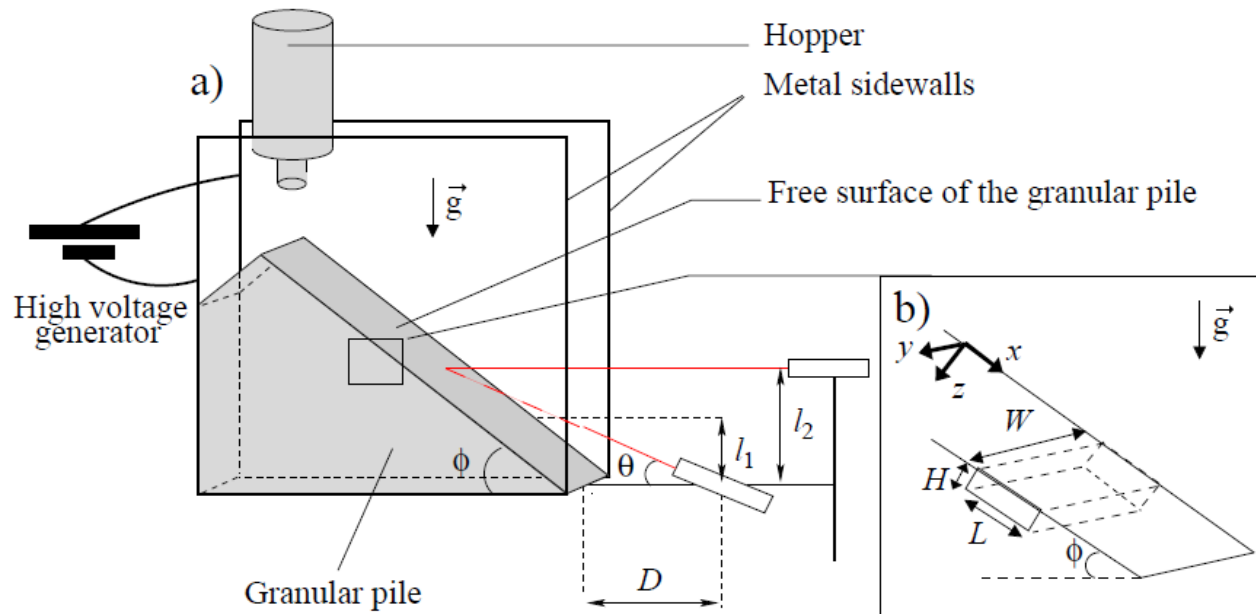


Stabilité et écoulement de milieux granulaires à cohésion contrôlée



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*Rien de stable dans ce monde : aujourd'hui au sommet, demain au bas de la roue.
Denis Diderot (Le neveu de Rameau)*

Granular avalanches

Avalanches are ubiquitous on earth (and elsewhere e.g. mars)
but their behavior is difficult to predict



- Difficult questions for real avalanches in nature...
 - Ø aging, perturbations...
 - Ø The dynamics is not easy to observe
- Can simple experiments help our understanding?
 - Ø Study at the grain scale

Blackhawk landslide (Photo Credit: Kerry Sieh)
5 miles (8 km) long 2 miles (3.2 km) wide

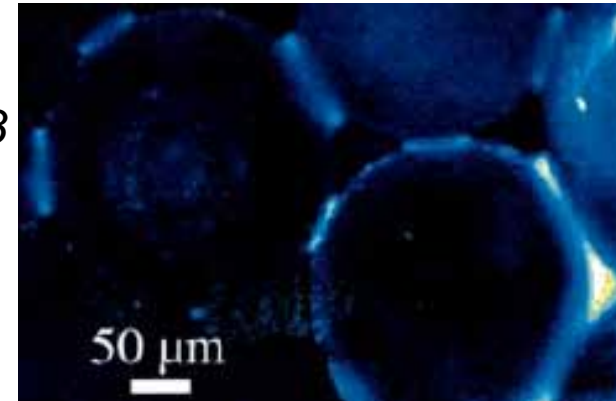
Physical model

Our physical model : glass beads on an erodible surface

Our aim : study the effect of cohesion (stability, flow)

How can we control cohesion?

Humidity : different cohesion regimes *Halsey & Levine 1998*
cohesion depends on the local normal stress



Magnetic forces (*Lumay & Vandewalle, 2007*) : beads need to be magnetic
: residual magnetization

Our approach: use electric forces can induce cohesion even if the grains are dielectrics

Estimation for 500 μ m glass beads

Dipole/dipole interactions due to the polarization of the grains

$$F_a / mg \gg 2 * 10^{-2}$$

Electrostatic force

$$F_b / mg \gg 4 * 10^{-7}$$

Interaction between charged grains

$$F_c / mg \gg 4 * 10^{-3}$$

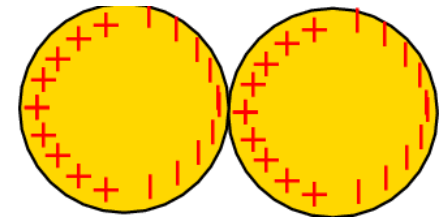
Electroclamping force $F_d / mg = 0.6$

$$F_d = 0.415 p e_0 d^2 E_{sat}^{0.8} (E \cos a)^{1.2}$$

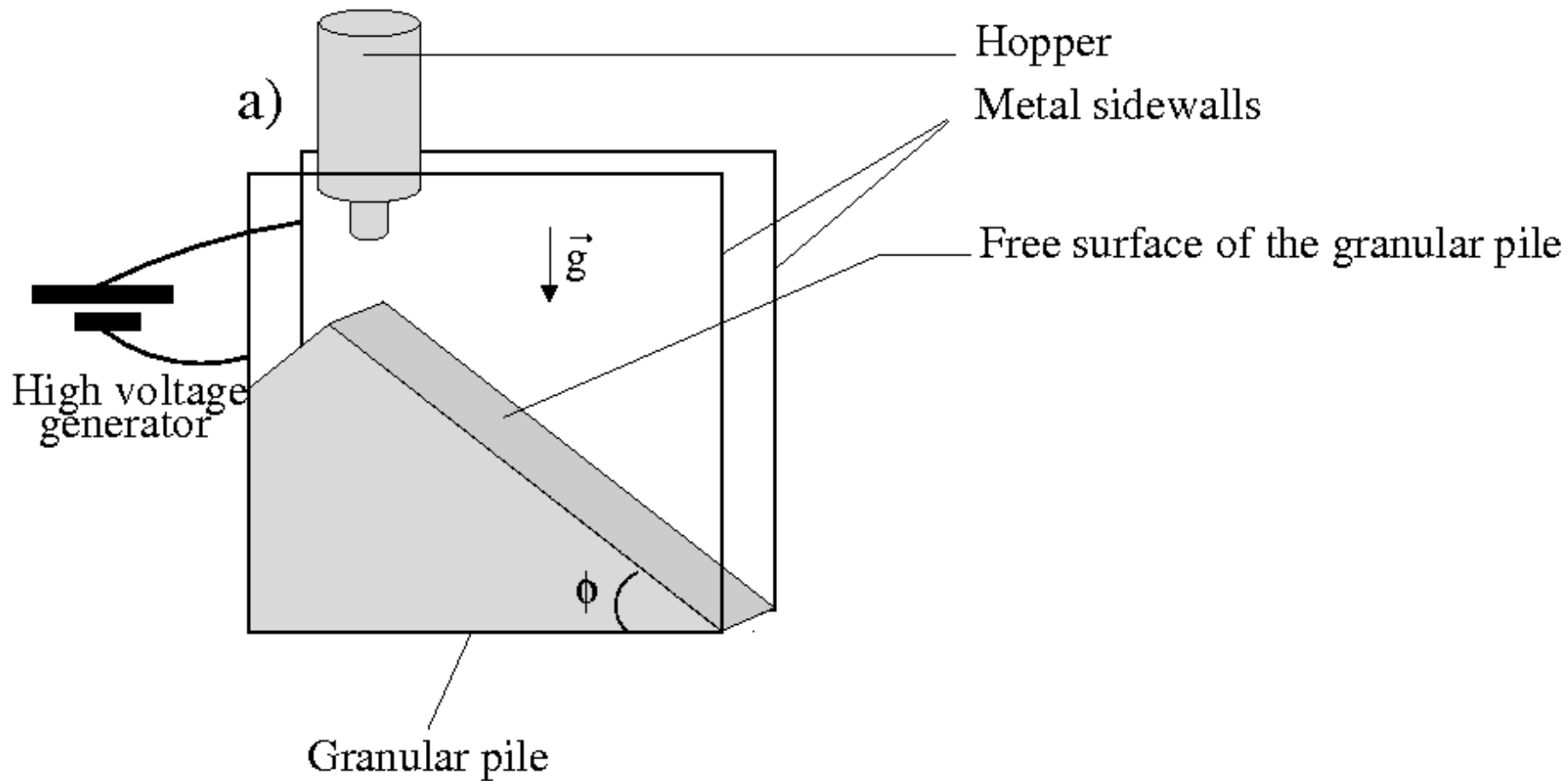
Dietz P.W. et al, Indust. Eng. Chem. Fund. 17 28 (1978)

induced by the electric current which pass through the system due to absorbed moisture at the surfaces

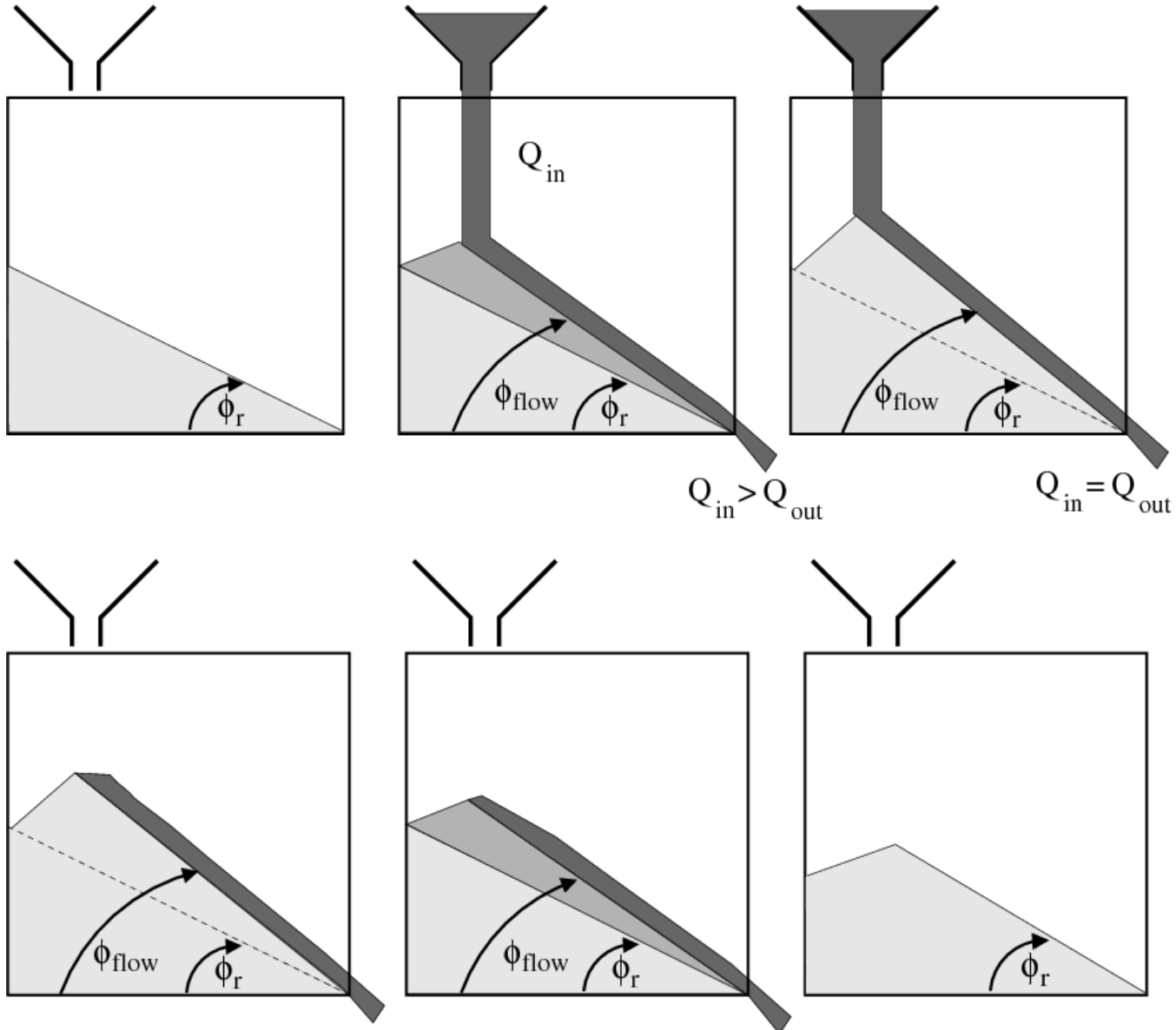
NO CONTACT- NO FORCE



Setup



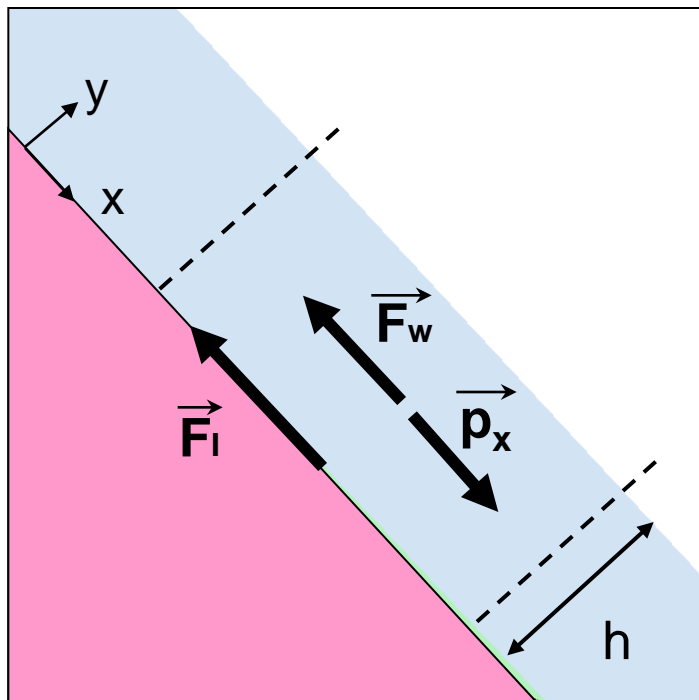
Setup



Stability of a granular packing

- Crude model : infinite box

Forces : weight ; sidewall friction; friction with the static grains



assumptions (Roberts 1969)

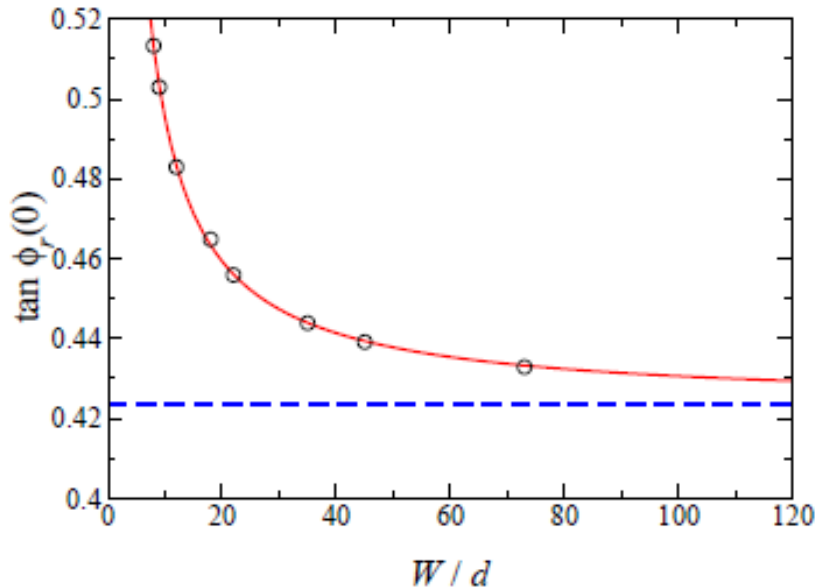
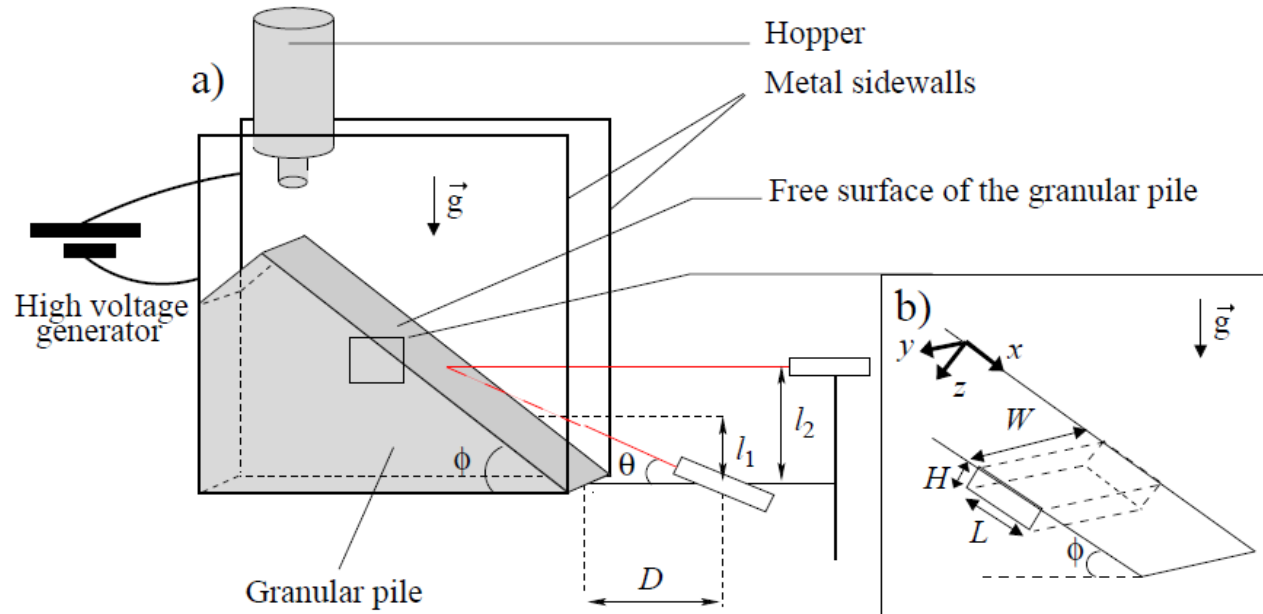
- Flowing layer (thickness : h – constant packing fraction) sliding at constant velocity on a static heap
- Hydrostatic and isotropic pressure
- Solid friction at the sidewalls (F_w)
- At the interface

$$F_{SSH} \leq \mu_i N$$

SSH (sidewall stabilized heap) equation:

$$\tan f = \mu_i + \mu_w h/W$$

$\tan f$ (W @ ¥) \rightarrow



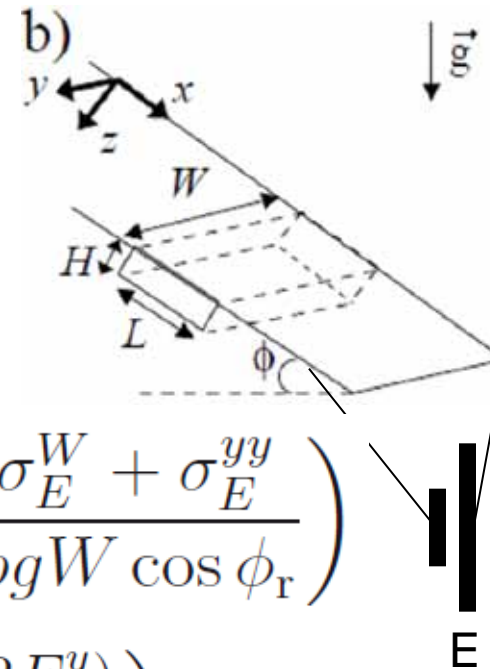
500 μm diameter glass beads

Dry case (no cohesion $E=0$)

- Important effect of confinement, even for $W/d \gg 1$ \Rightarrow long range correlation in granular systems

- $\tan \phi \sim 1/W$

Cohesive packings...



Cohesion Corresponding stress tensor \mathbf{s}_E^{ij}

Force balance leads to

$$\tan \phi_r = \mu_B \left(1 + \frac{\sigma_E^{zz}}{\rho g H \cos \phi_r} \right) + \mu_W \left(\frac{H}{W} + 2 \frac{\sigma_E^W + \sigma_E^{yy}}{\rho g W \cos \phi_r} \right)$$

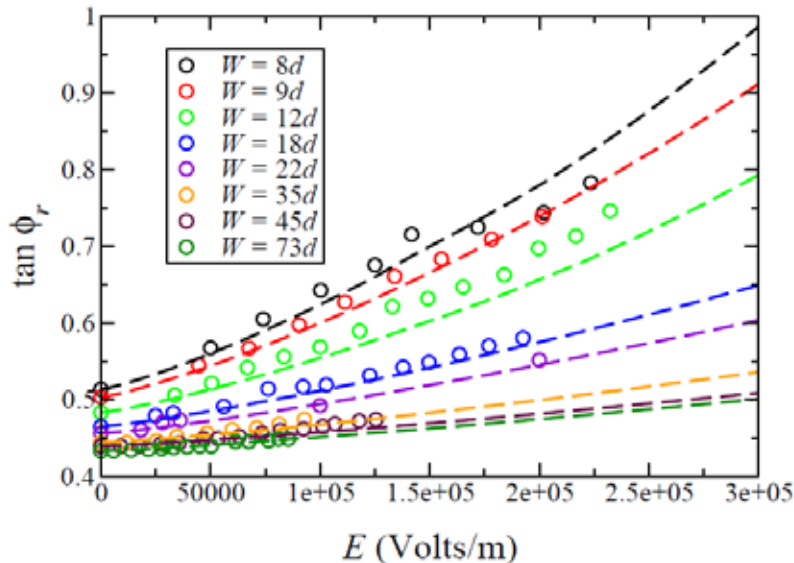
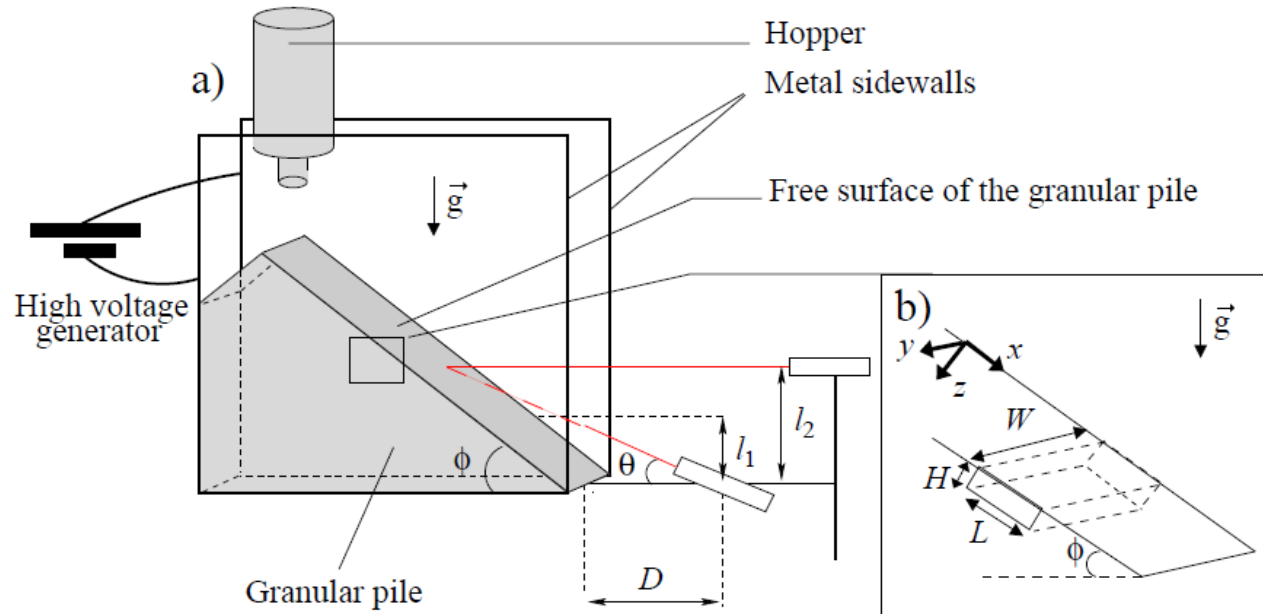
→
$$\tan \phi_r = \mu_B + \mu_W \left(\frac{H}{W} + \frac{4 (2\kappa F_d^w + 3F_d^y)}{\pi \rho_g g d^2 W \cos \phi_r} \right),$$

with $F_d^y = F_d^w = k_D E^{1.2}$

Prediction of a scaling law

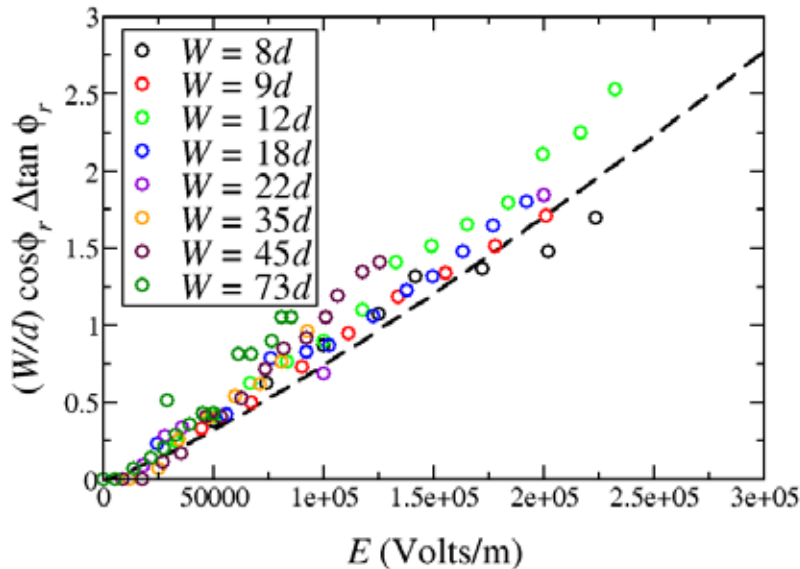
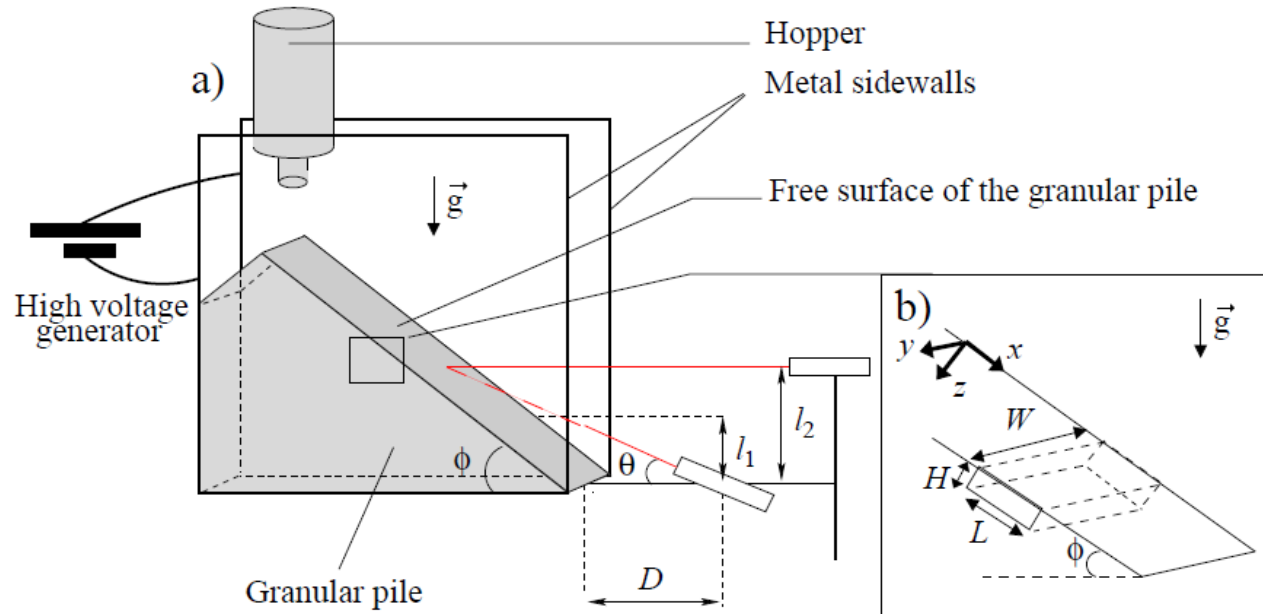
$$\frac{W}{d} \cos \phi_r \underbrace{\Delta \tan \phi_r}_{\Delta \tan \phi_r = \tan \phi_r(E) - \tan \phi_r(0)} = \frac{4\mu_W}{\pi \rho_g g d^3} (2\kappa F_d^w + 3F_d^y)$$

$$\Delta \tan \phi_r = \tan \phi_r(E) - \tan \phi_r(0)$$



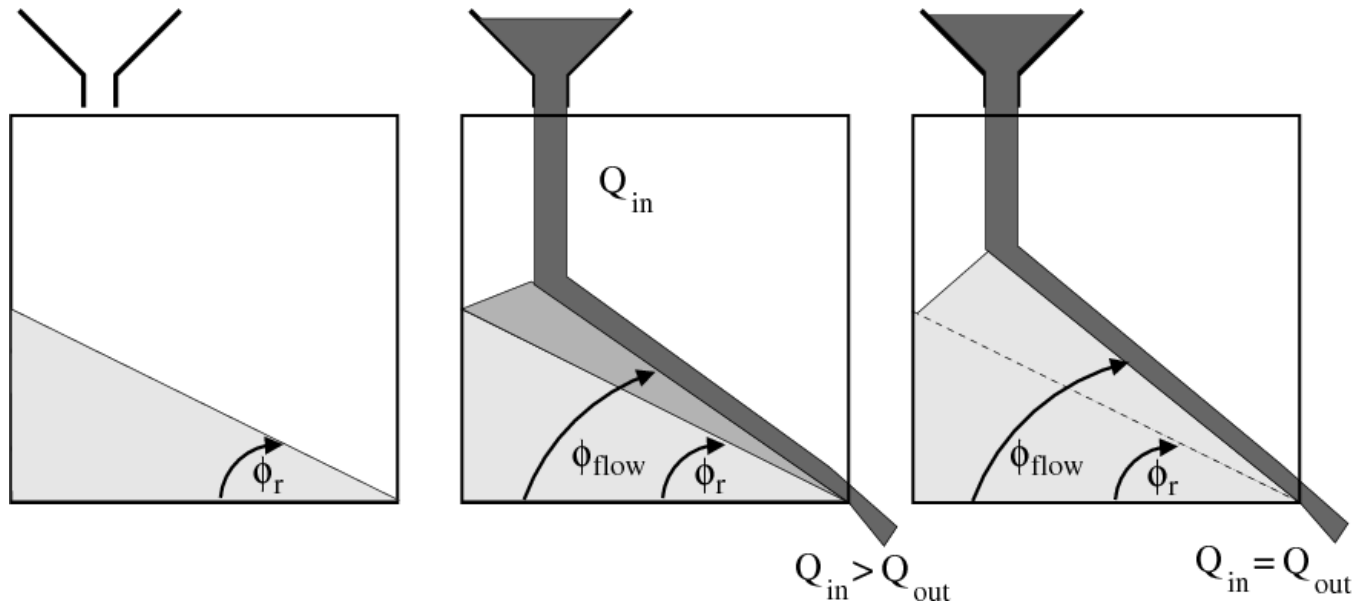
Effect of cohesion

- Cohesion increases stability angle
- Confinement increases stability angle
- Effect of confinement and effect of cohesion are both captured by our model

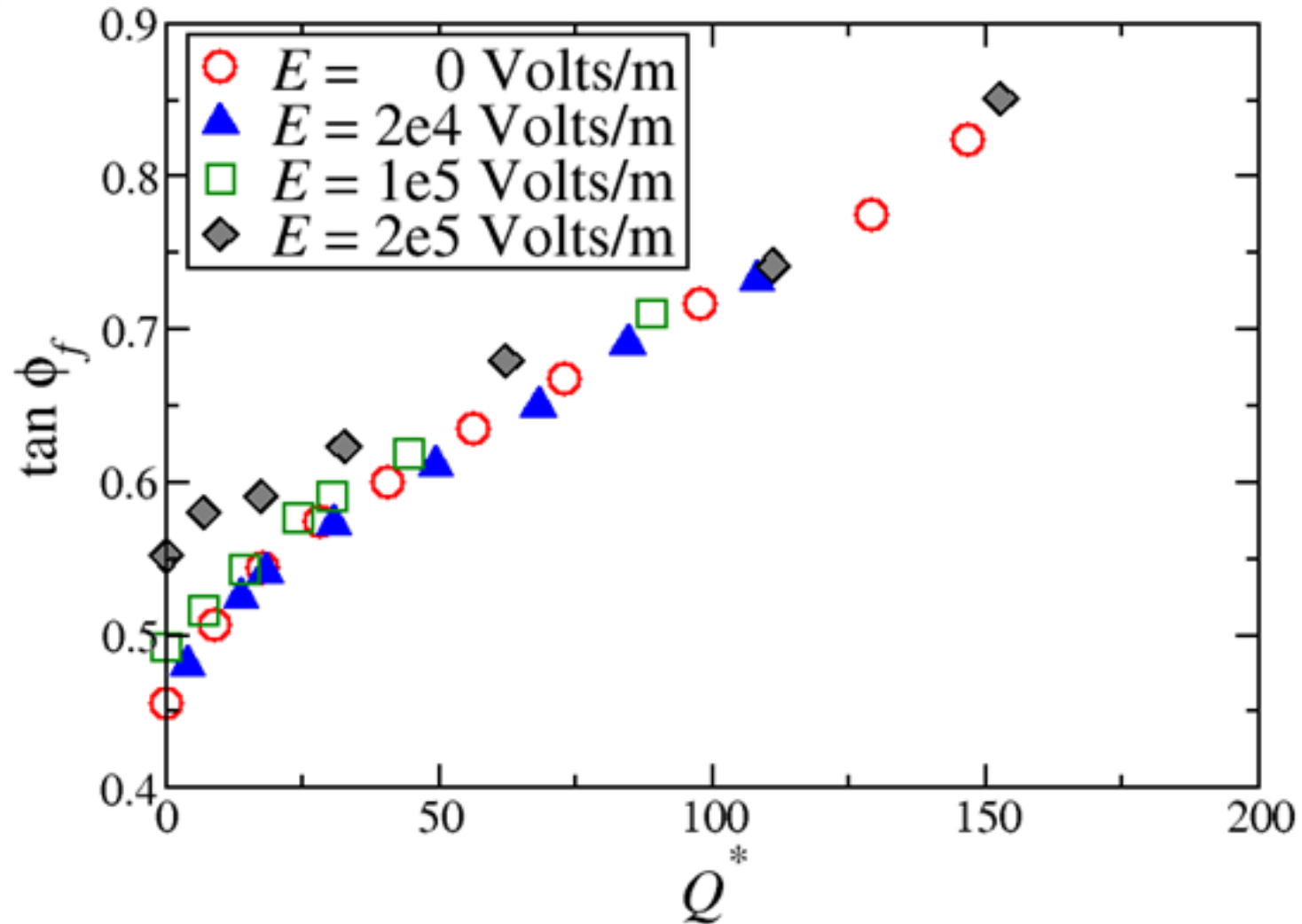


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Steady and fully developed flows



- An electric field can induce cohesion through the Dietz' law
 - ▷ $F_{\text{elec}} \gg mg$
- Cohesion and sidewall effects increase stability
- Such kind of cohesion has little effect on granular flows
 - ▷ No contact – no forces