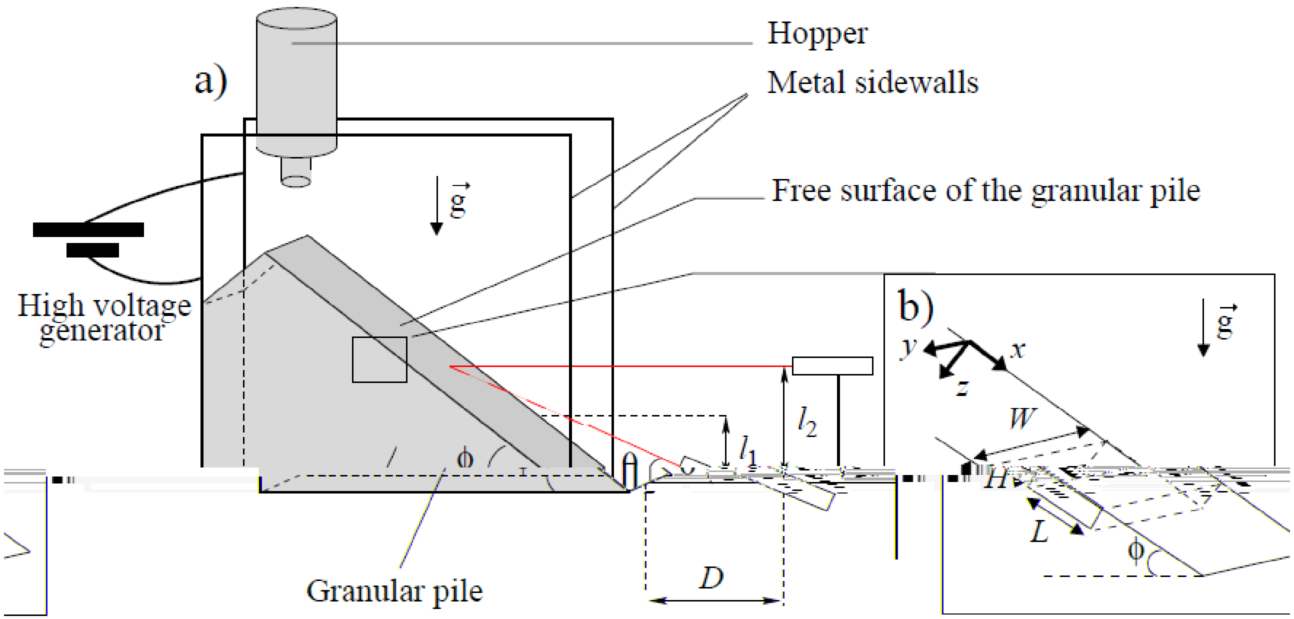
# Stabilité et écoulement de milieux granulaires à cohésion contrôlée





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*Avec Jean-Francois Métayer, Renaud Delannay, Alain Faisant et Jérôme S. Lambert*


*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…
  - Øaging, perturbations…
  - ØThe dynamics is not easy to observe
- Can simple experiments help our understanding?
  - ØStudy at the grain scale

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

# *Physical model*

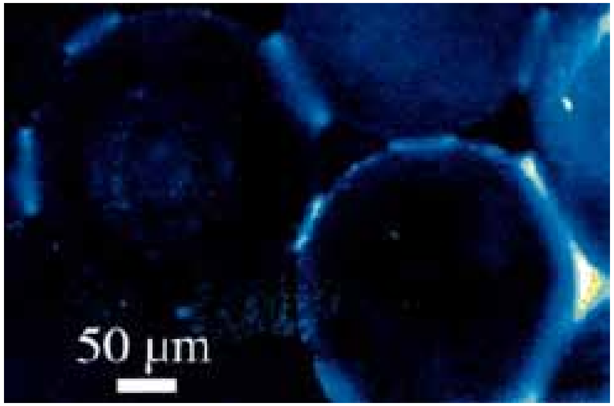
**Our physical model** : glass beads on an erodible surface

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

# Forces induced by an electric field

Mersch E. et al, Phys. Rev. E 81 041309 (2010)

Estimation for 500µm glass beads

**Dipole/dipole interactions due to the polarization of the grains**

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

**Electrostatic force**

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

**Interaction between charged grains**

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

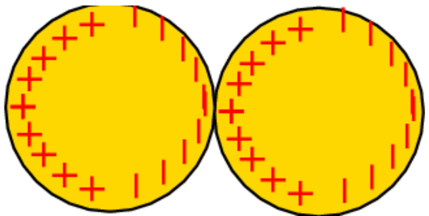
**Electroclamping force** $F_d / mg = 0.6$

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

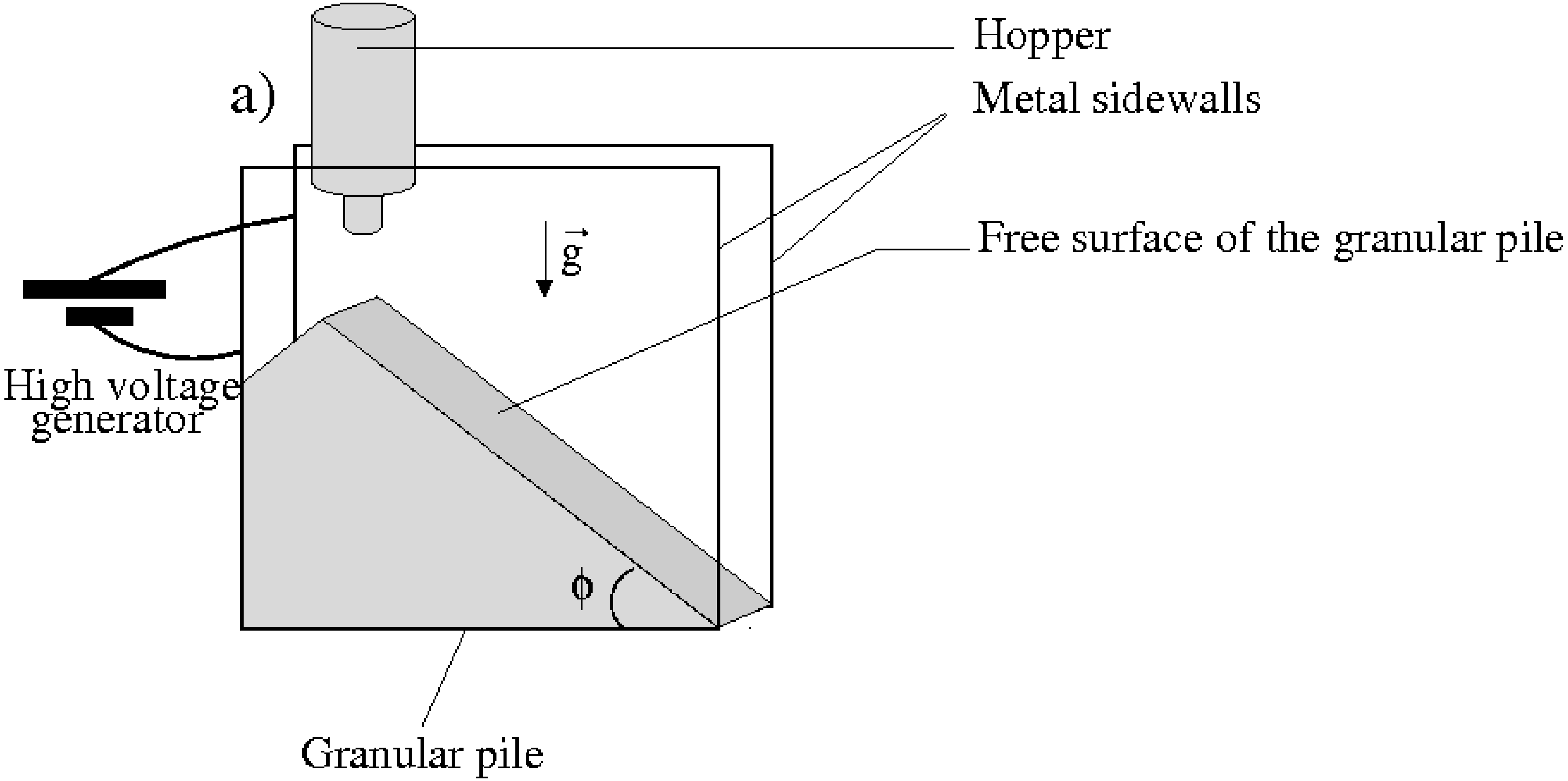
NO CONTACT- NO FORCE

$$F_d = 0.415\pi\varepsilon_0 d^2 E_{sat}^{0.8} (E \cos \alpha)^{1.2}$$

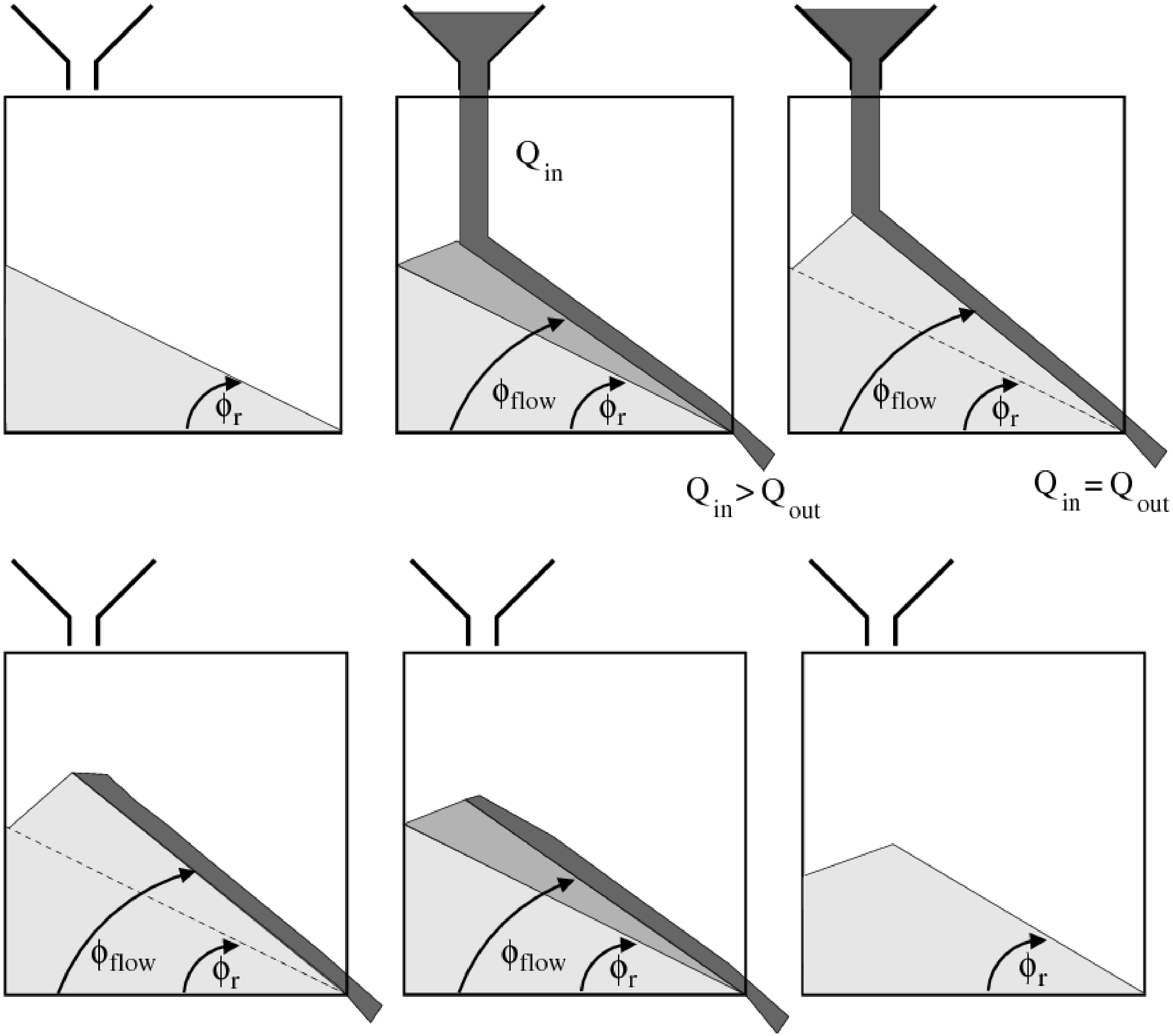
Dietz P.W. et al, Indust. Eng. Chem. Fund. 17 28 (1978)



# *Setup*


a)
Hopper
Metal sidewalls
Free surface of the granular pile
g
High voltage generator
ϕ
Granular pile

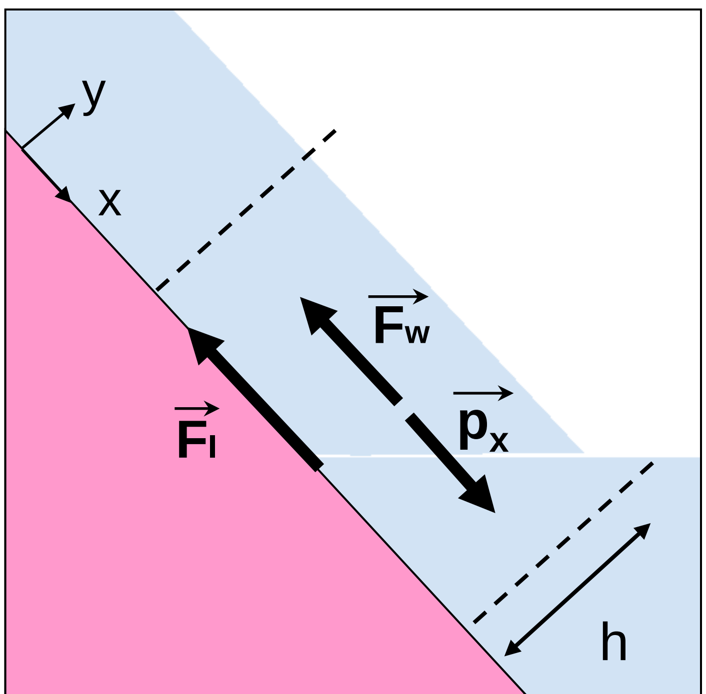
# *Setup*



# *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

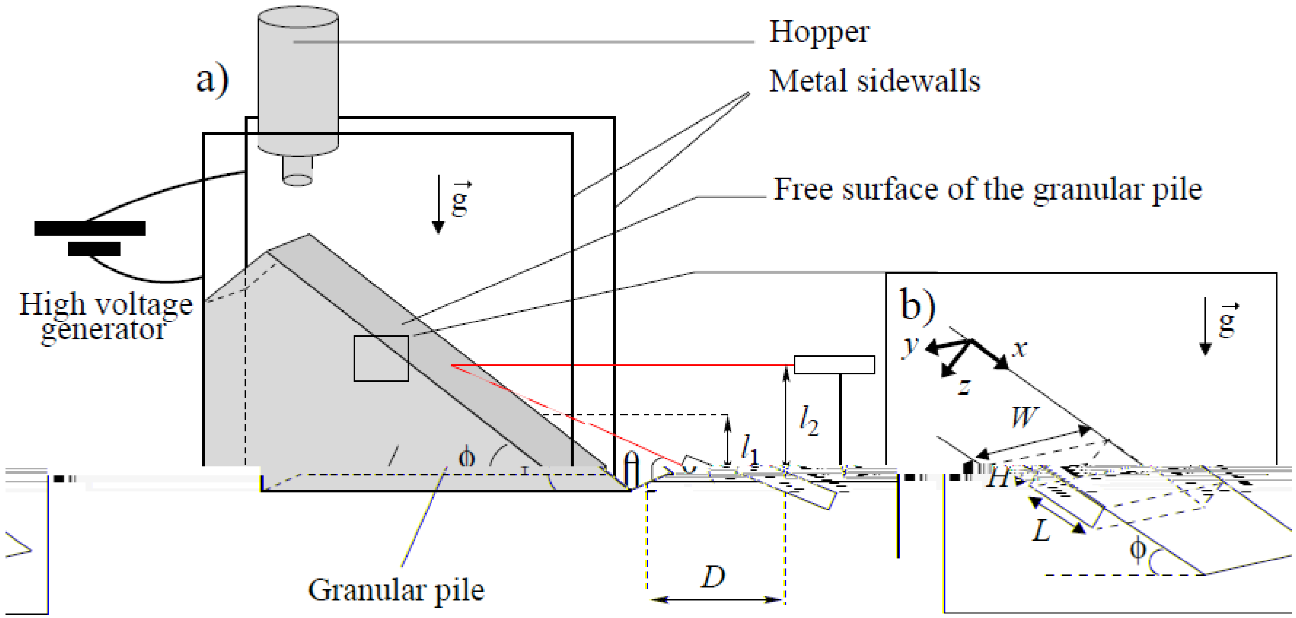
  $F_{SSH} \leq \mu_i N$

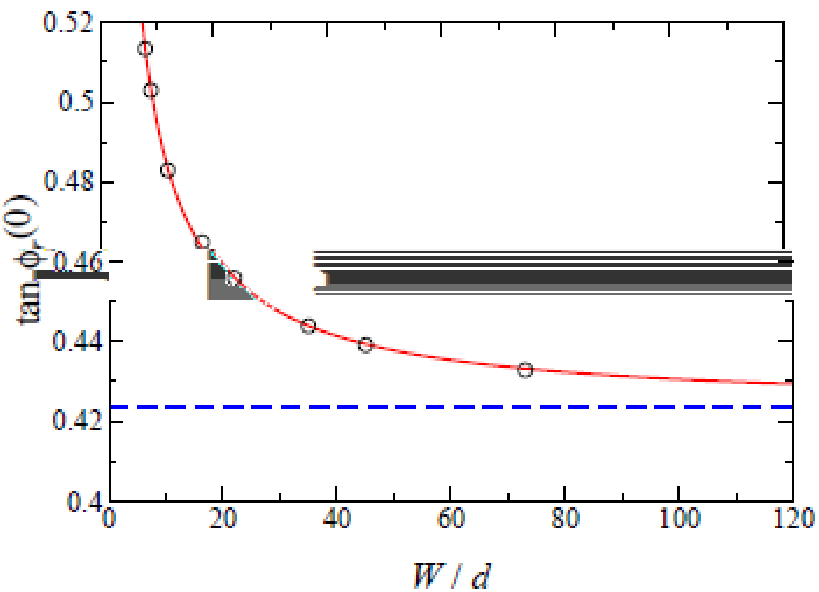
  SSH (sidewall stabilized heap) equation:

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

tan f (W ® ¥)

# Experiments




500 µm diameter glass beads

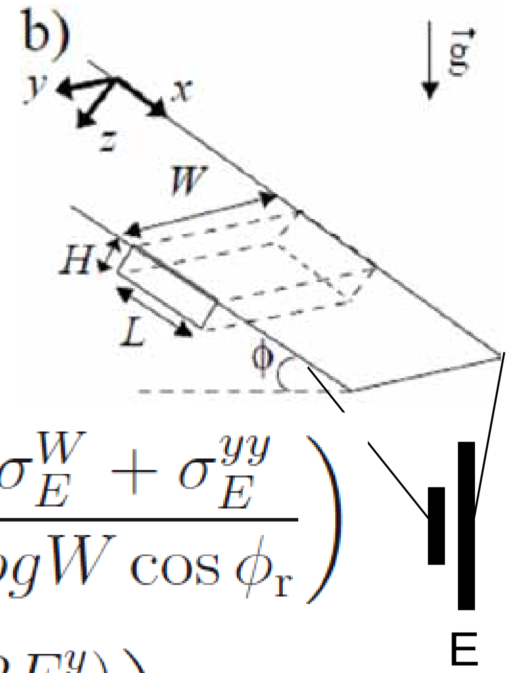
Dry case (no cohesion E=0)

- Important effect of confinement, even for W/d >> 1 Þ long range correlation in granular systems

- tan f µ 1/W

# Cohesive packings...

**Cohesion** Corresponding stress tensor $s_E^{ij}$




Force balance leads to

$$\tan\phi_{\rm r} = \mu_{\rm B}\left(1+\frac{\sigma_E^{zz}}{\rho g H\cos\phi_{\rm r}}\right)+\mu_{\rm W}\left(\frac{H}{W}+2\frac{\sigma_E^{W}+\sigma_E^{yy}}{\rho g W\cos\phi_{\rm r}}\right)$$

$$\Longrightarrow \quad \tan\phi_{\rm r} = \mu_{\rm B}+\mu_{\rm W}\left(\frac{H}{W}+\frac{4\left(2\kappa F_d^w+3F_d^y\right)}{\pi\rho_{\rm g} g d^2 W\cos\phi_{\rm r}}\right),$$

with $$F_d^y = F_d^w = k_{\rm D} E^{1.2}$$

Predicion of a scaling law

$$\boxed{\frac{W}{d}\cos\phi_{\rm r}\underbrace{\Delta\tan\phi_{\rm r}}_{\Delta\tan\phi_{\rm r}=\tan\phi_{\rm r}(E)-\tan\phi_{\rm r}(0)} = \frac{4\mu_{\rm W}}{\pi\rho_{\rm g} g d^3}\left(2\kappa F_d^w+3F_d^y\right)}$$

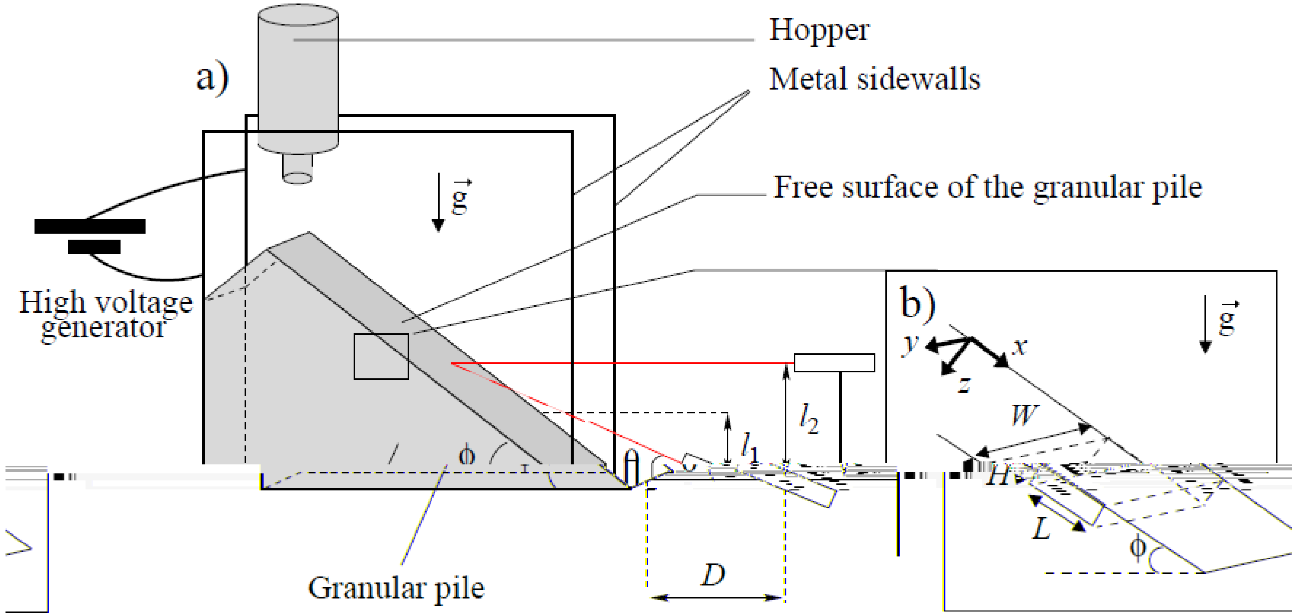
# *Experiments*

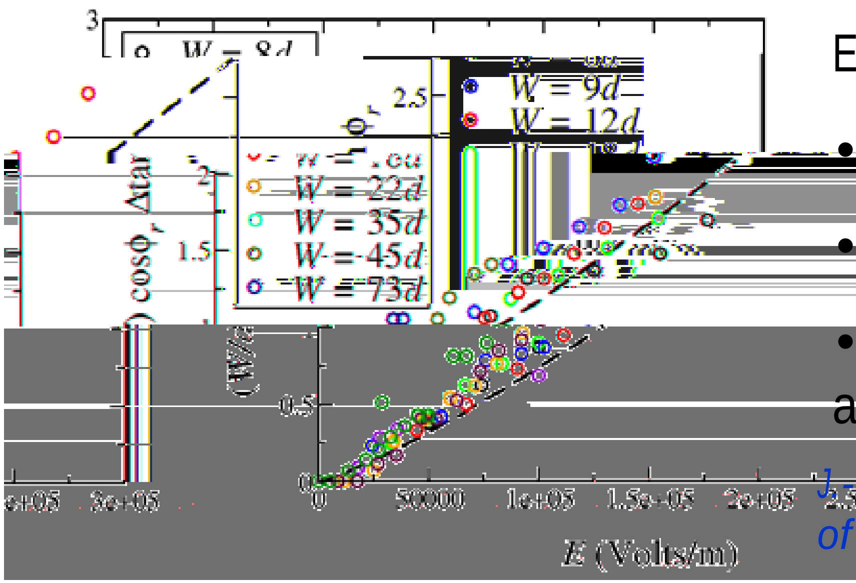
Effect of cohesion

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

*J.-F Metayer, P. Richard, A. Faisant and R. Delannay, Journal of Statistical Mechanics, 2010*

# Experiments

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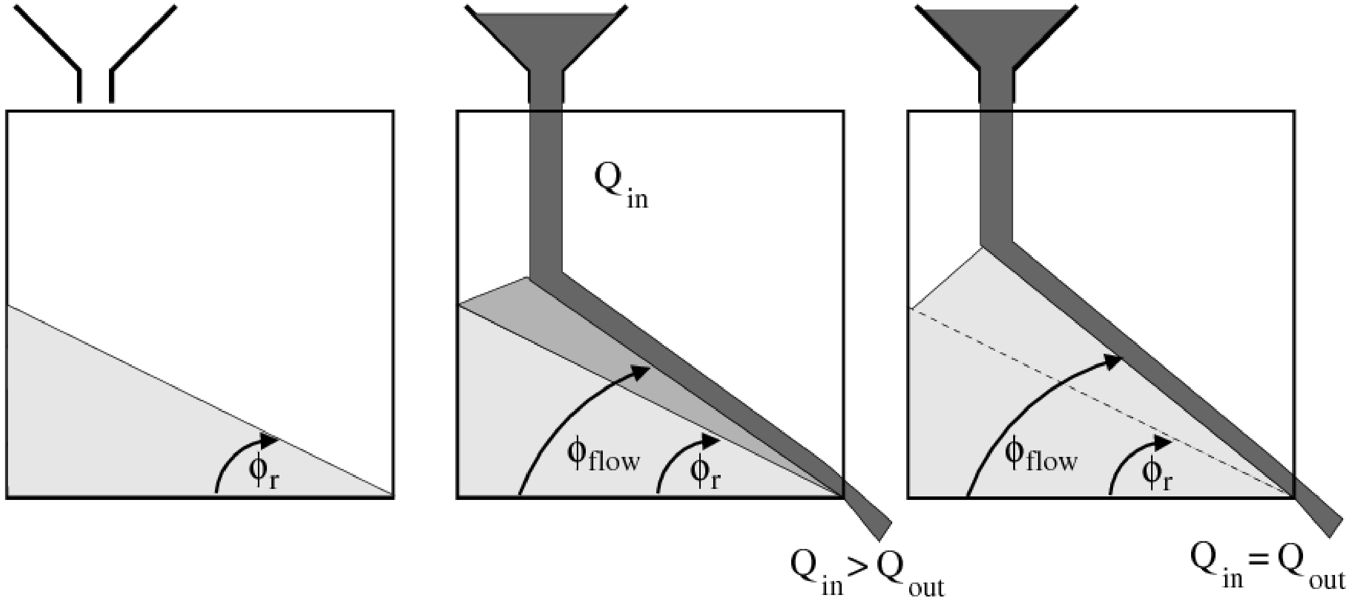
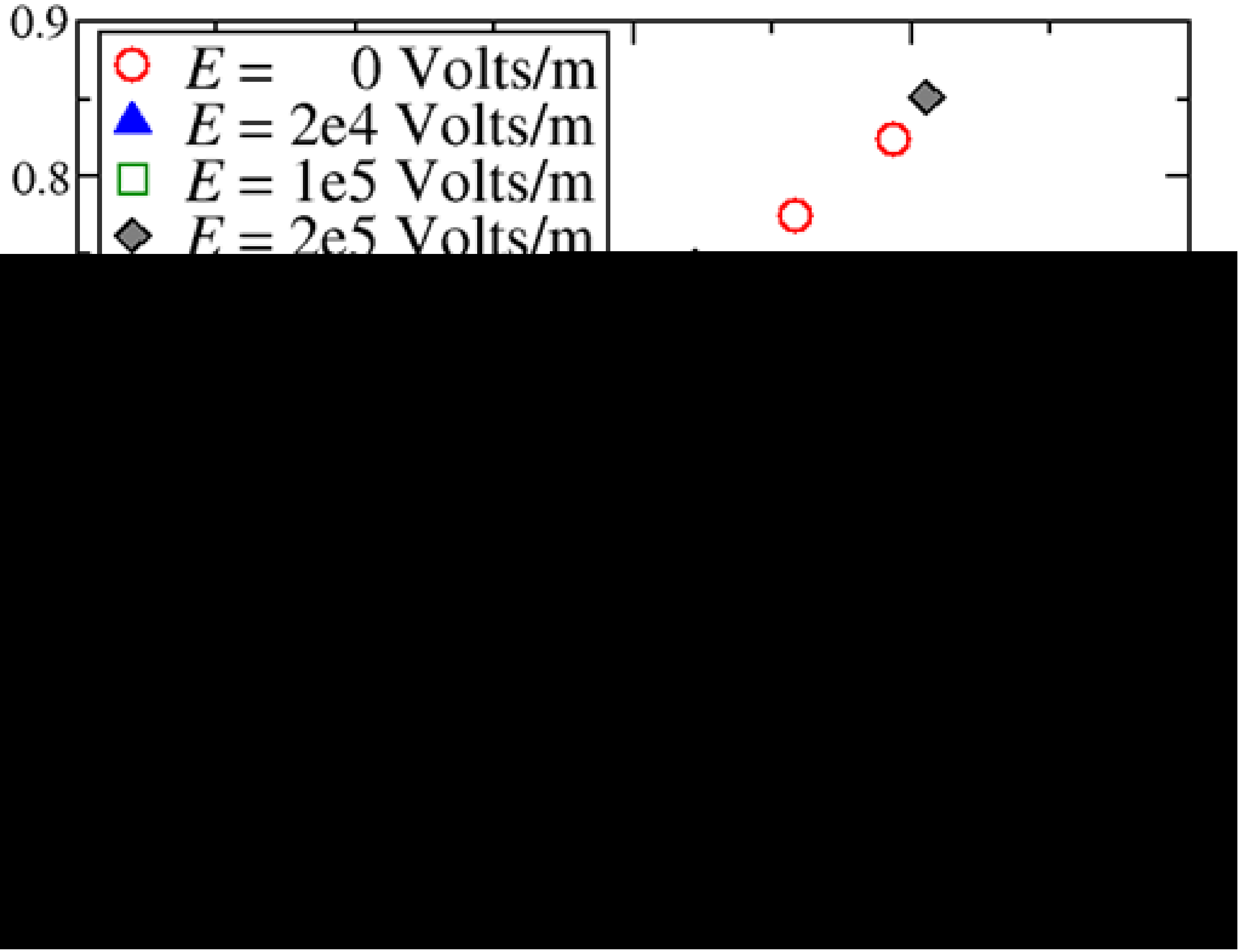
# Cohesive granular flows




Steady and fully developed flows

# Cohesive granular flows




[redacted]

# *Conclusion*

- An electric field can induce cohesion through the Dietz’ law

  Þ $F_{elec}$ » mg

- Cohesion and sidewall effects increase stability

- Such kind of cohesion has little effect on granular flows

  Þ No contact – no forces