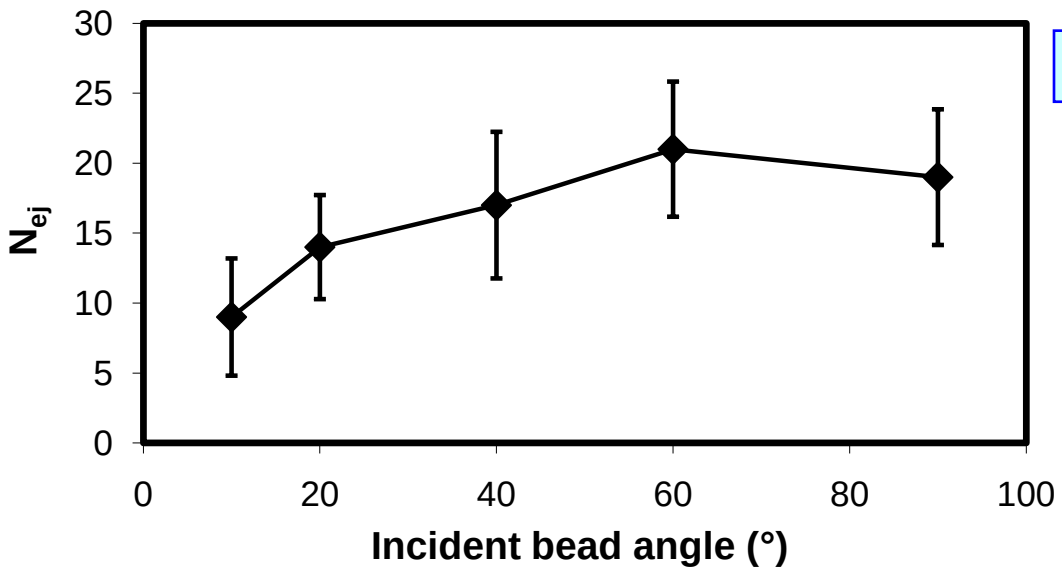
Velocity 26m/s



Angle 10°

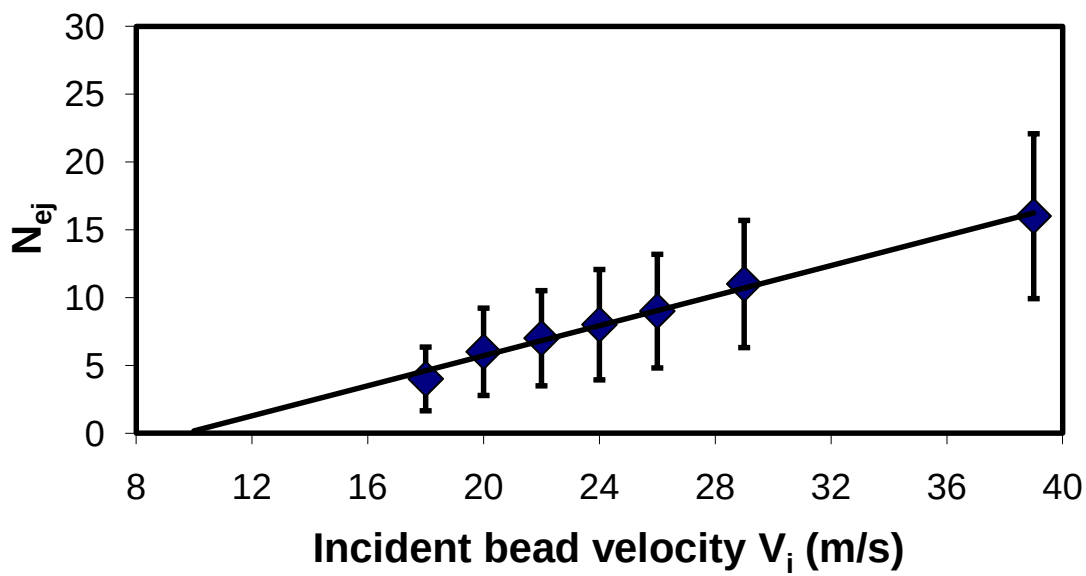


Number of ejected beads



Velocity 26m/s

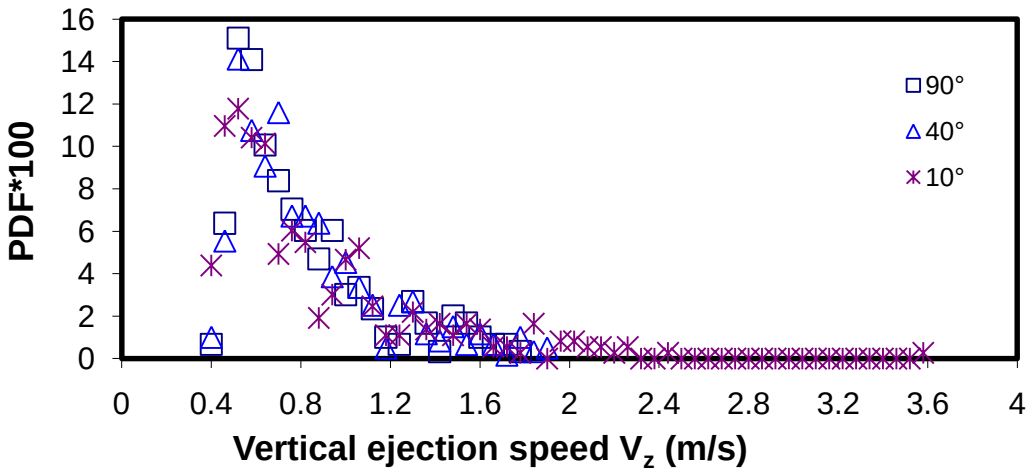
Angle 10°



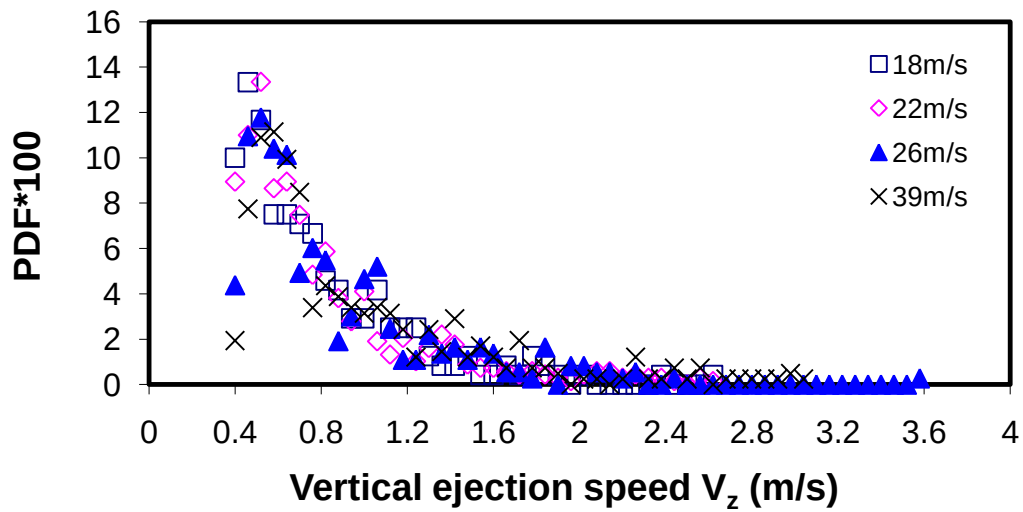
$V_i^{th} = 10$ *m/s*

Distribution of the vertical velocity components of ejected beads

Velocity 26m/s



Angle 10°



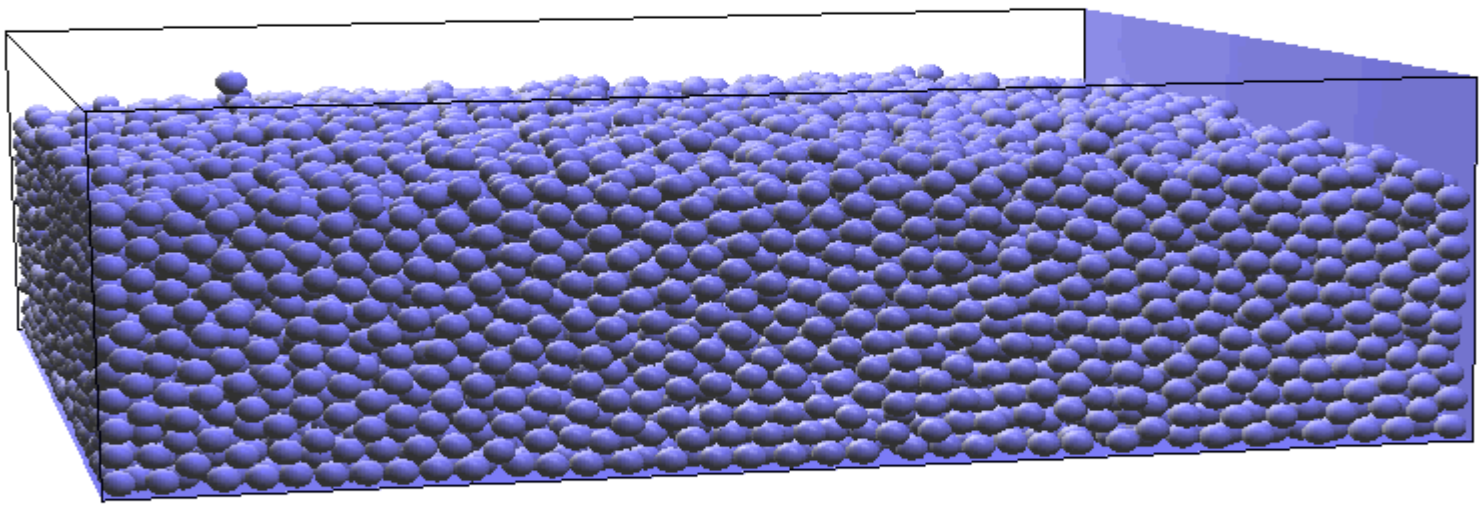
Distribution is independent of the angle and the incident velocity

Numerical simulation

- Discrete Element Method
  - Soft sphere model (“Spring-dashpot”)
- 30000 spheres for the packing (43x43x16)
- Same physical and mechanical parameter as the real beads :
  - Diameter = 6mm, weight= 0.2g
  - Stiffness= 1.0 E9 N/m
  - Restitution coefficient= 0.75 -0.95
  - Friction coefficient= 0.2-0.4

Visualization of the sphere displacements

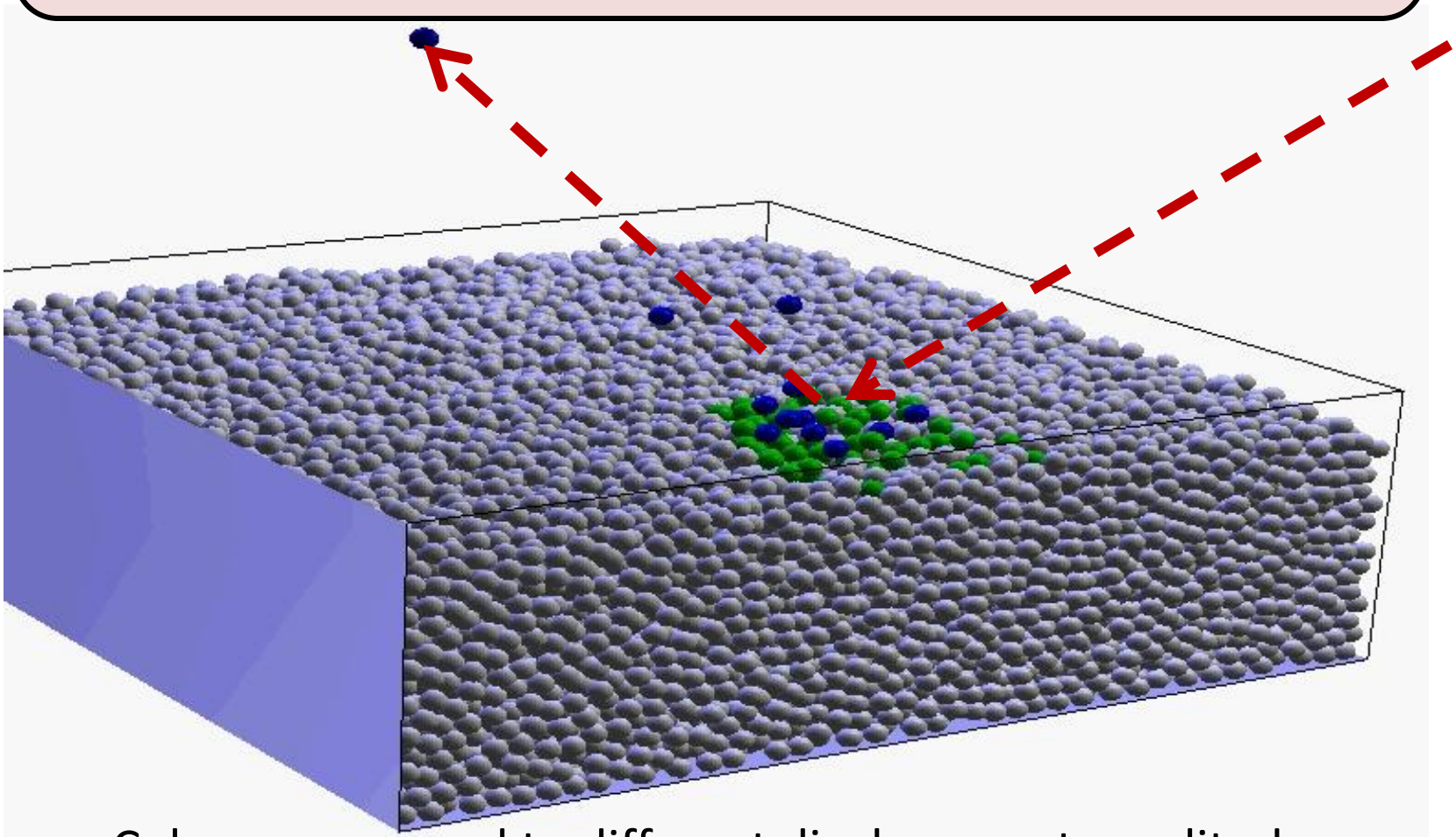
Incident bead : angle =10° and velocity =50 m/s



Green = displacement higher than 0.25 diameter
Dark blue = displacement higher than 1 diameter

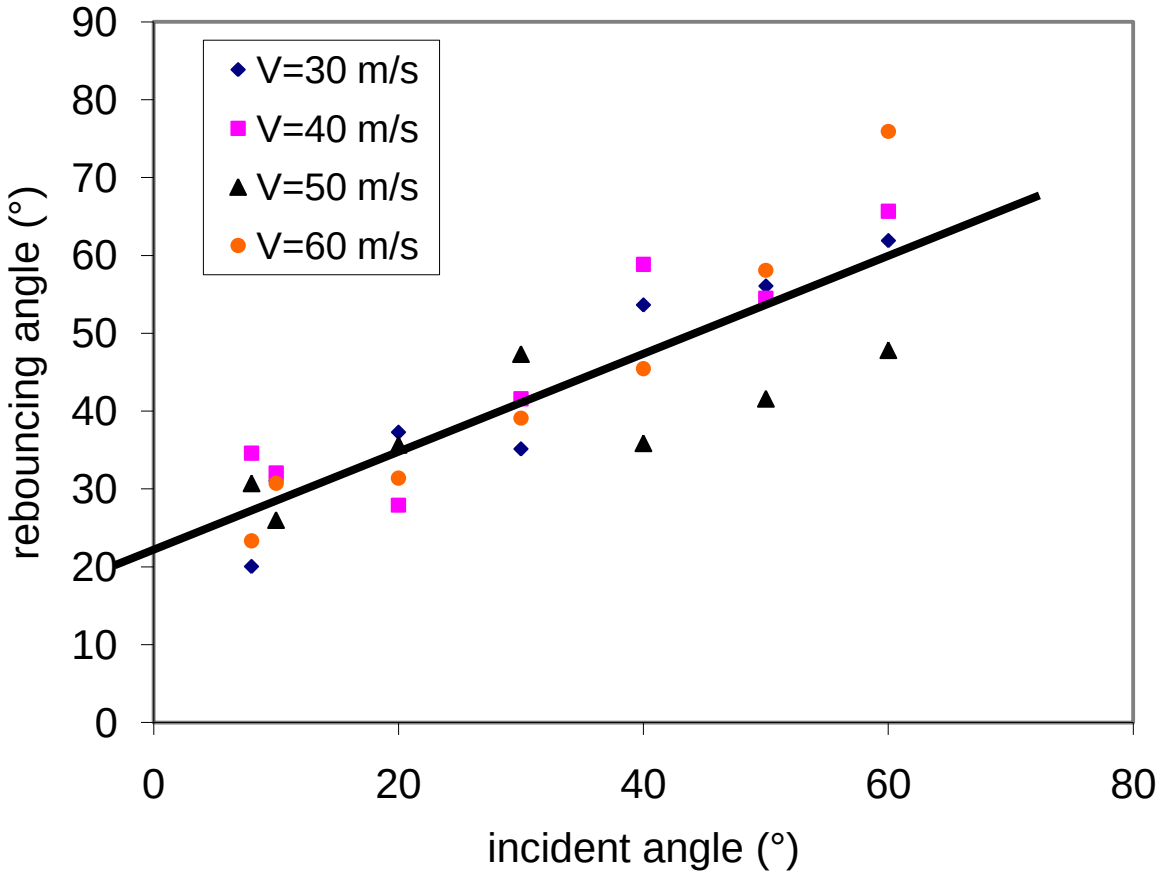
DEM approach

(Discrete Element Method - Soft model)

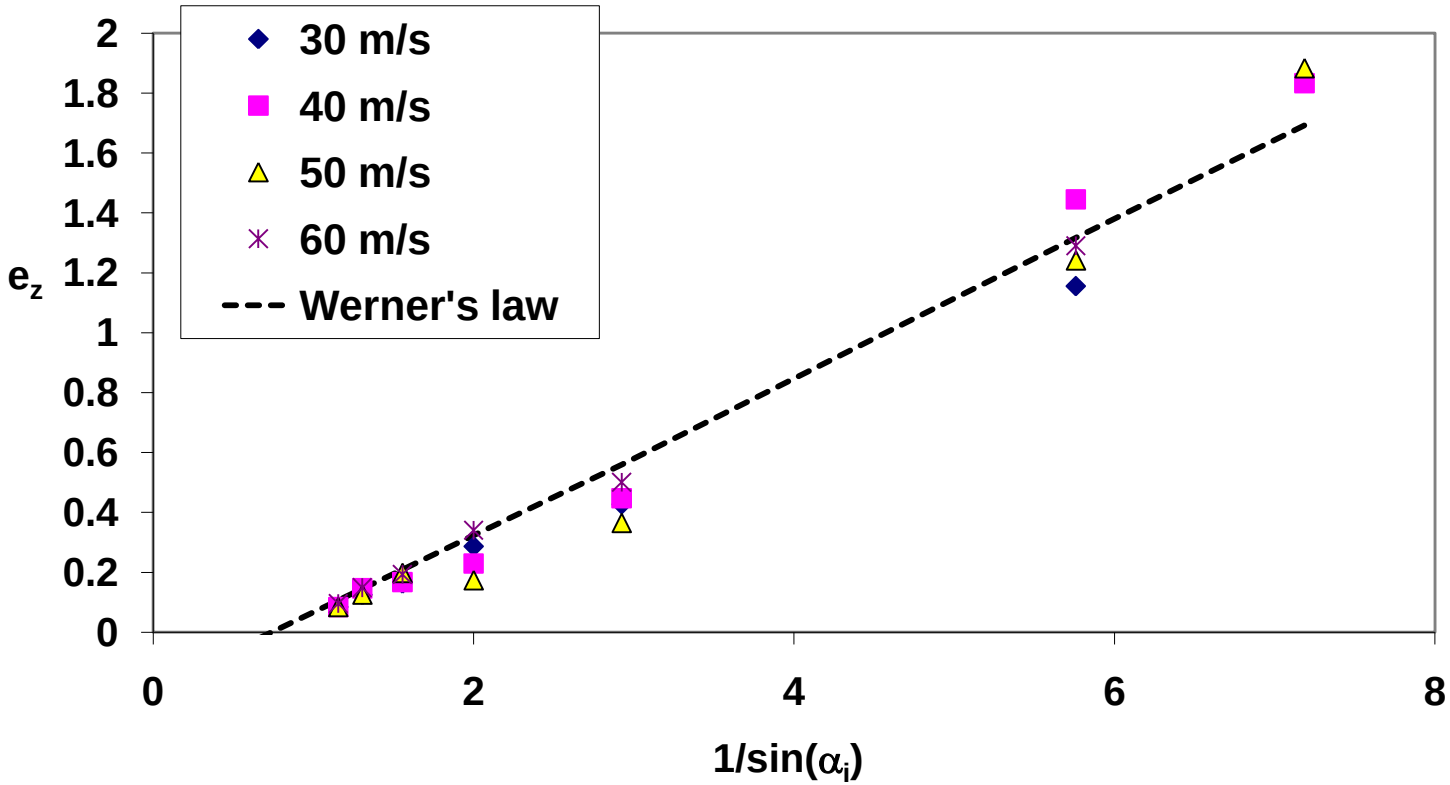


Colors correspond to different displacement amplitudes

Analysis of the rebound of the incident bead

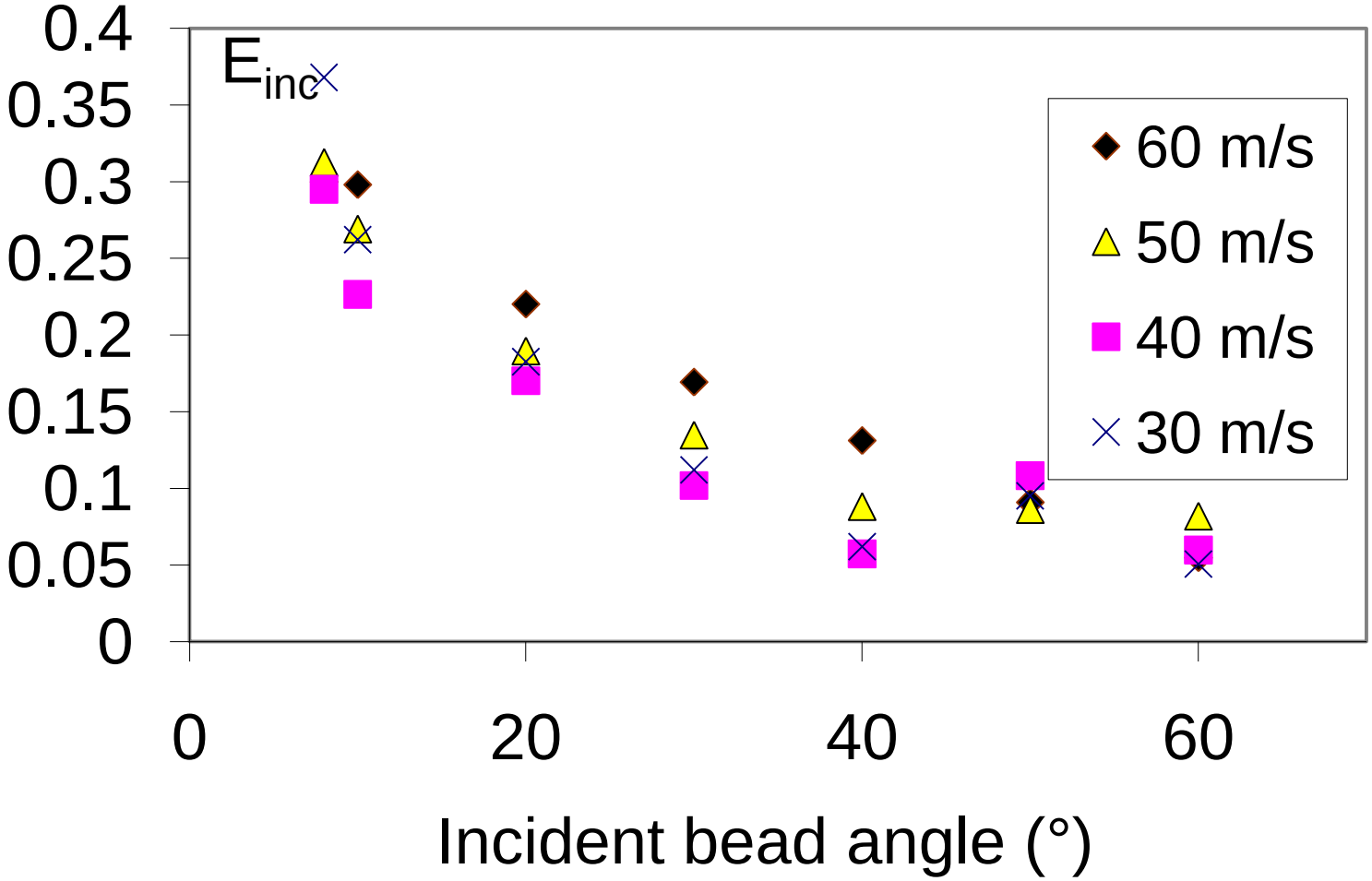


Vertical velocity restitution

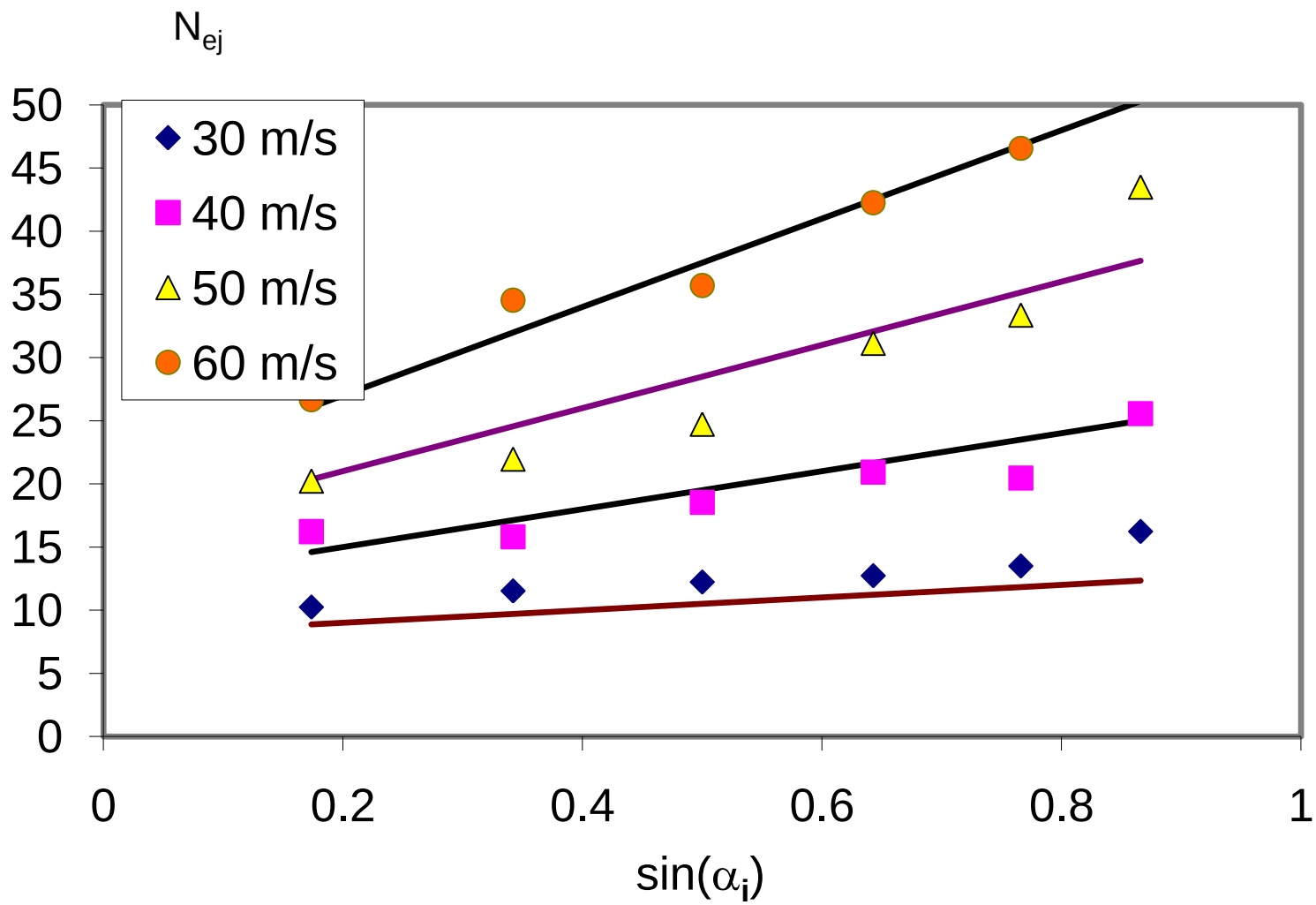


Werner's law: $$\overline{e_z}(\alpha_i) = \left(\frac{0.320}{\sin(\alpha_i)} - 0.236\right)\overline{e_z}(15°)$$

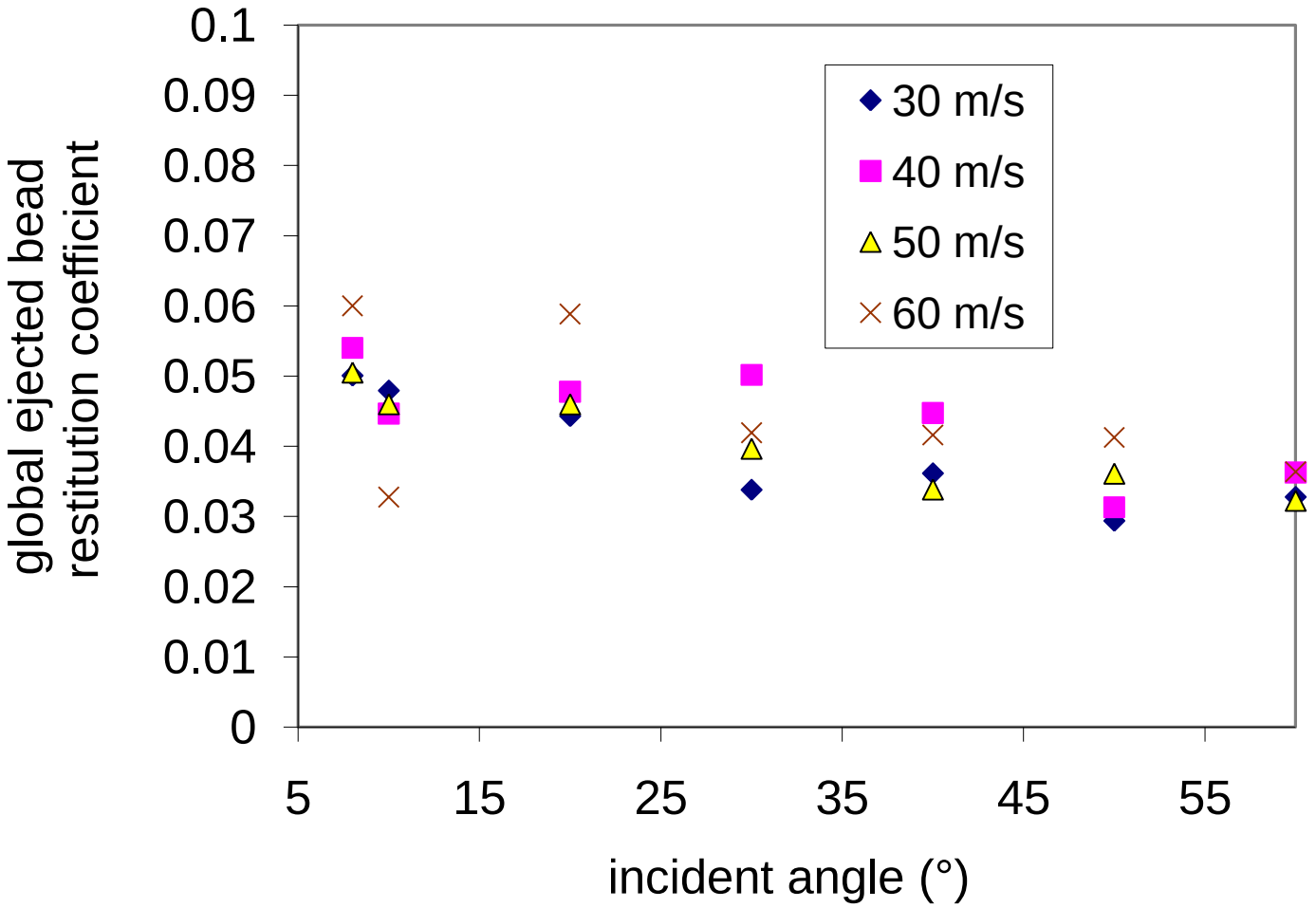
Global energy restitution for the incident bead



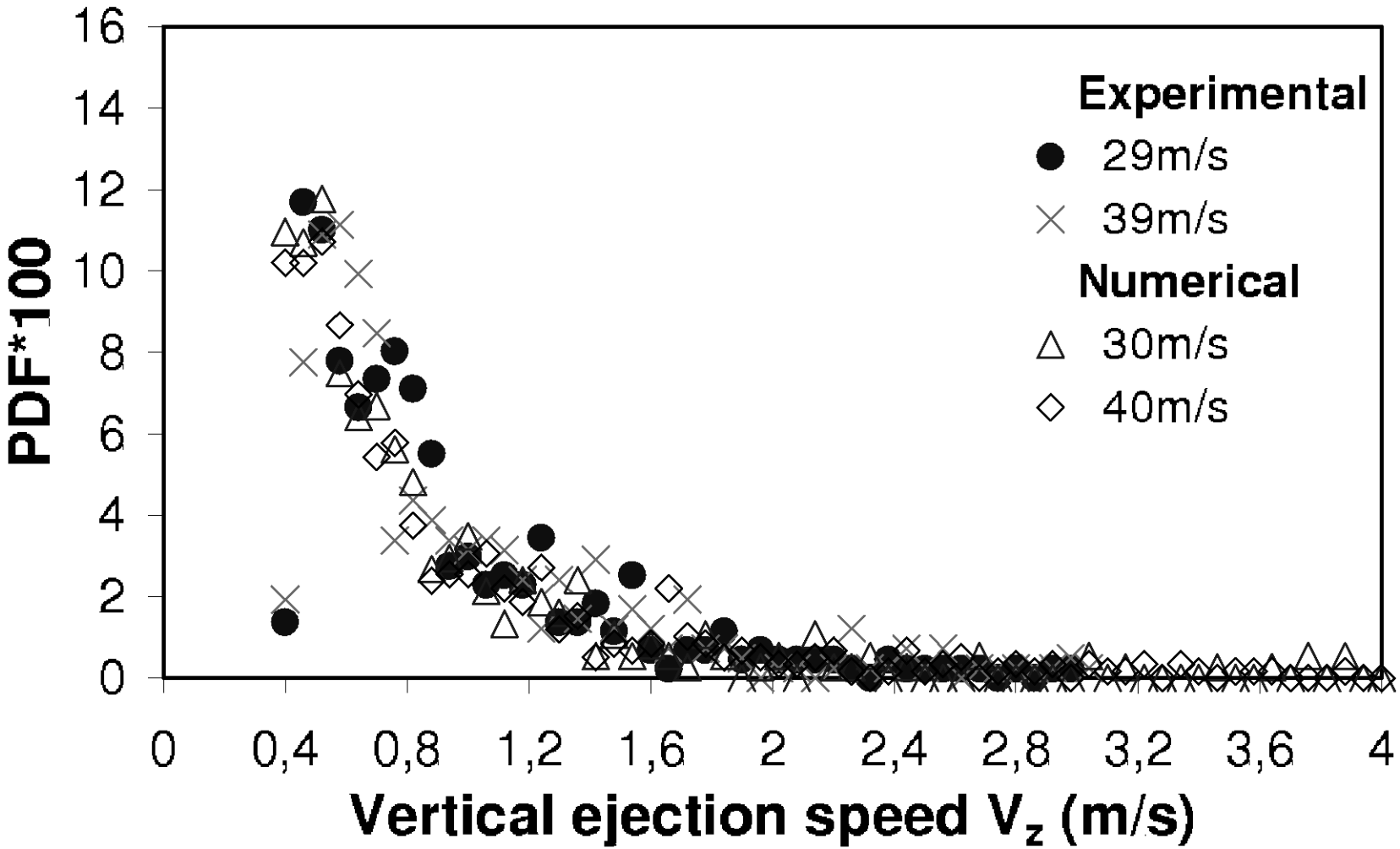
Number of ejected beads



Energy of the ejected beads



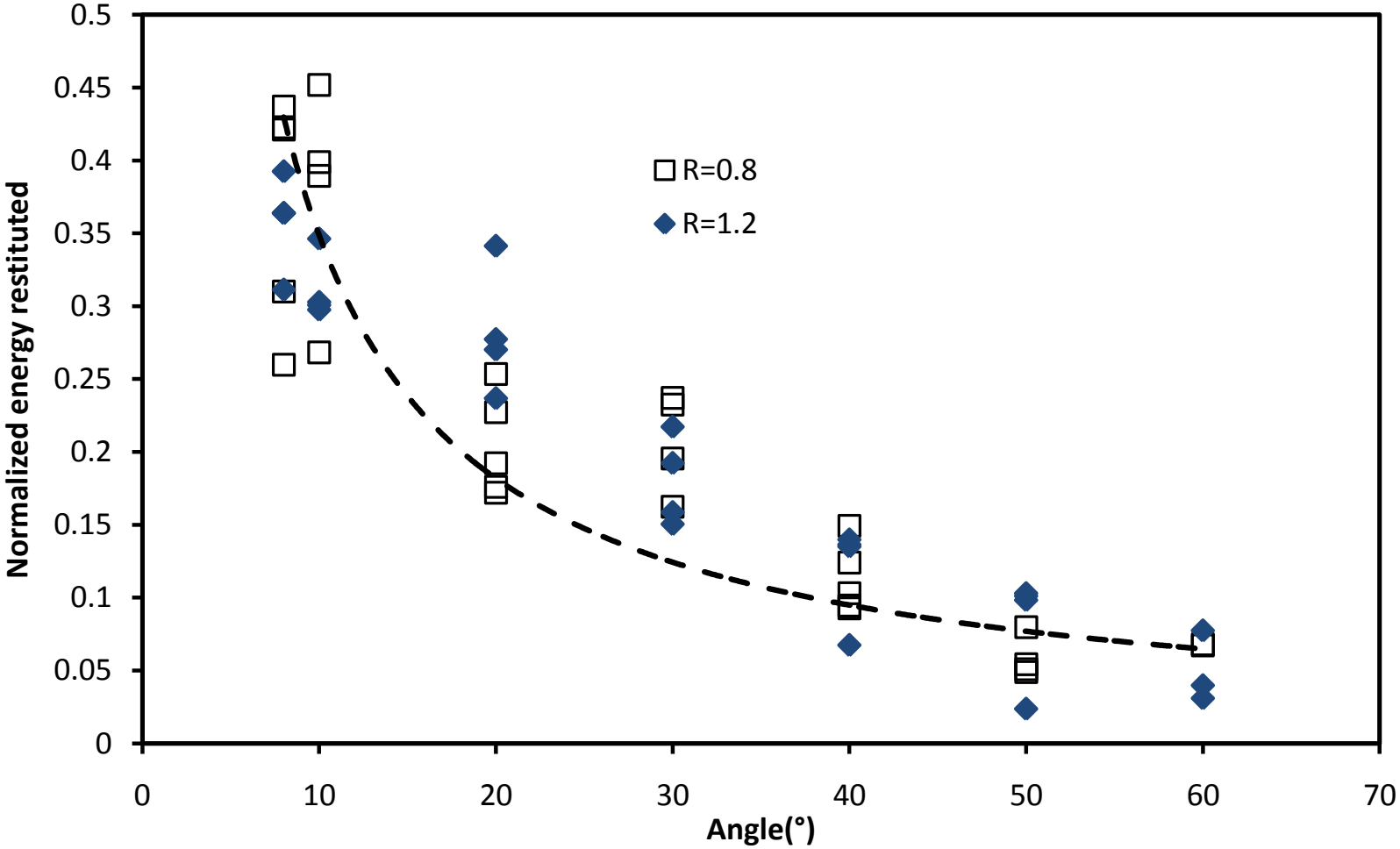
Comparison between experimental and numerical results



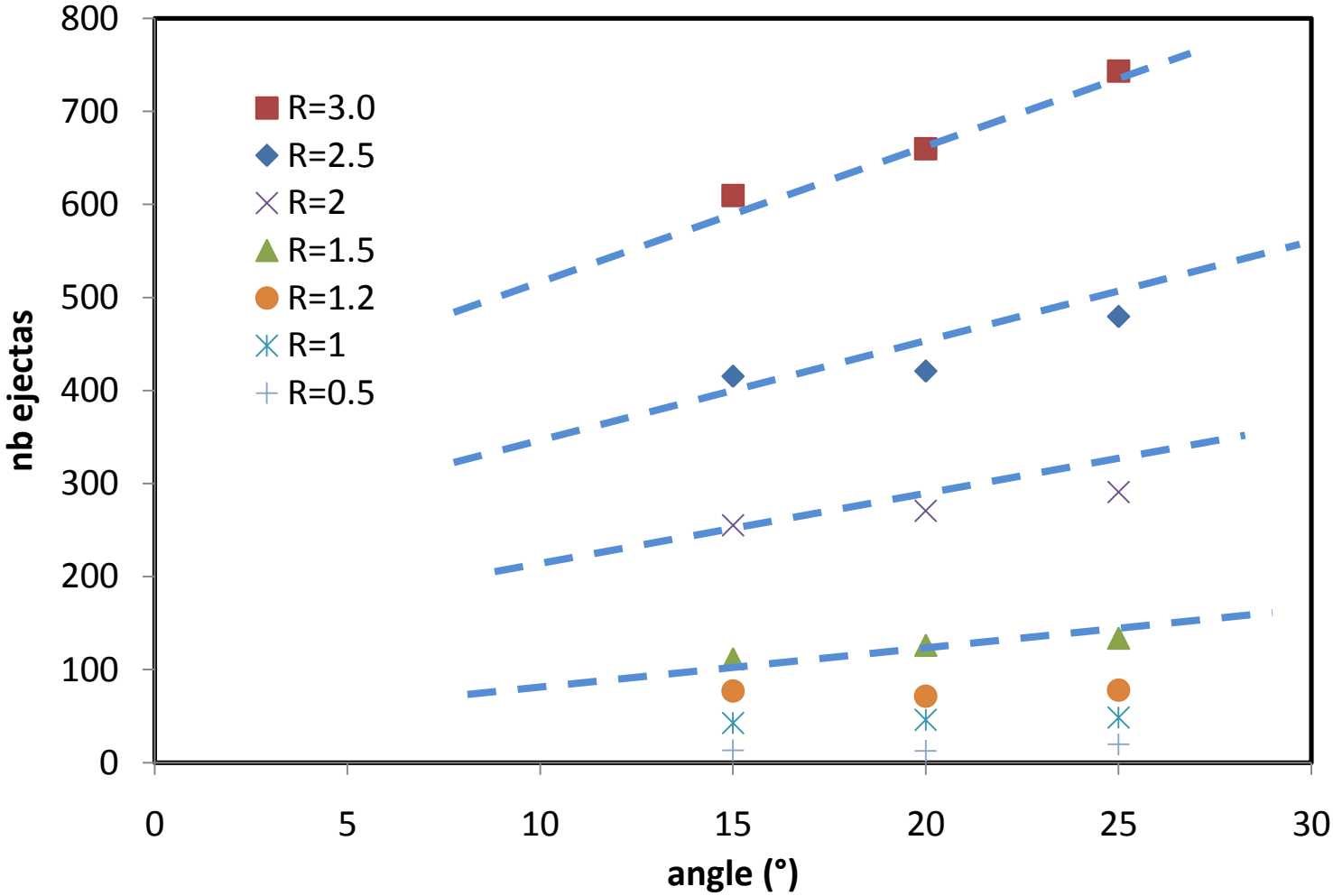
But with different sizes!

- Monosize or binary packing of sphere
- Size of the impactant different (0.5 up to 4)
- Variable velocities and angles

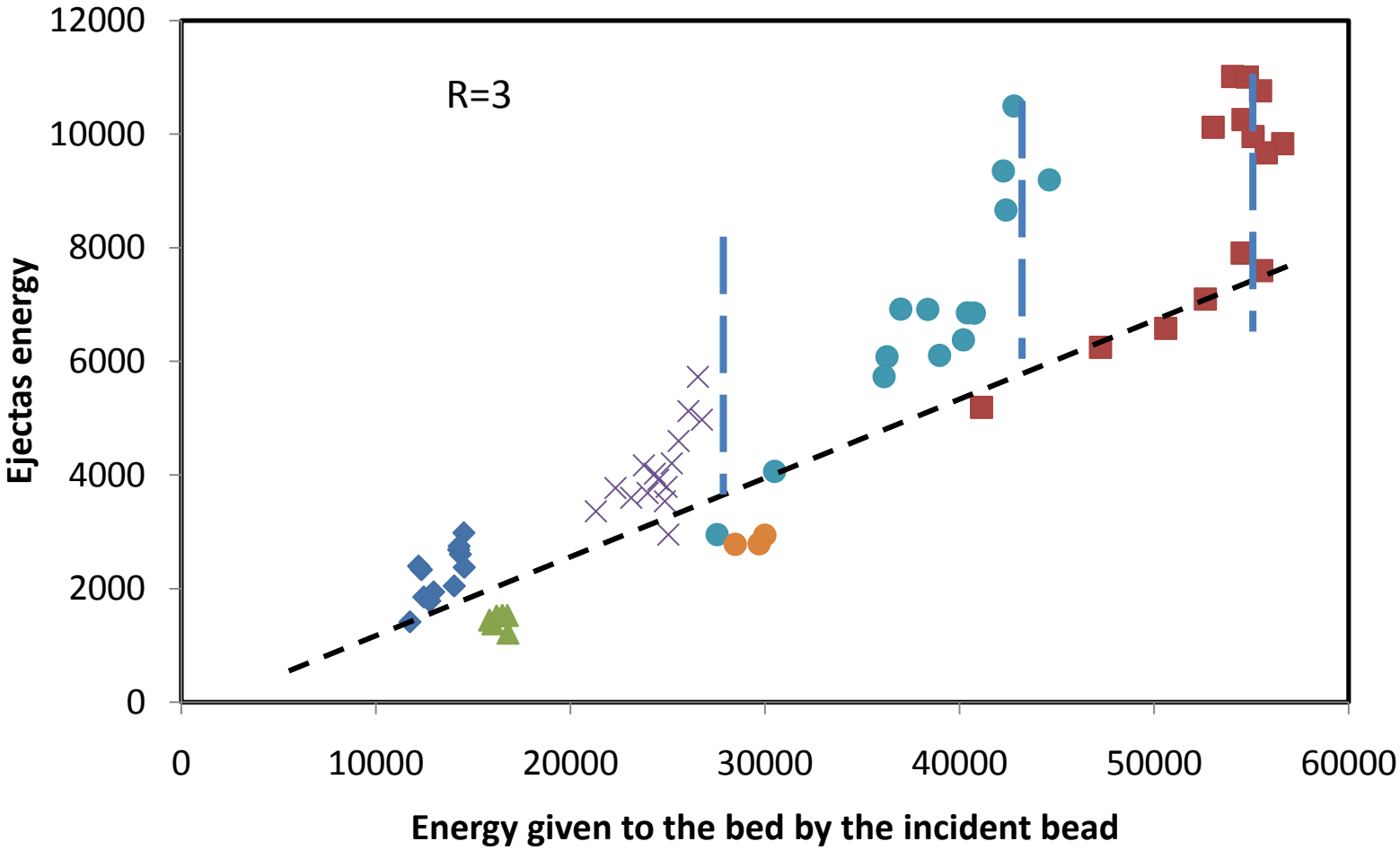
Incident bead



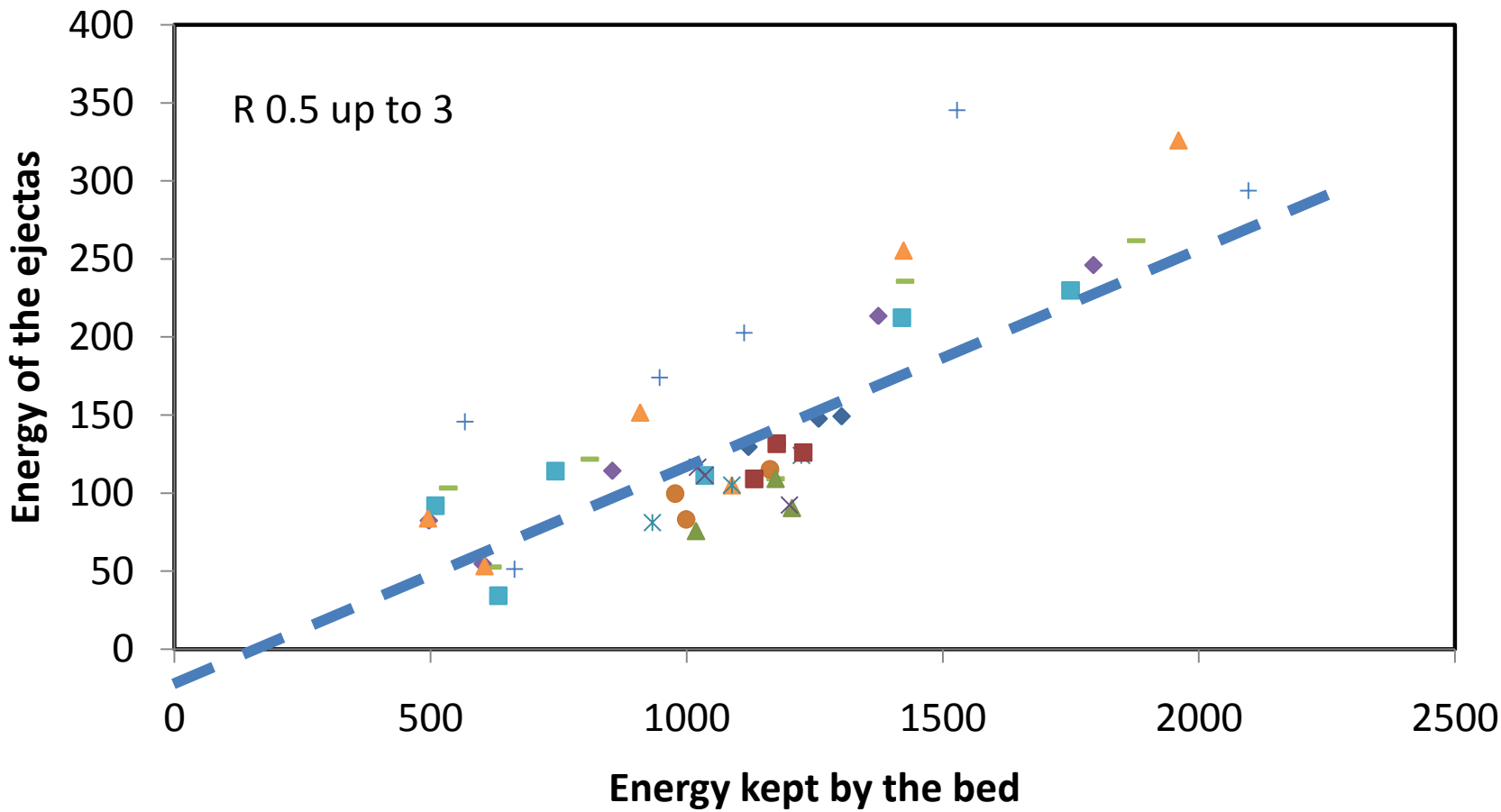
Same impact velocities, different sizes



1 symbol = 1 run for 1 velocity



For different size ratio, angle and impact velocities



§3: Concluding results on SPLASH function

- Depends on :
  - angle
  - shot velocity
  - Coefficient of restitution of the grains
  - Coefficient of friction of the grains
  - Initial packing fraction of the grain bed
  - And so on…

Easy to analyse on single shot

§4: Dry saltation problem

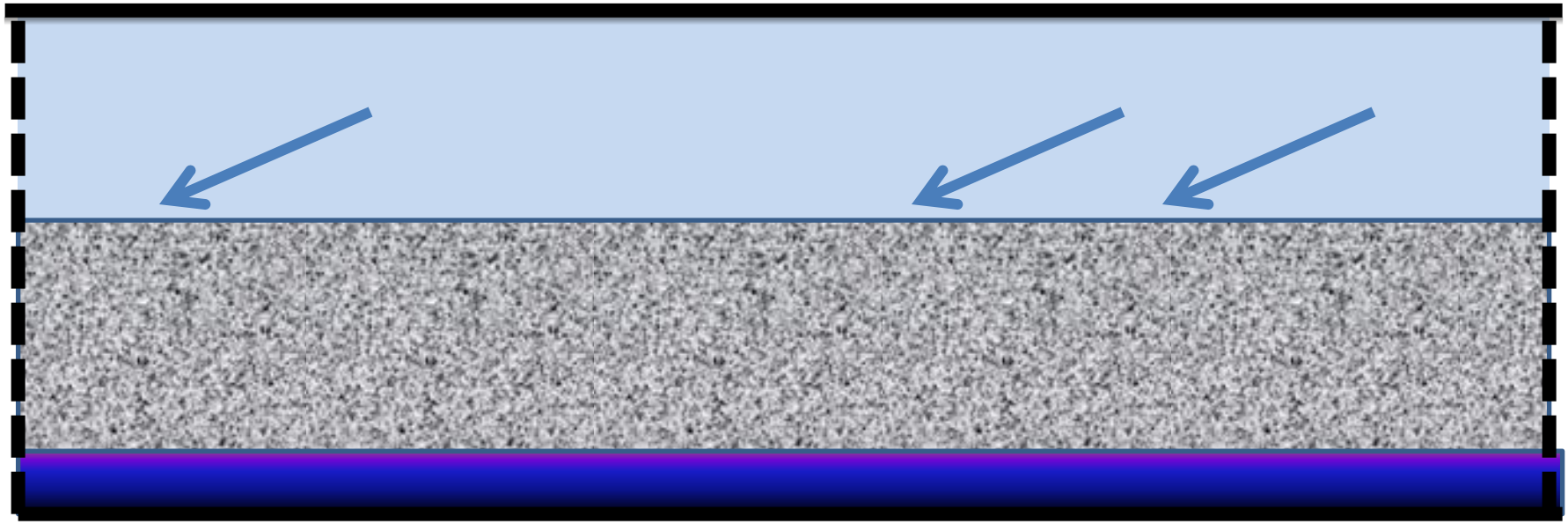
If 3D analysis:

- Too CPU consuming (i.e. too many particles)
- Problems for the periodic boundary
- Definition of the impact zone too wide

If 2D analysis:

- CPU time reasonable
- Periodic boundary on one direction
- Impact zone clear

2D saltation model assumptions



Horizontal boundary conditions
Full progressive dumping (v_x et v_y) in depth on SP= 20. x Rayon)
Upper perfect mirror (at H=250 x Diameter)

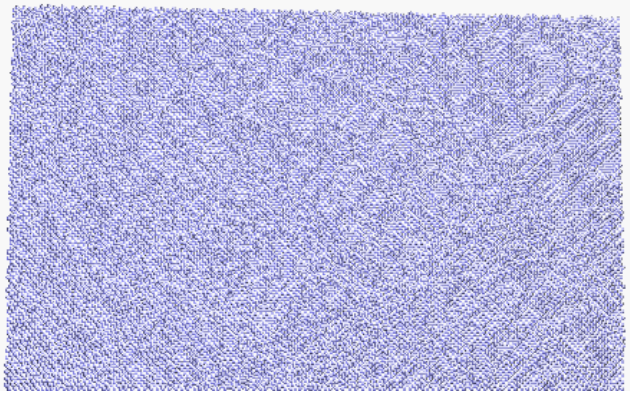
Defined initial shot Angle (10°)
One defined shot velocity for a given run (E_c=cste)
Random horizontal position for the shot (X=random(0,L), Y=Cst)
Interval between shots: T_{mean}+ random(0,1).Δt

Run Conditions

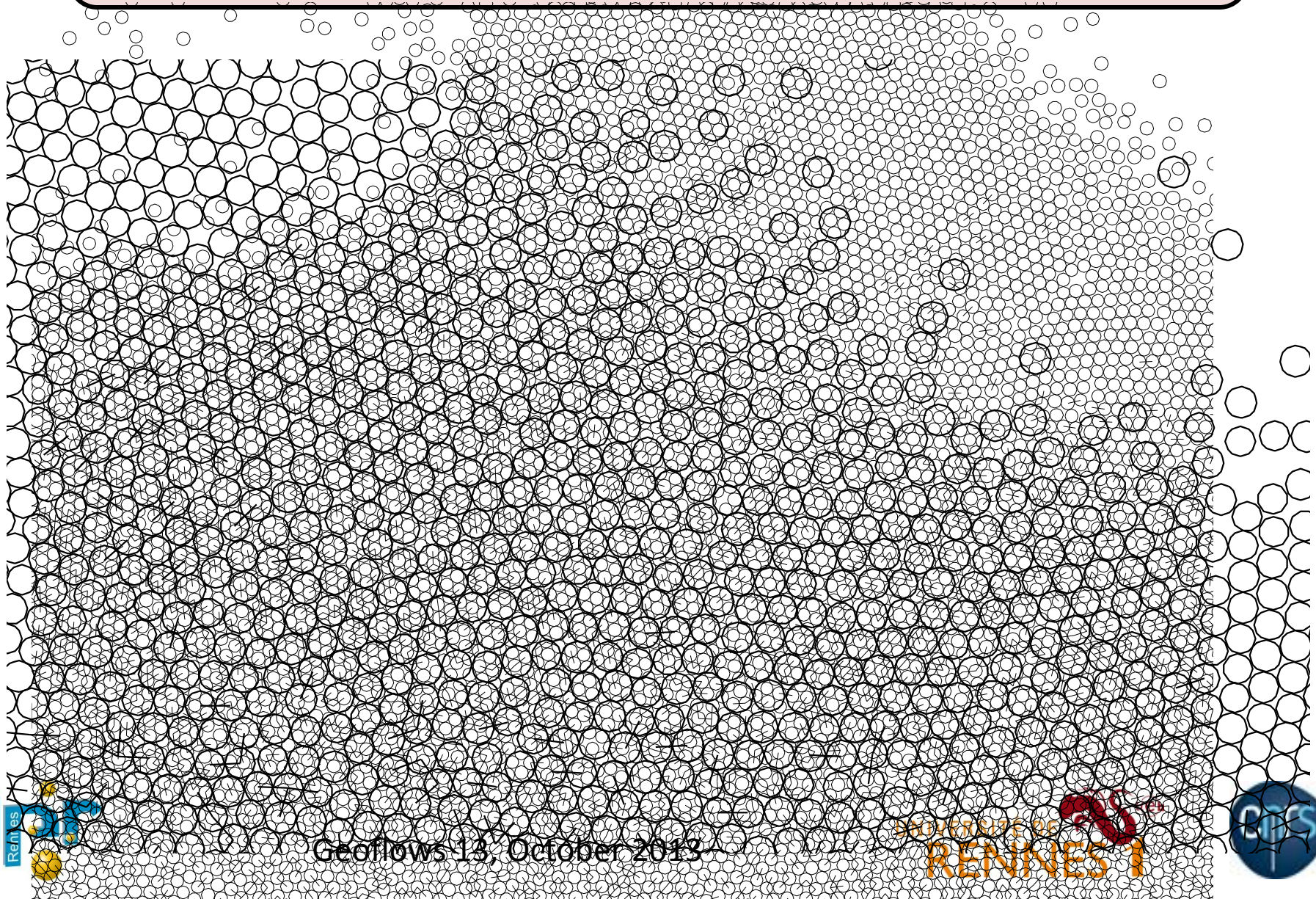
- up to 62 000 disks in 350 disks on X direction
  and 180 disks on Y direction
- Mirror at Y_{max}= 250 disks
- restitution Coefficient = 0.8
- Shot Angle =10°
- Disk diameter = 250µm (sable)
- Shot velocities between 10 and 25 m/s
- Time interval between shots : 25 µs to 200 µs
- Dumping-factor(a=0,4 & SP=25xR)

$$DF= 1-\{a(1-y/SP)^3 +(1-a)(1-y/SP)^6\}$$

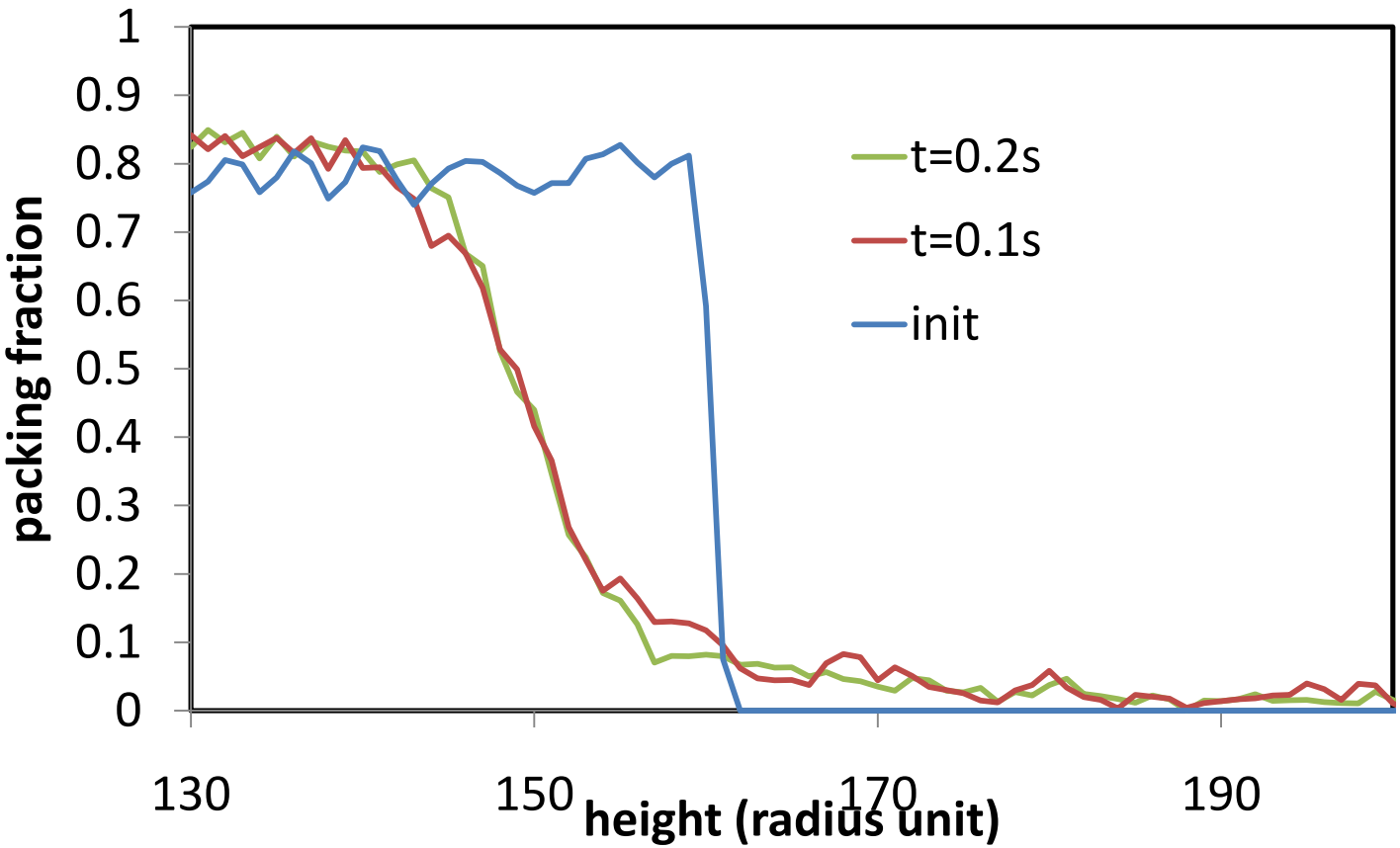
Continuous movie of sequential shots



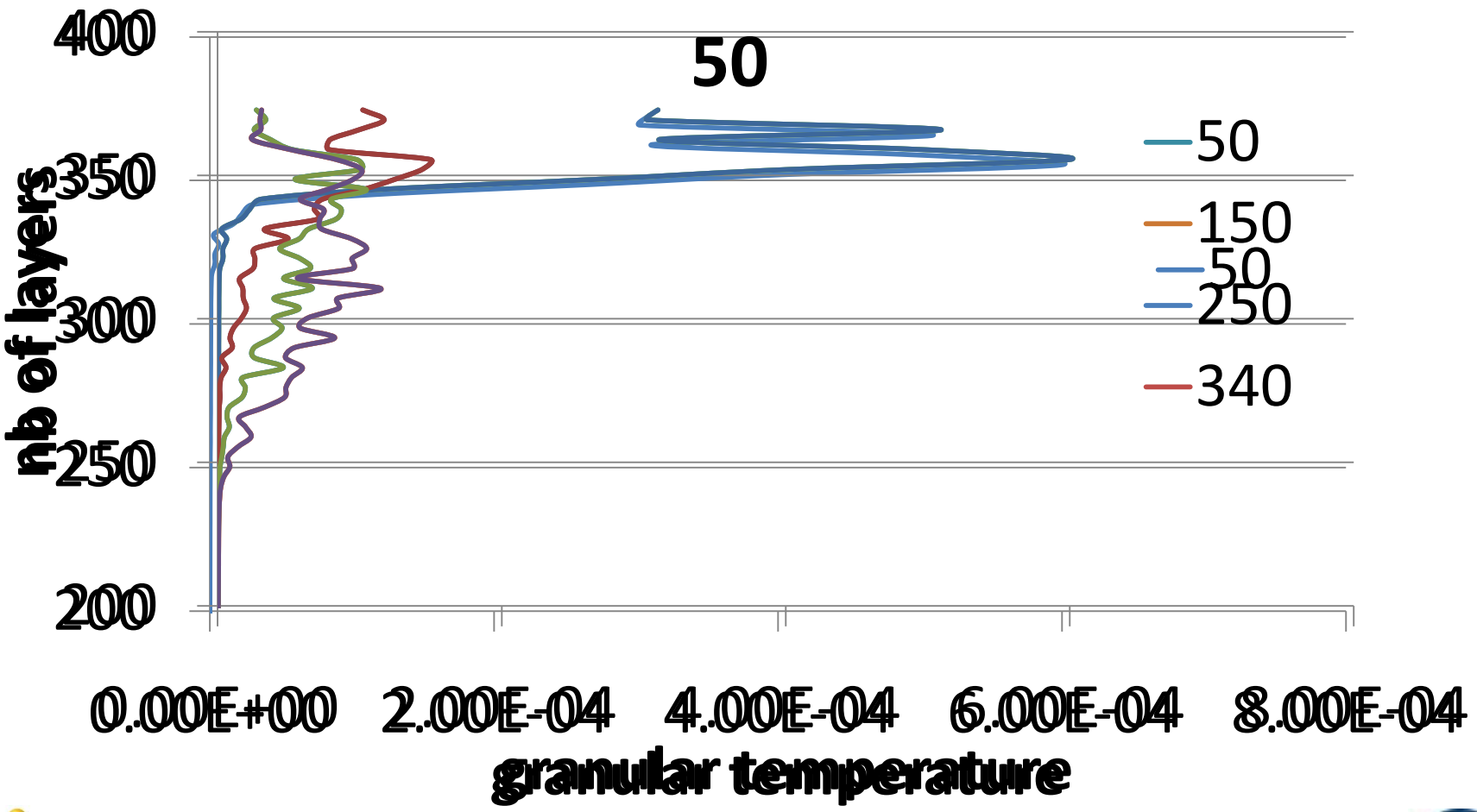
Force network inside the bead bed



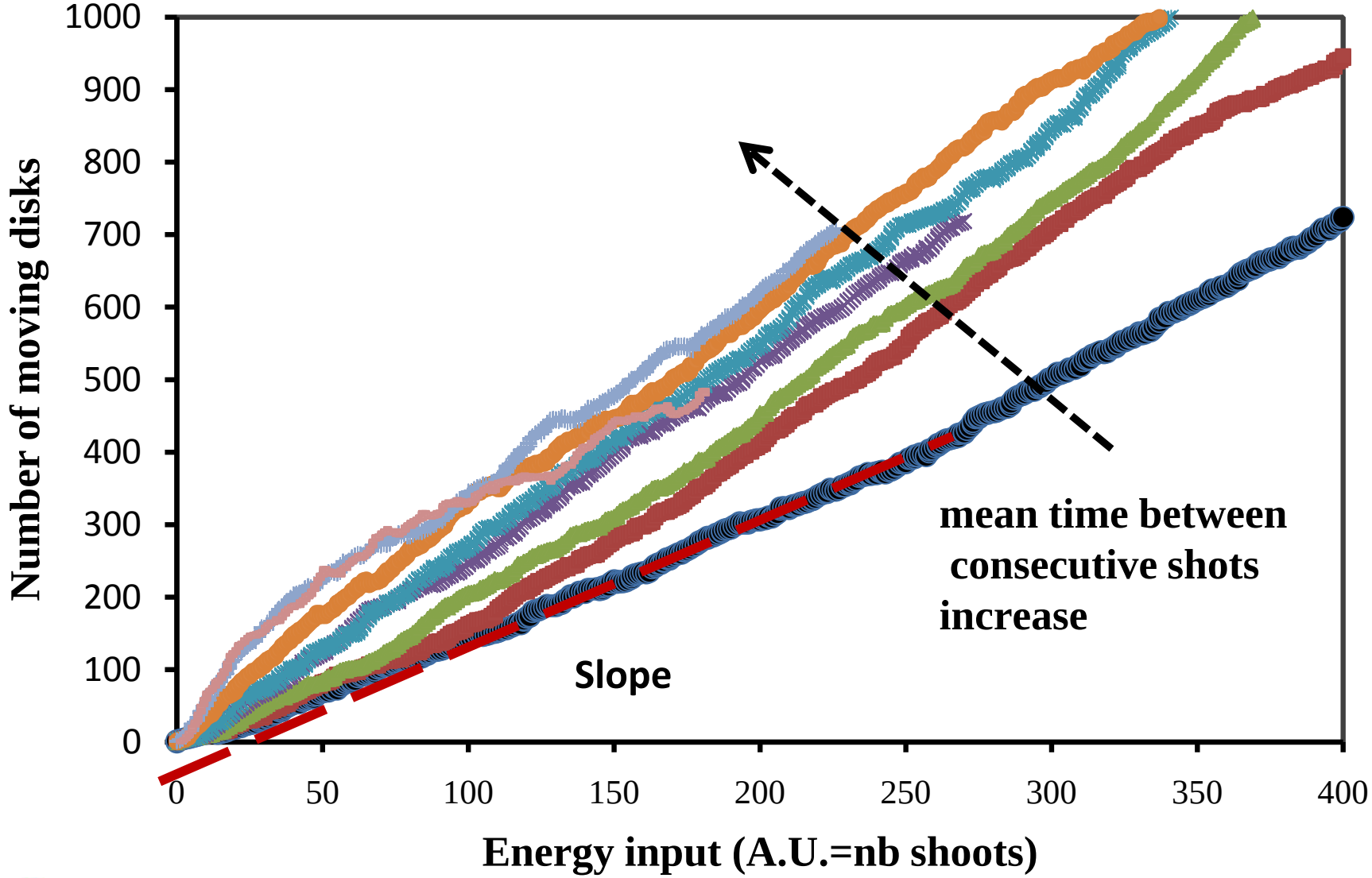
Packing fraction



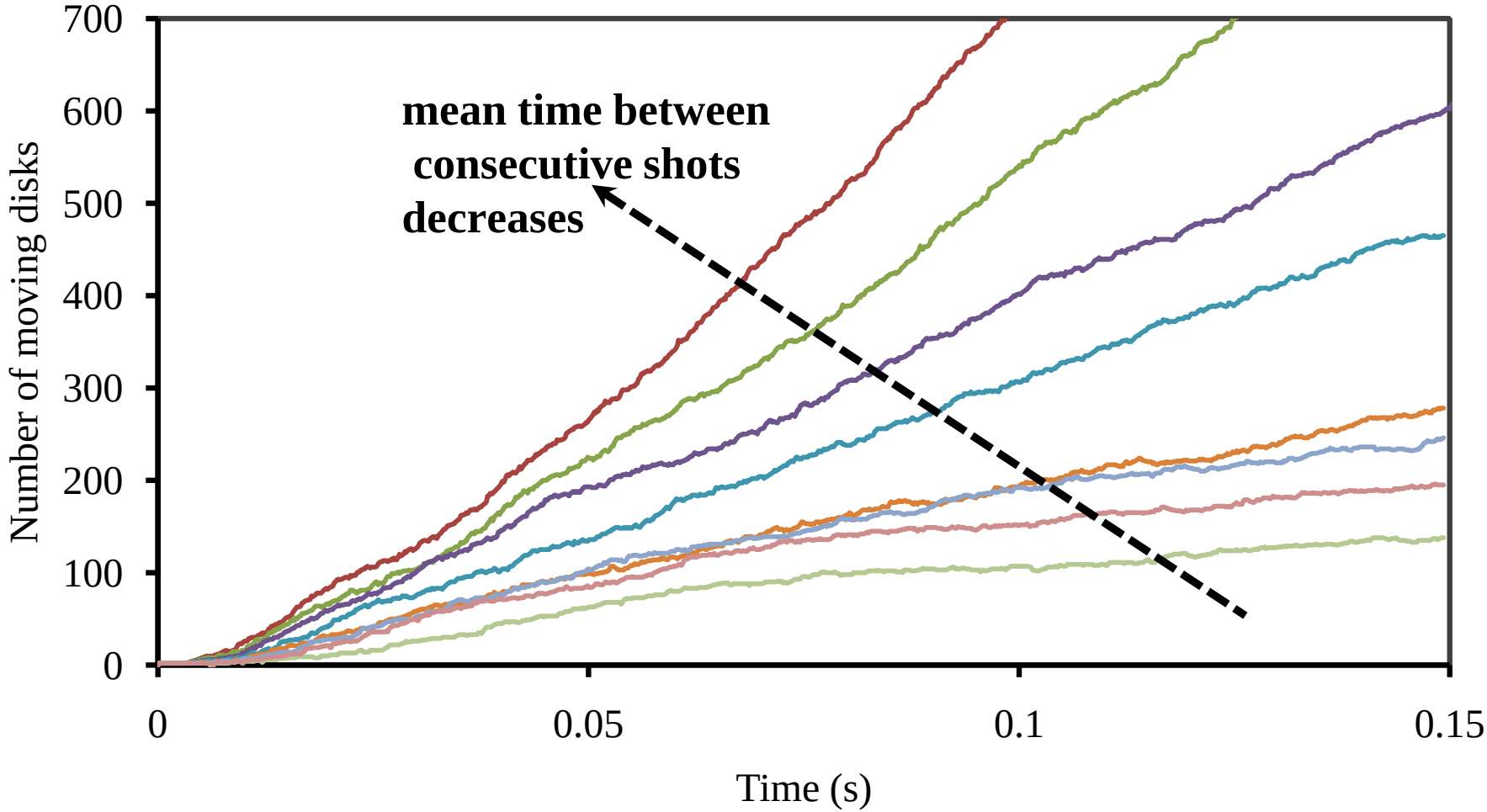
Perturbated Layers



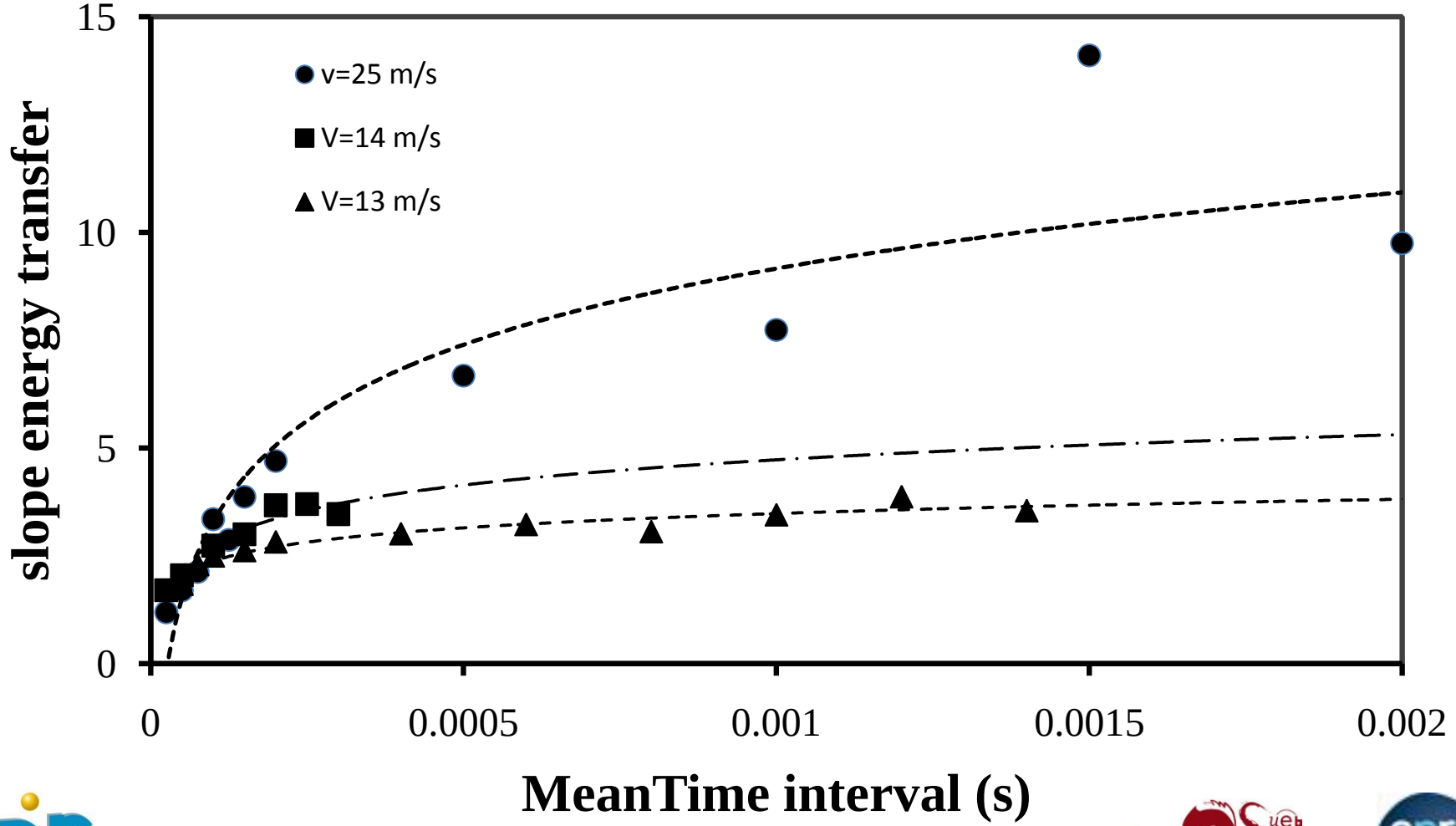
Evolution of the moving disk amount



Moving disks



Energy restitution efficiency



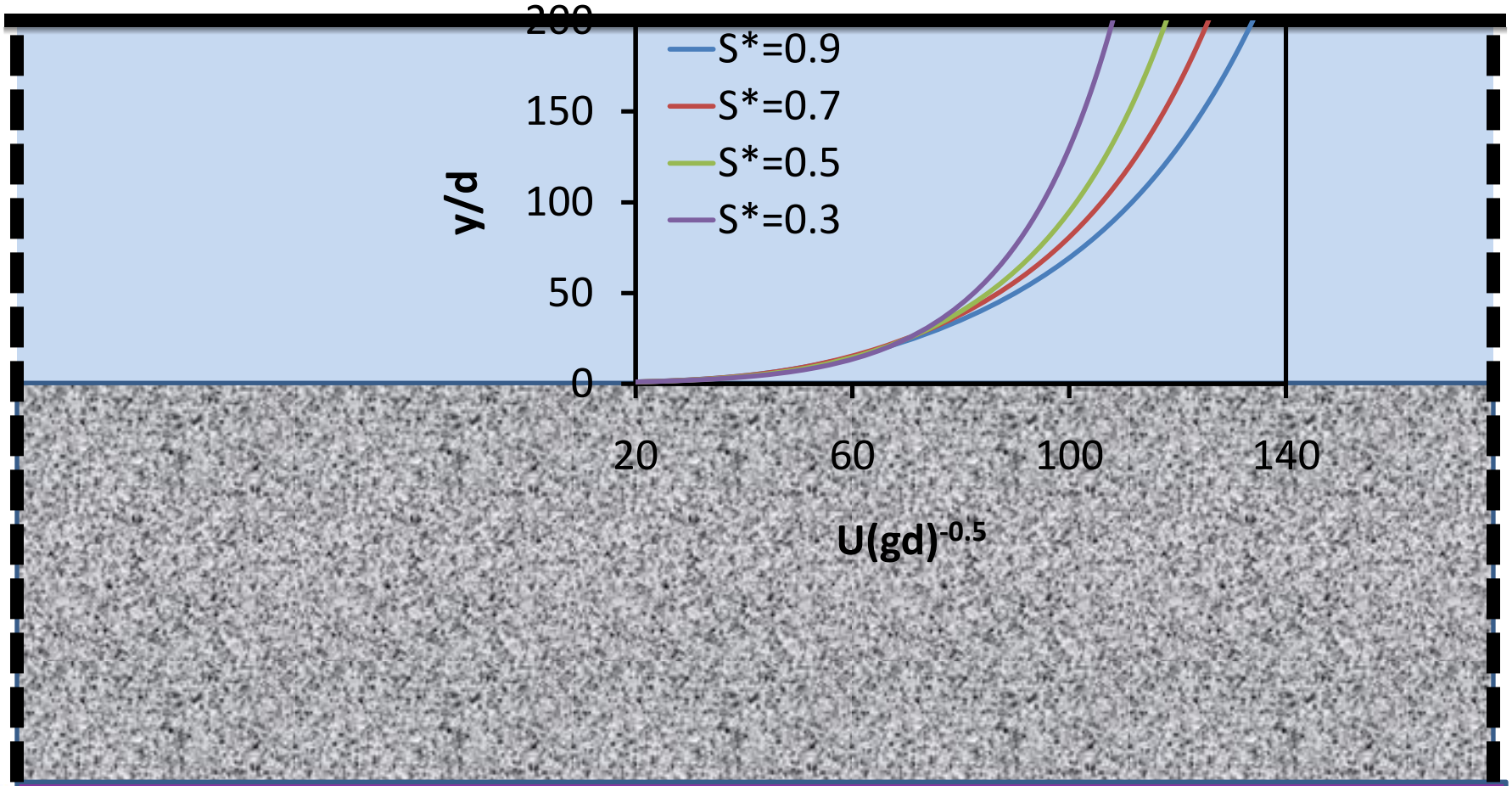
§4: conclusions

- The analysis of the saltation process cannot be deduced from the classical results of the 3D “Splash function”

- The initial saltation process needs a large amount of energy to mobilize the upper layer of the dune

- The conservation of the moving saltation region needs less energy than the initiation regime

§5: with wind interaction



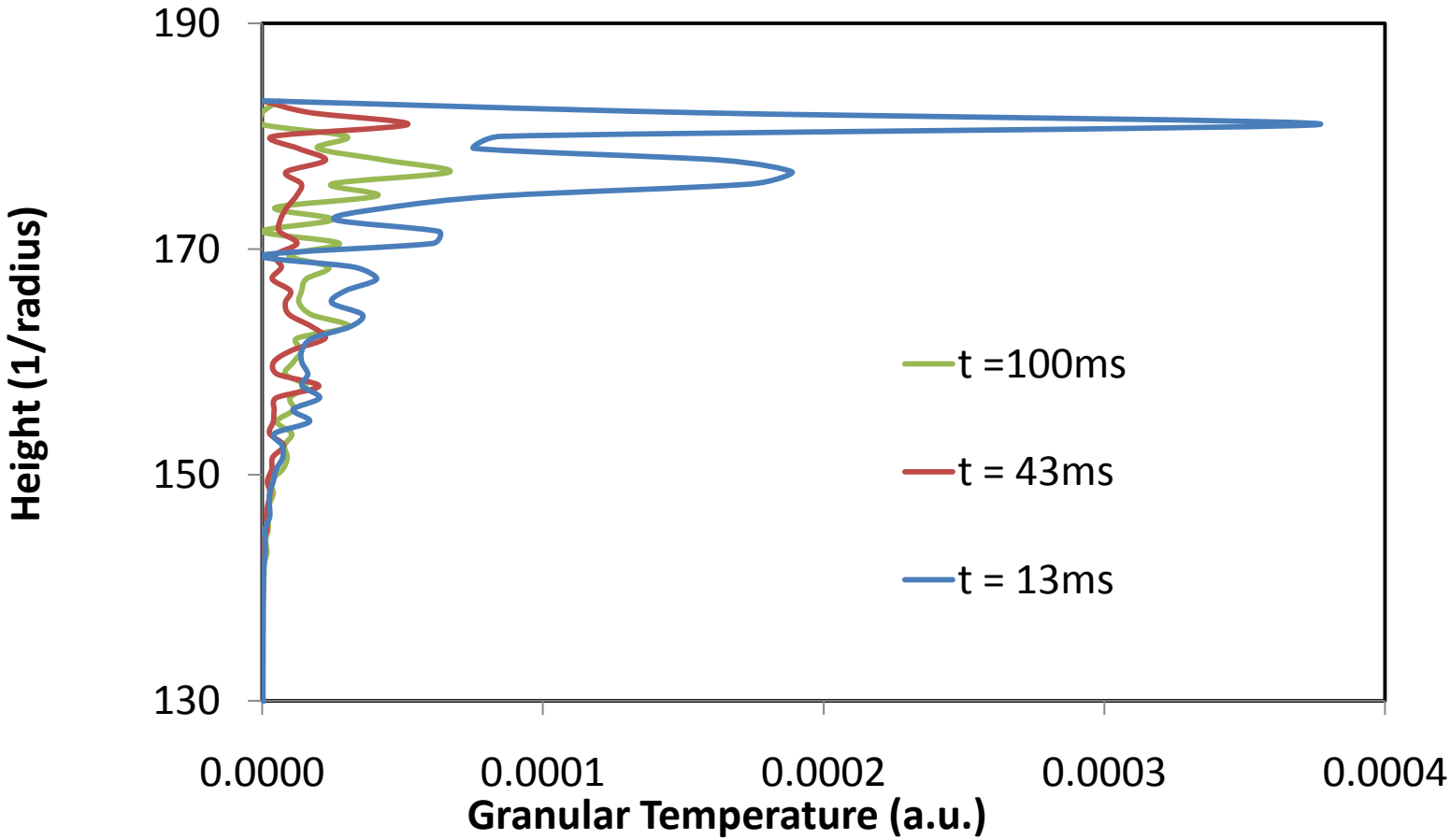
Practical conditions

- Initial shot of N given disks at a given initial velocities and angles and variables time intervals.
- Given initial wind velocity profiles according to Creyssels et al (JFM 2010)

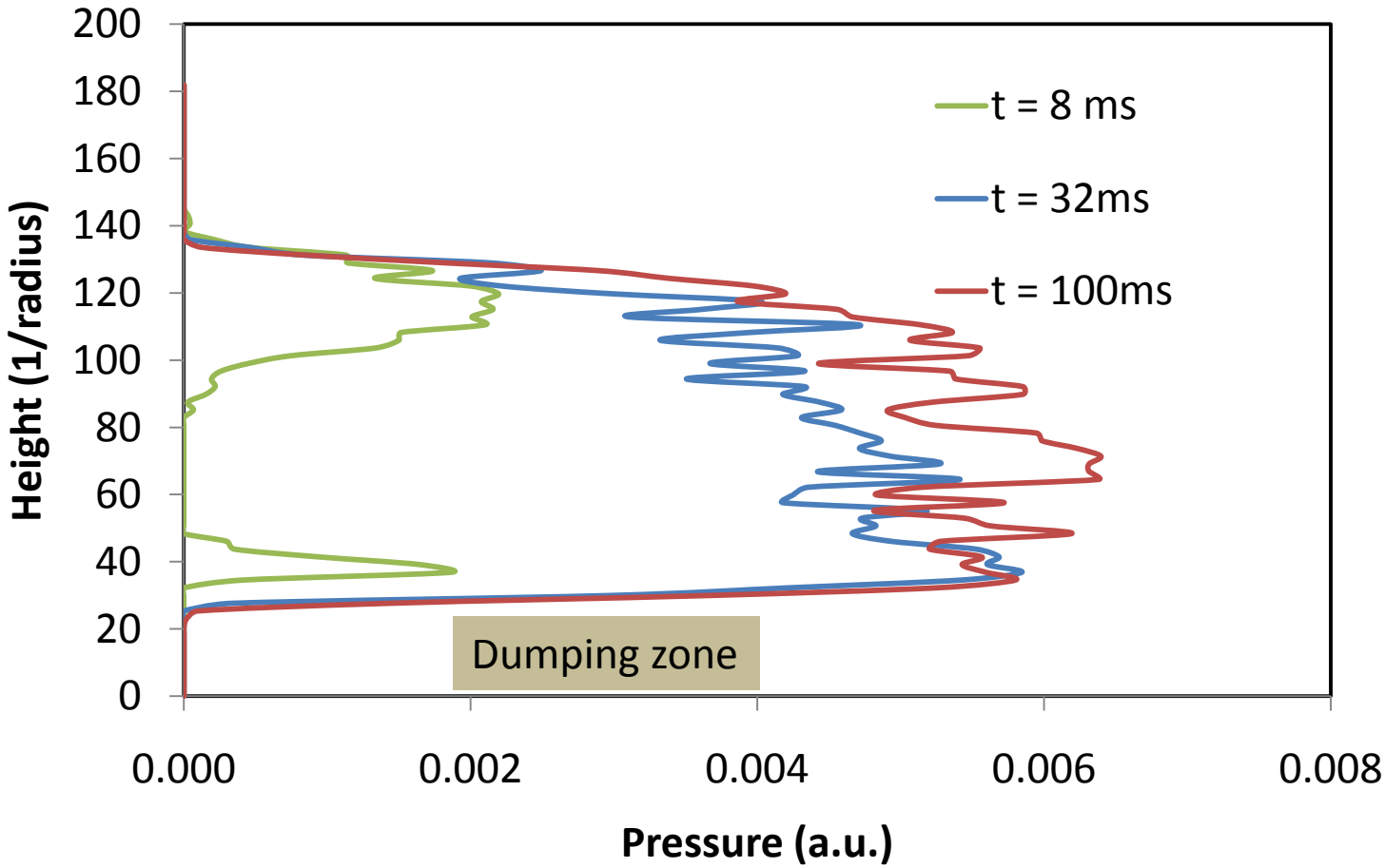
After a given number of time steps : equilibrium time

- calculus of the real grain pressure profile
- Wind velocities profiles according to the grain pressure

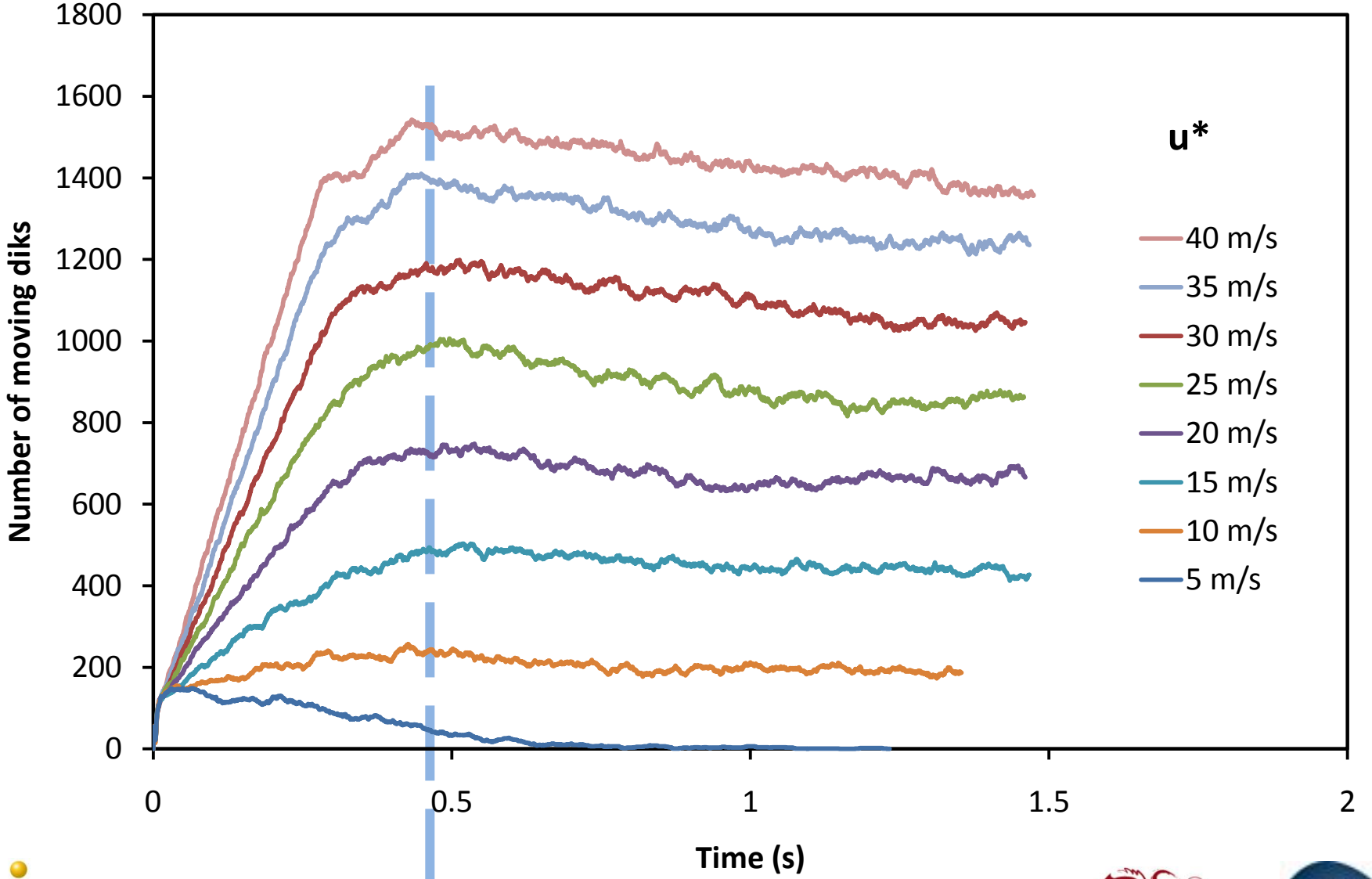
Granular temperature



Pressure vs height

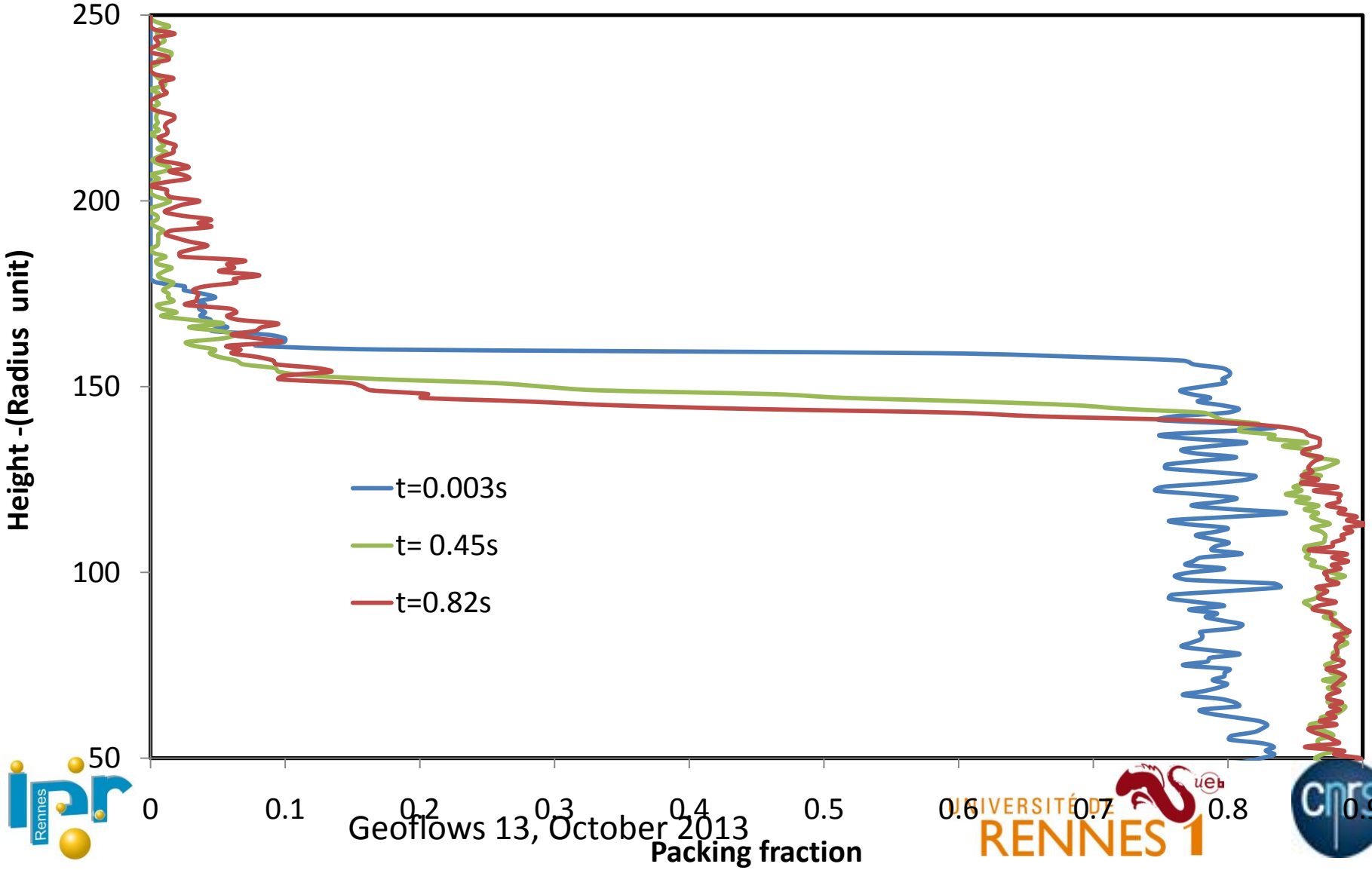


Constant wind velocity profile

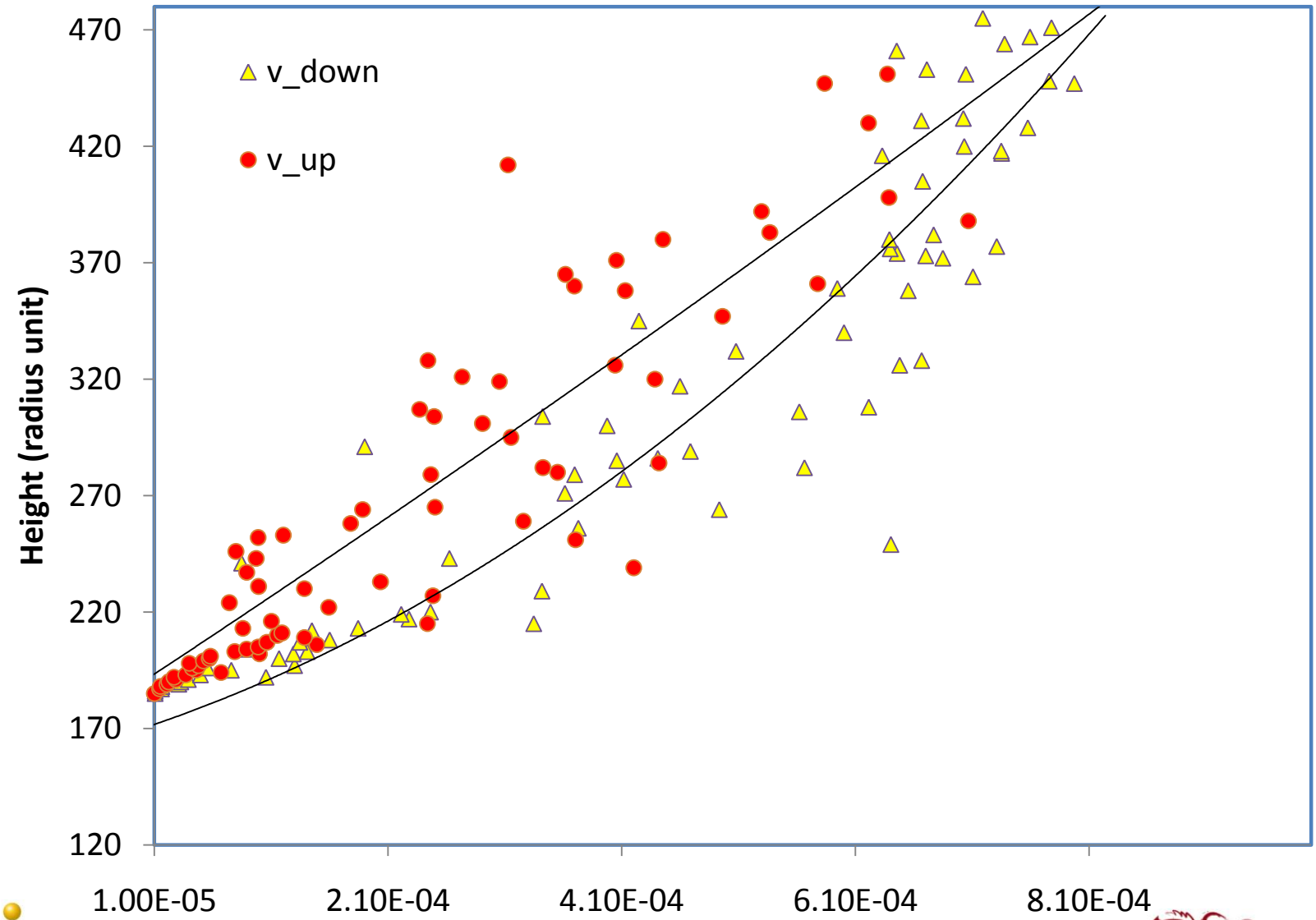


Threshold for established flux-→ possible calculi of wind coupling

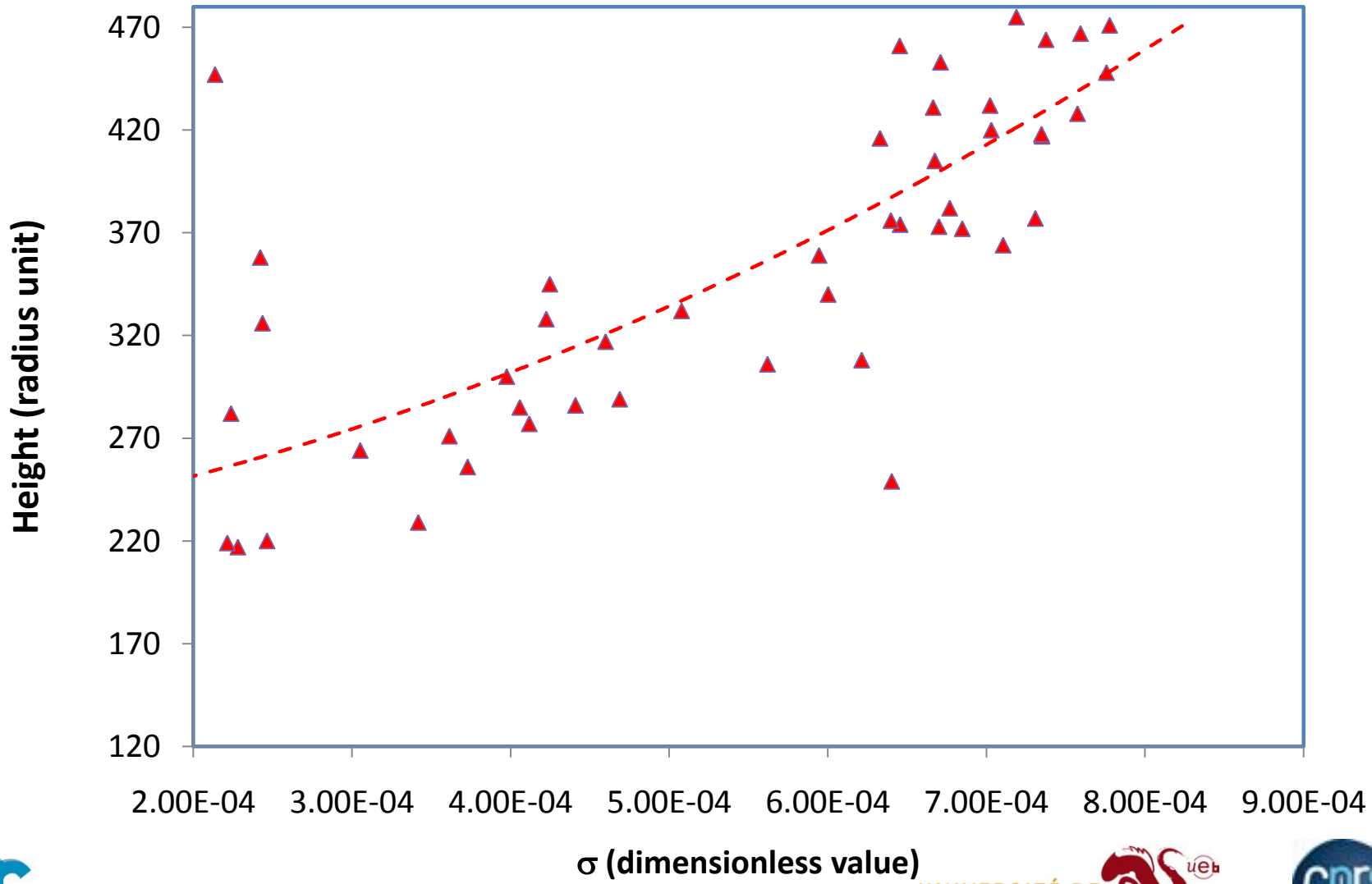
Profile at different times



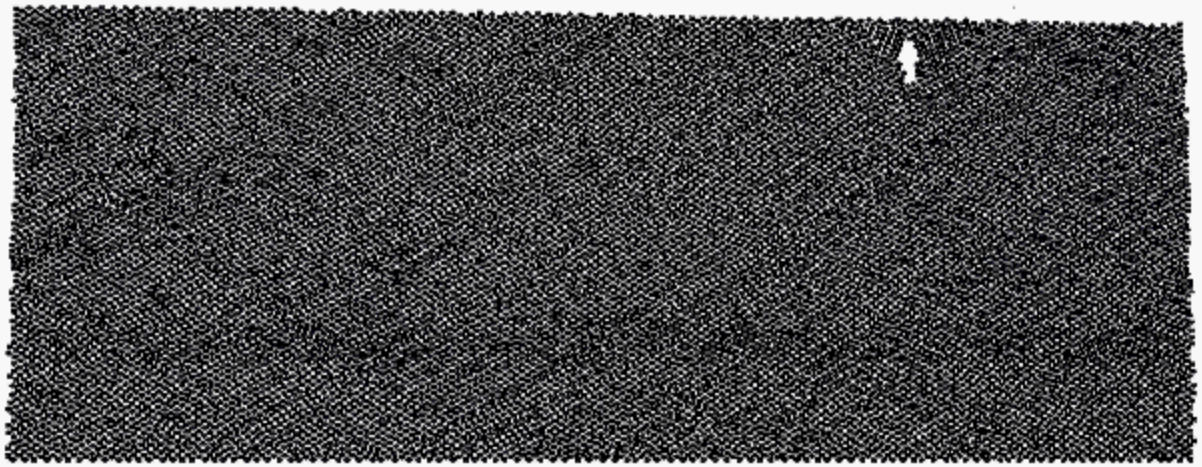
V_{up} & V_{down} when stabilized



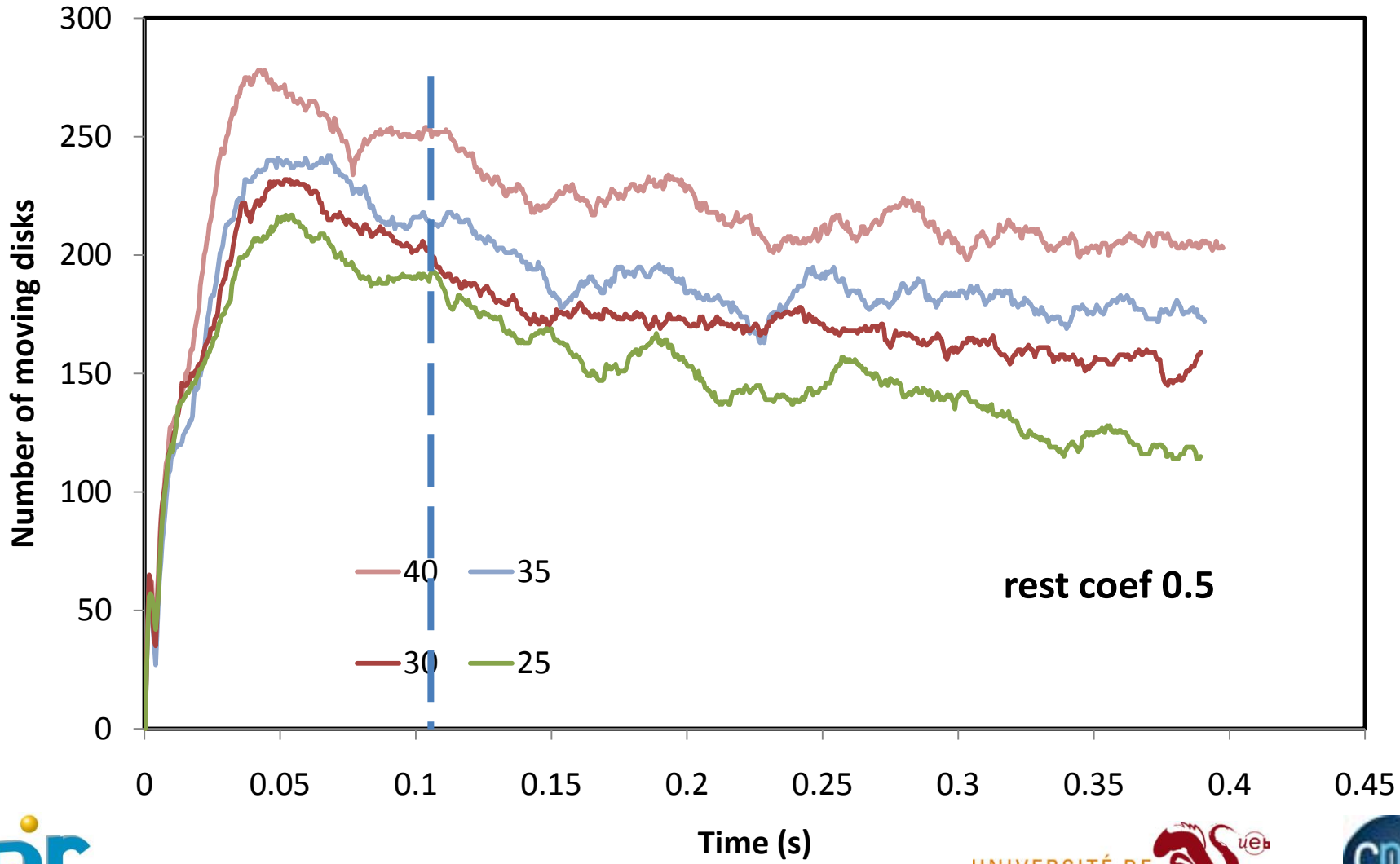
Calculus of the pressure



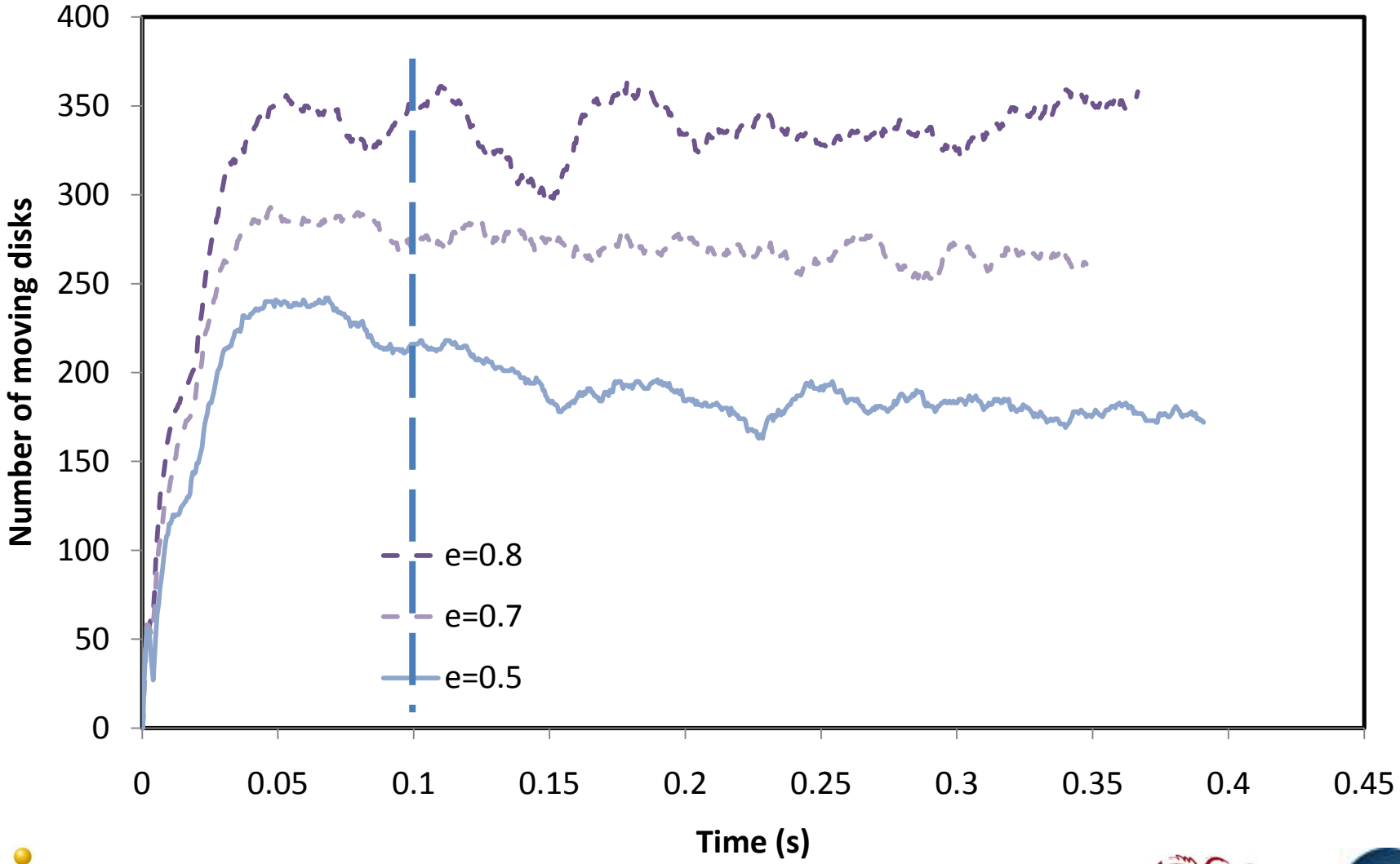
One full run for 16000 disks, restitution coefficient=0.4



Variable wind velocities



Variable restitution coefficient



Conclusions

- **The saltation process can be modeled from the classical DEM code with a simple wind grain interaction and no artificial parameters.**

- **The initial saltation process needs 'some' energy to mobilize the upper layer of the dune but the conservation of the moving saltation region can be controlled classically by the grain characteristics and the wind velocities.**

- **Improvements : local calculi of the wind profile**

Conclusions for §3-5

- Good correspondence between experimental and numerical results are possible

- We can and we do use the real mechanical and physical parameters of our granular problems to make a correct numerical and experimental comparisons

- some improvements can be made by adding extra effects such as :
    - Humidity
    - Electrostatic forces
    - roundness of the grains (rolling resistance)
    - and so on…