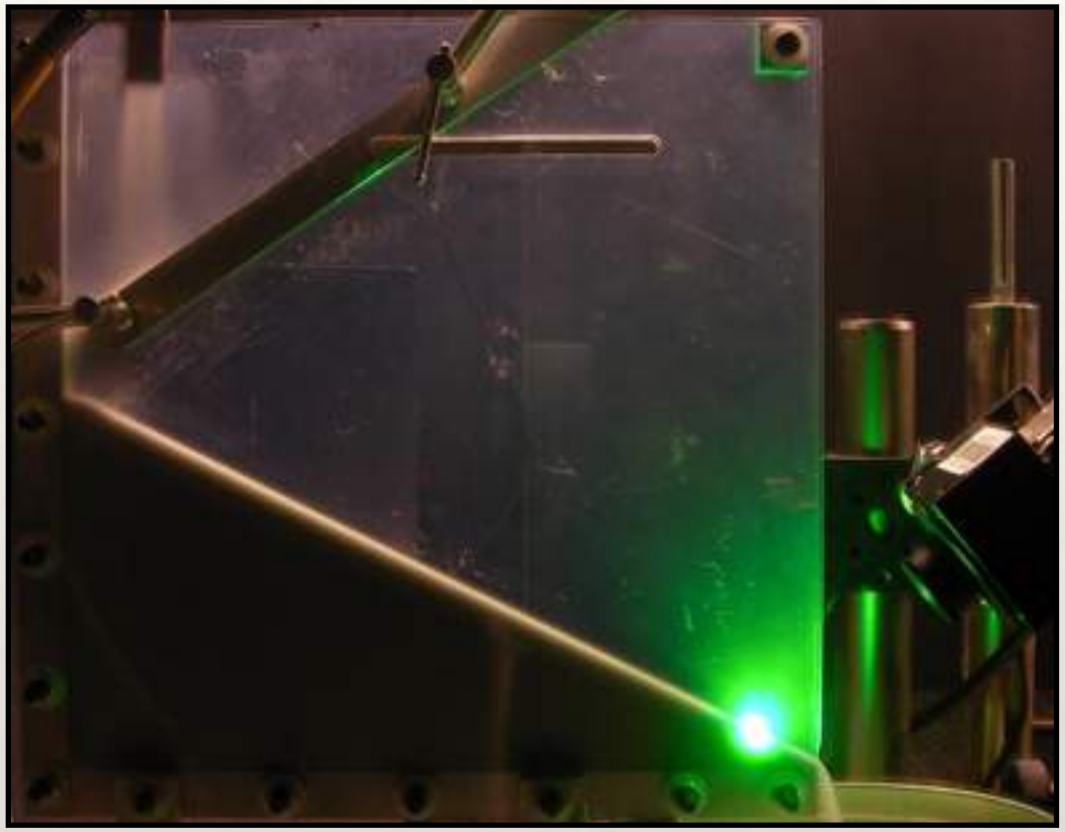
Flow fluctuation and deformation in dense granular matter

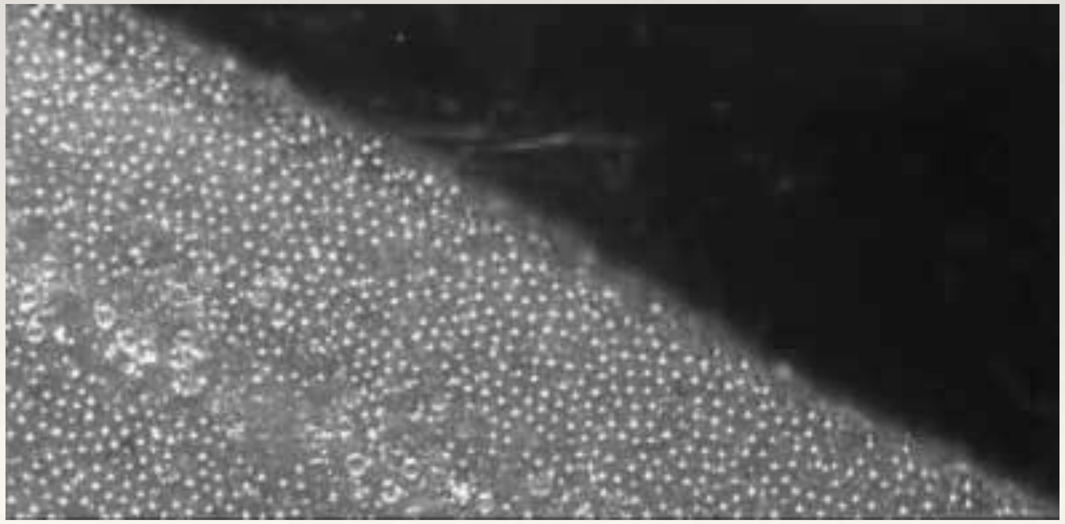
Hiroaki Katsuragi, Nagoya University

(collaborators: D. J. Durian, K. Endo)

Avalanches, plasticity, and nonlinear response in nonequilibrium solids, Kyoto, March 7-9, 2016

Granular avalanches





Heap (or chute) flow

Discharge flow

Granular flow and fluctuation

- In general, hot (high temperature) matters cannot be solidified.
- Although the granular matter is athermal system, it has “granular temperature.”
- Does this granular temperature (fluctuation) play an essential role for maintaining the flow?
    - Heap flow (depth-dependent slow down)
    - Discharge flow (clogging)

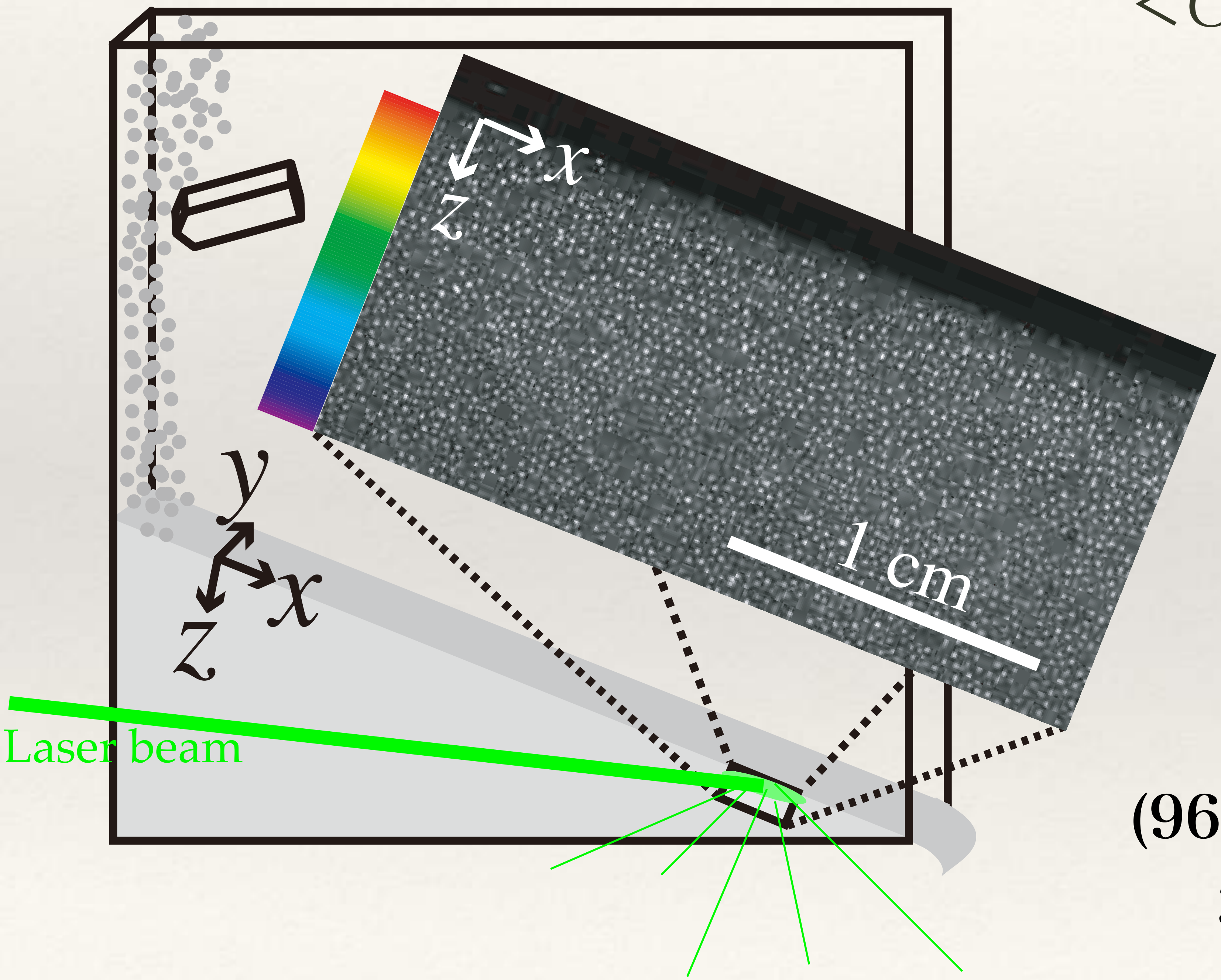
Granular heap flow

(with Doug Durian)

Motivation for heap flow analysis

- In granular heap flow avalanches, only the shallow part flows (shear banding formation).
- To create the heap flow and associated shear banding, does fluctuation (granular temperature) play a crucial role?
- To estimate the contribution of fluctuation, we have to measure it and compare it with the effects by other mechanisms such as shearing by gravity.

Experiments



<Continuous flow>

[PTV] (particle tracking velocimetry)

- flow velocity $v_x(z)$
- Grains number density

[DLS] (dynamic light scattering)

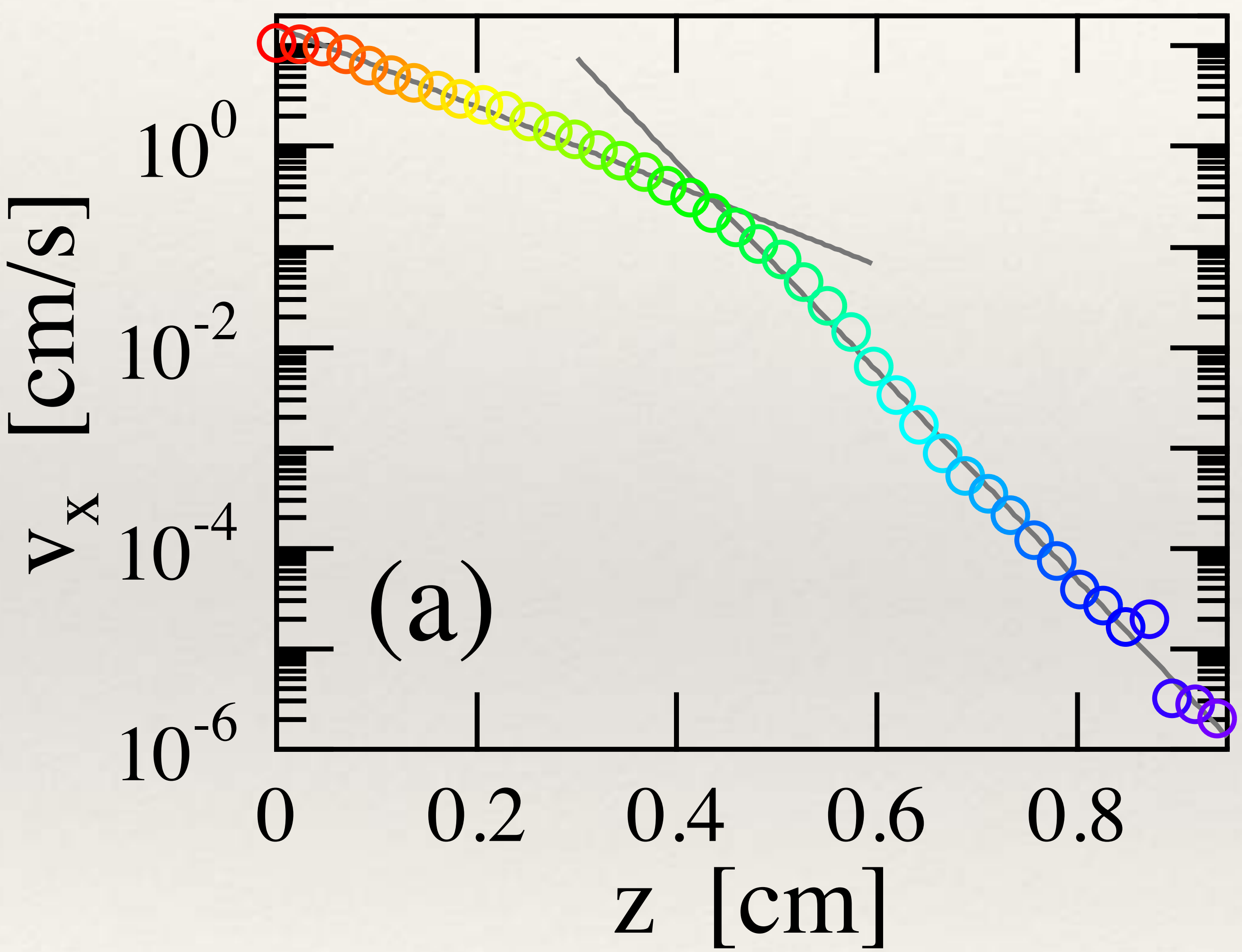
- flow fluctuation $\delta v(z)$

(960×480, 1,000 frames)

3900 fps - 0.25 fps

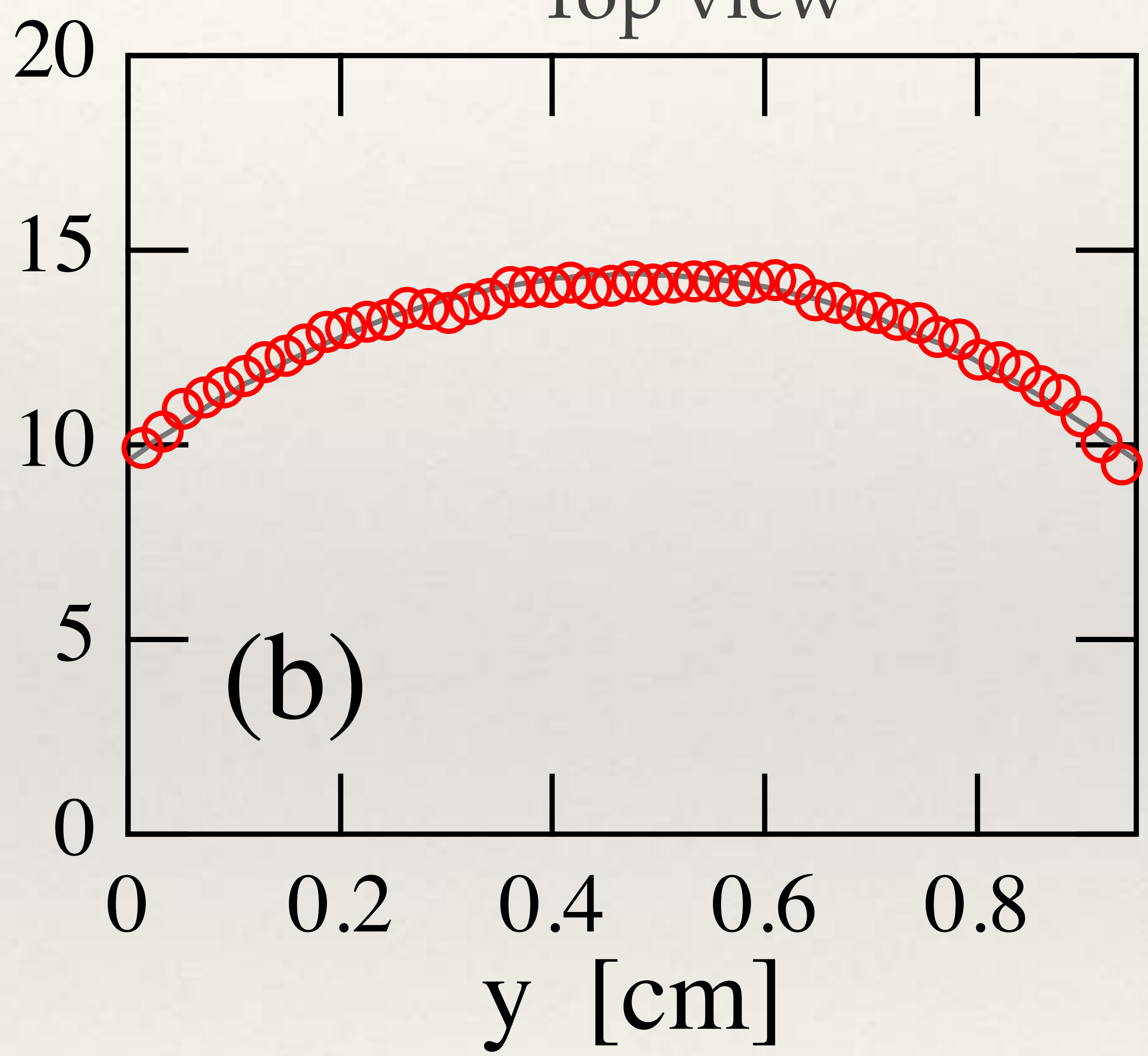
Velocity profile

Side view



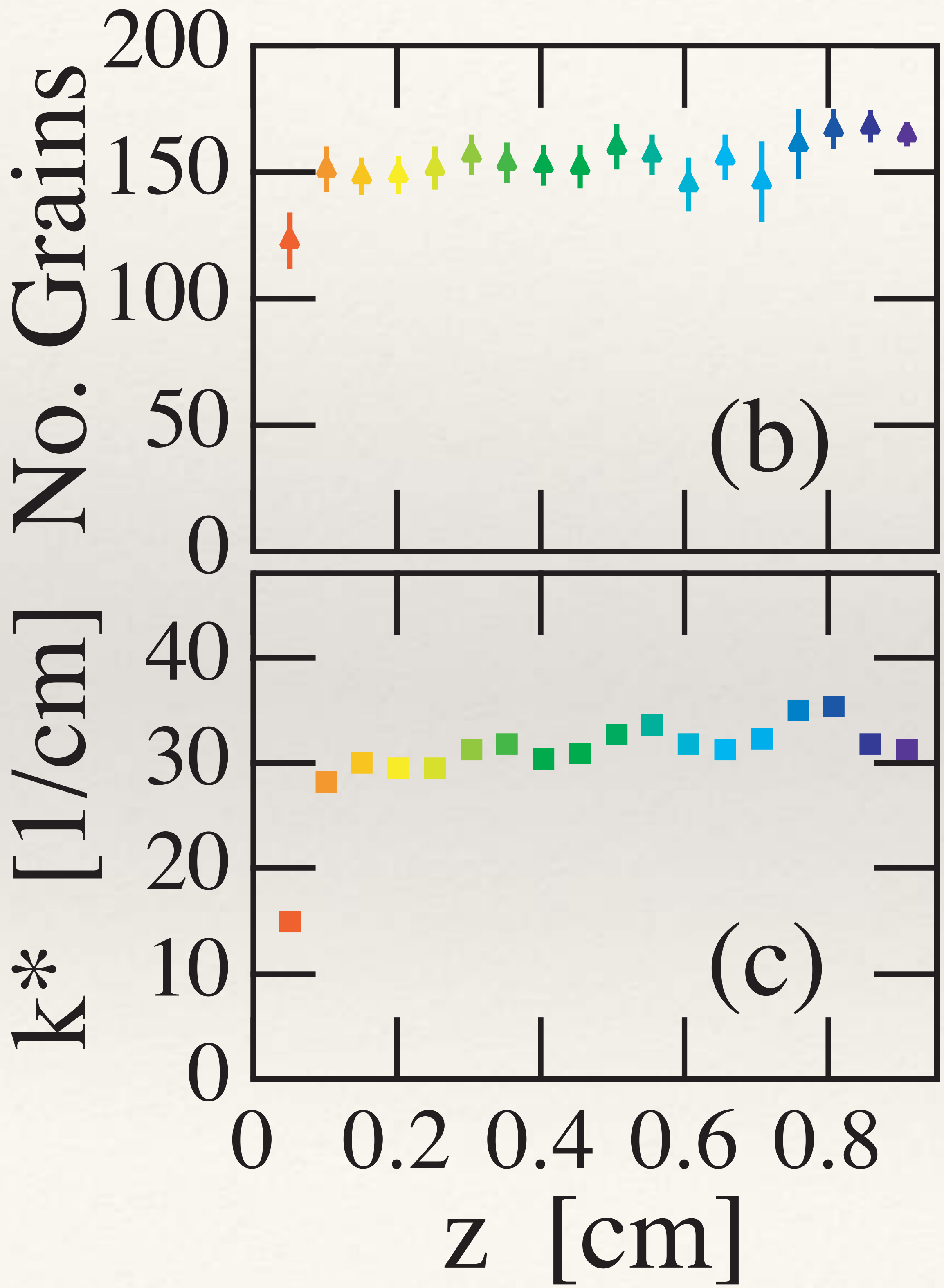
Two exponential forms

Top view



Plug flow like

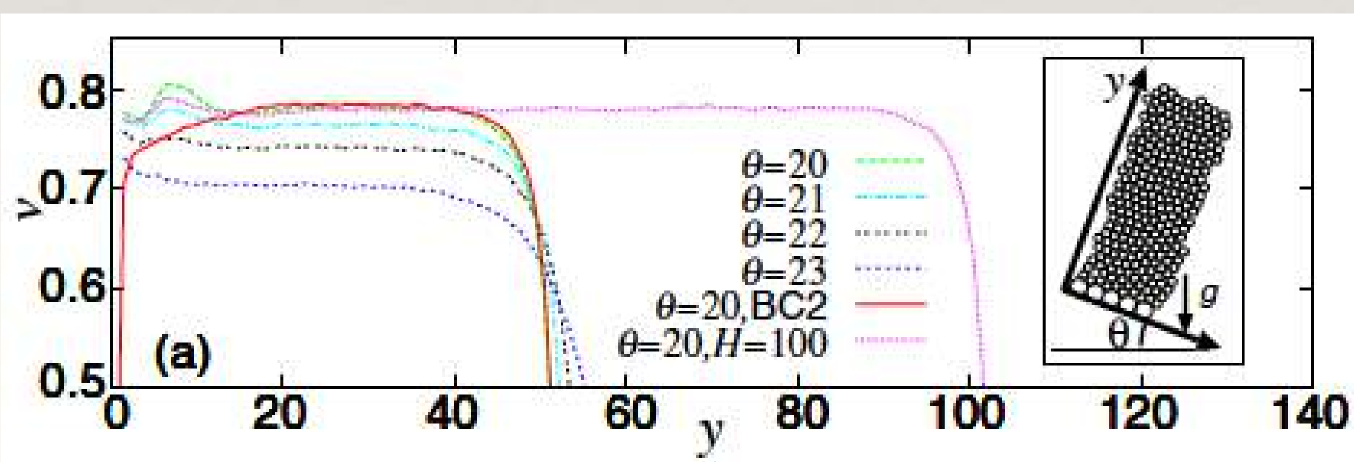
Grain number density



Constant grain number density

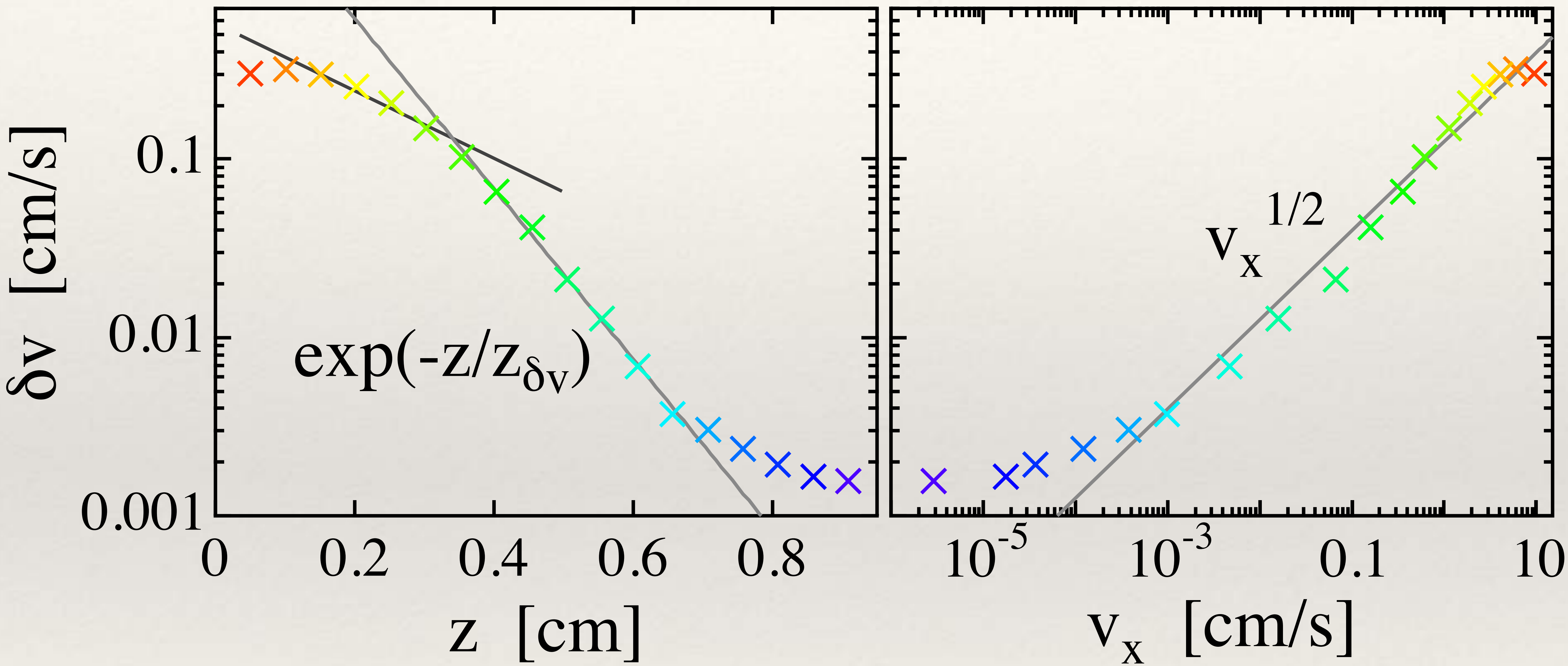
(Velocity profile shows a crossover around z=0.4 mm)

Similar numerical results



Mitarai & Nakanishi, PRL 2005

Granular temperature



$\delta v \sim \exp(-z/z_{\delta v})$

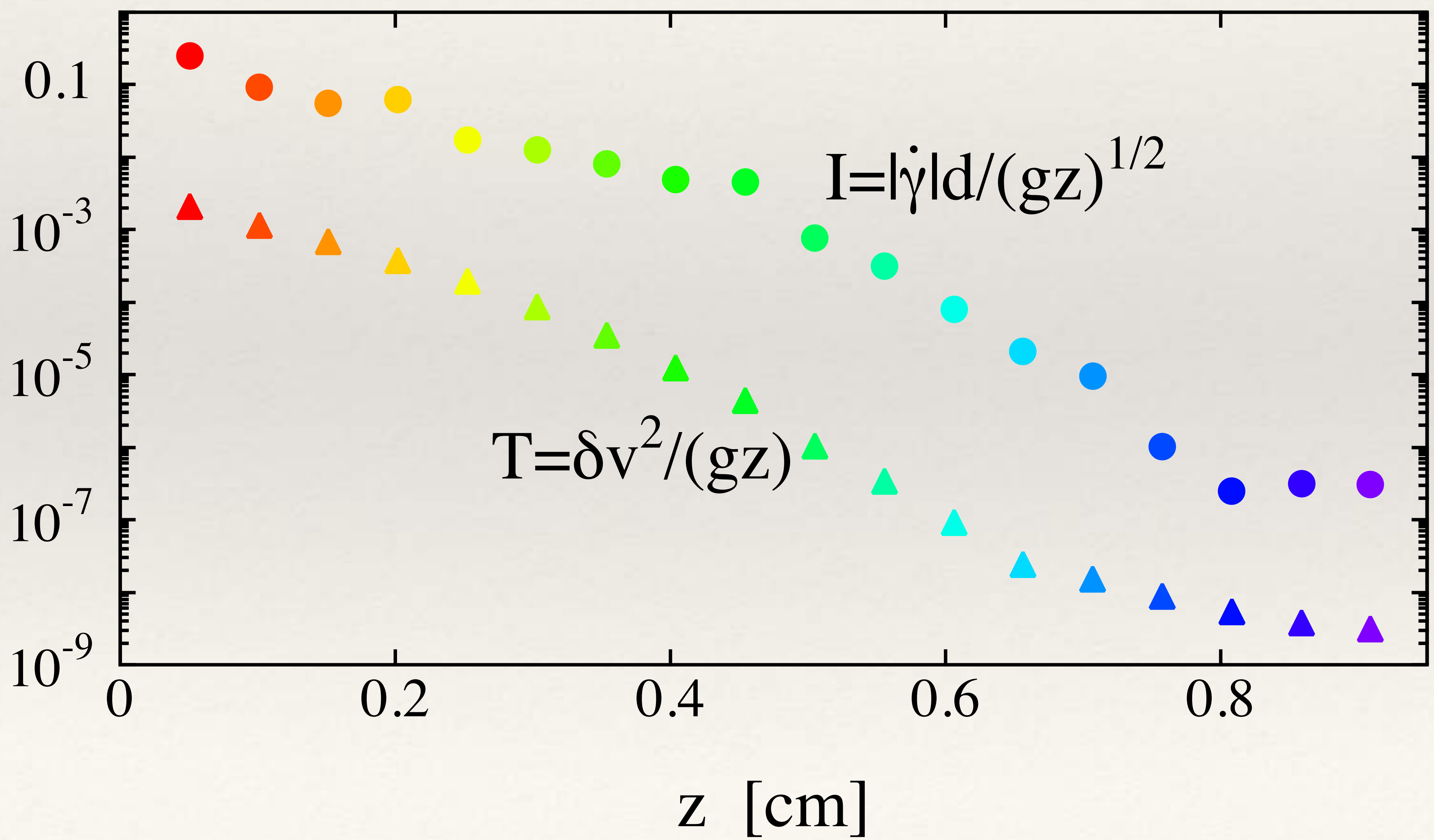
$\delta v \sim v^{1/2}$

consistent with Abate, Katsuragi, & Durian, Phys. Rev. E 2007

Shear or temperature?

$$T = \frac{\delta v^2}{gz} << I = \frac{\dot{\gamma} d}{\sqrt{gz}}$$

Shearing (inertial number) is always much greater than fluctuation (normalized granular temperature)



Summary of chute flow experiment

- Depth-dependent slow down of granular heap flow velocity is measured and analyzed using PTV and DLS methods.
- From the obtained data of velocity profile $v_x(z)$ and velocity fluctuation $\delta v(z)$, shearing degree and fluctuation degree (granular temperature) are estimated.
- The shearing is much more important than fluctuation in the gravity-driven heap flow (shear banding).

Katsuragi, Abate & Durian, Soft Matter 2010

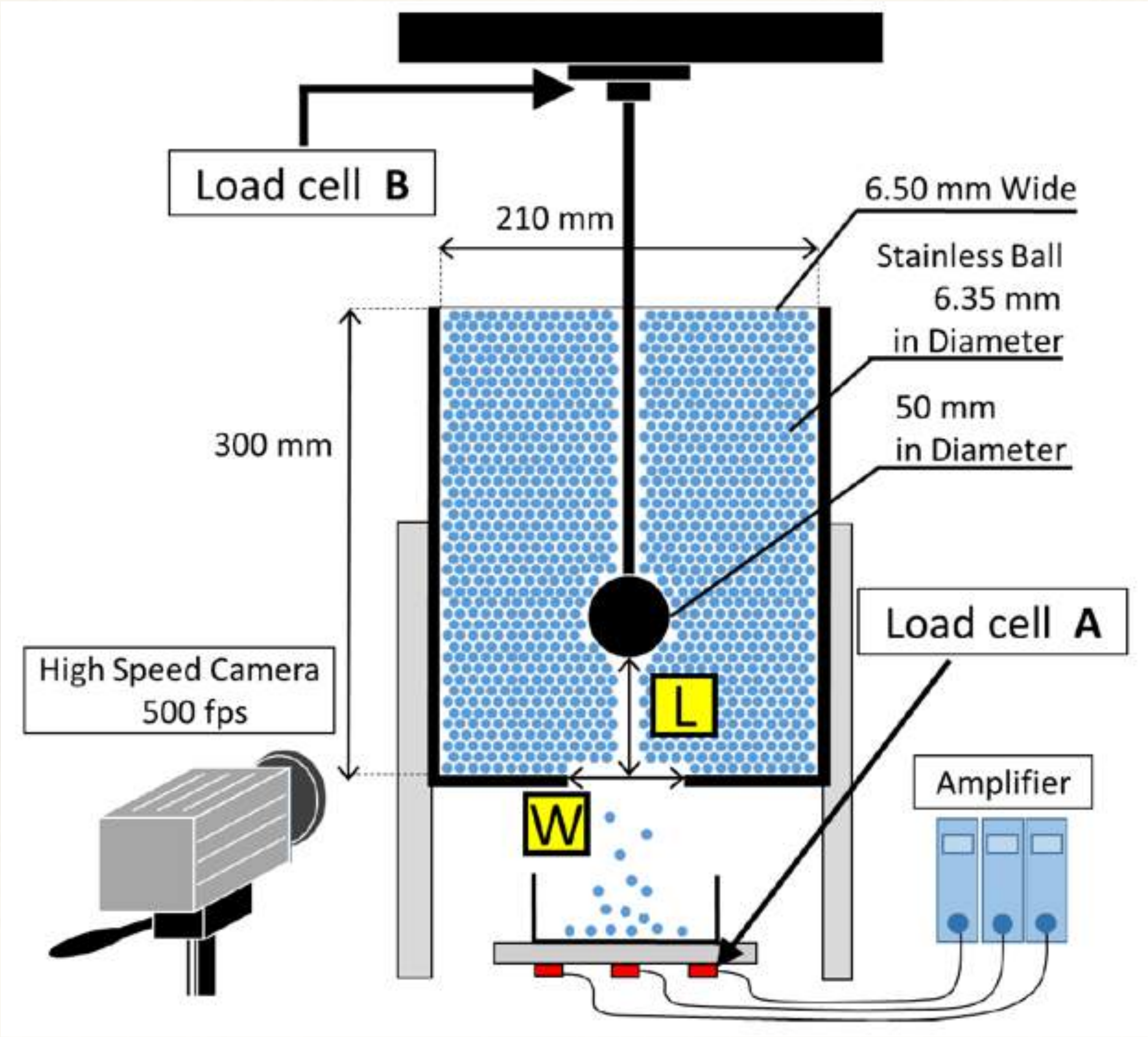
Discharge flow

(with Keita Endo)

Motivation for discharge flow analysis

- Clogging of discharge flow frequently occurs when the bottleneck size is very small.
- In general, by placing an obstacle in front of the bottleneck, the clogging probability can be reduced.
- Why? How?
- Contribution of fluctuation (granular temperature)?

Experiment



Parameters:

Exit width W

Obstacle-exit distance L

Measurements:

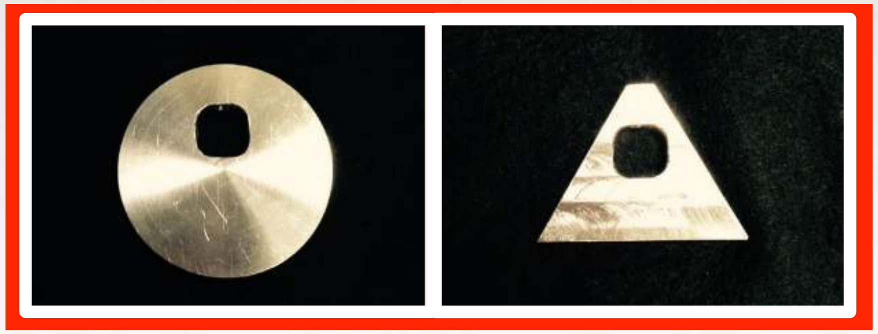
Flow rate

Drag force

Flow field

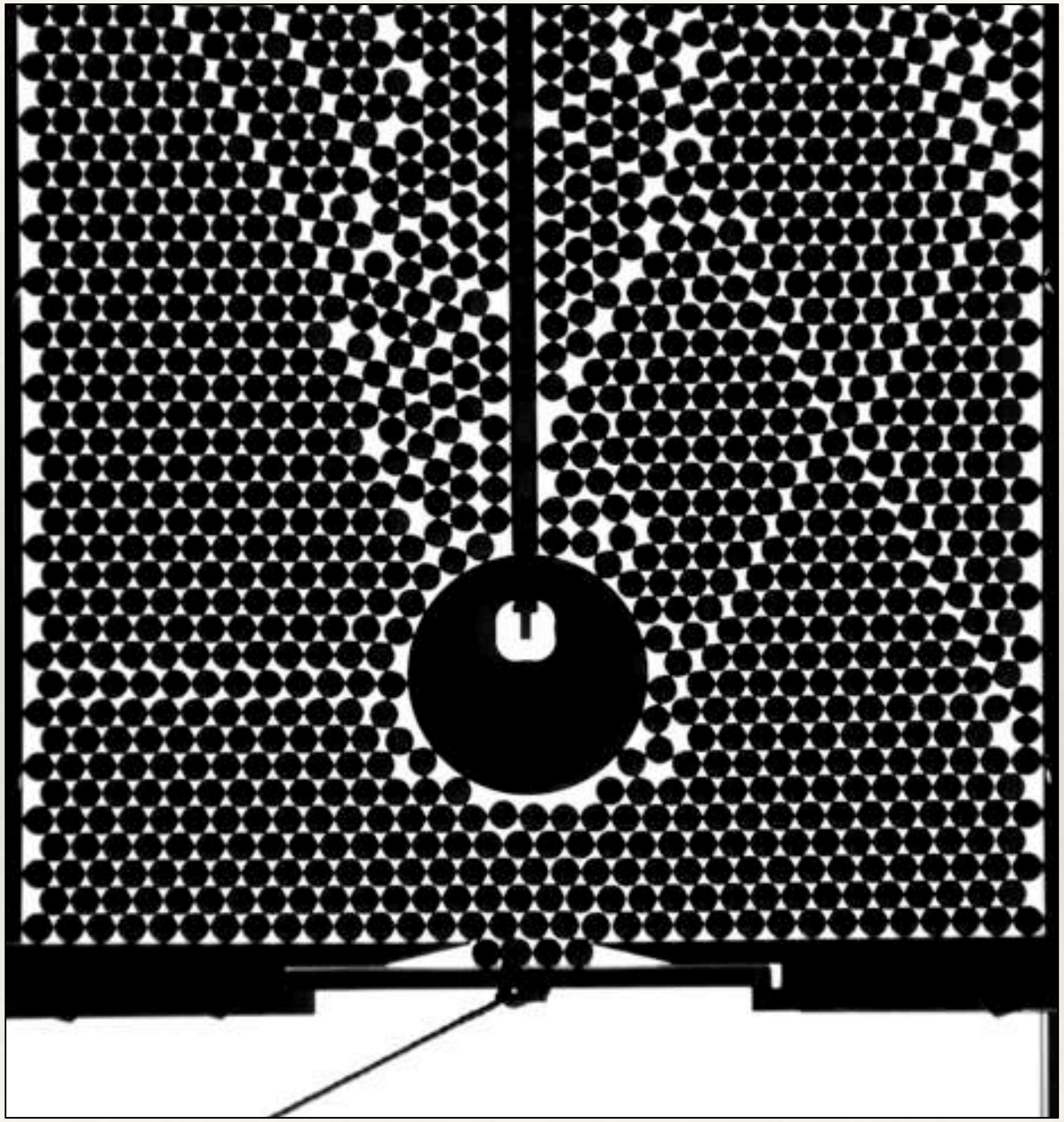
(high speed imaging)

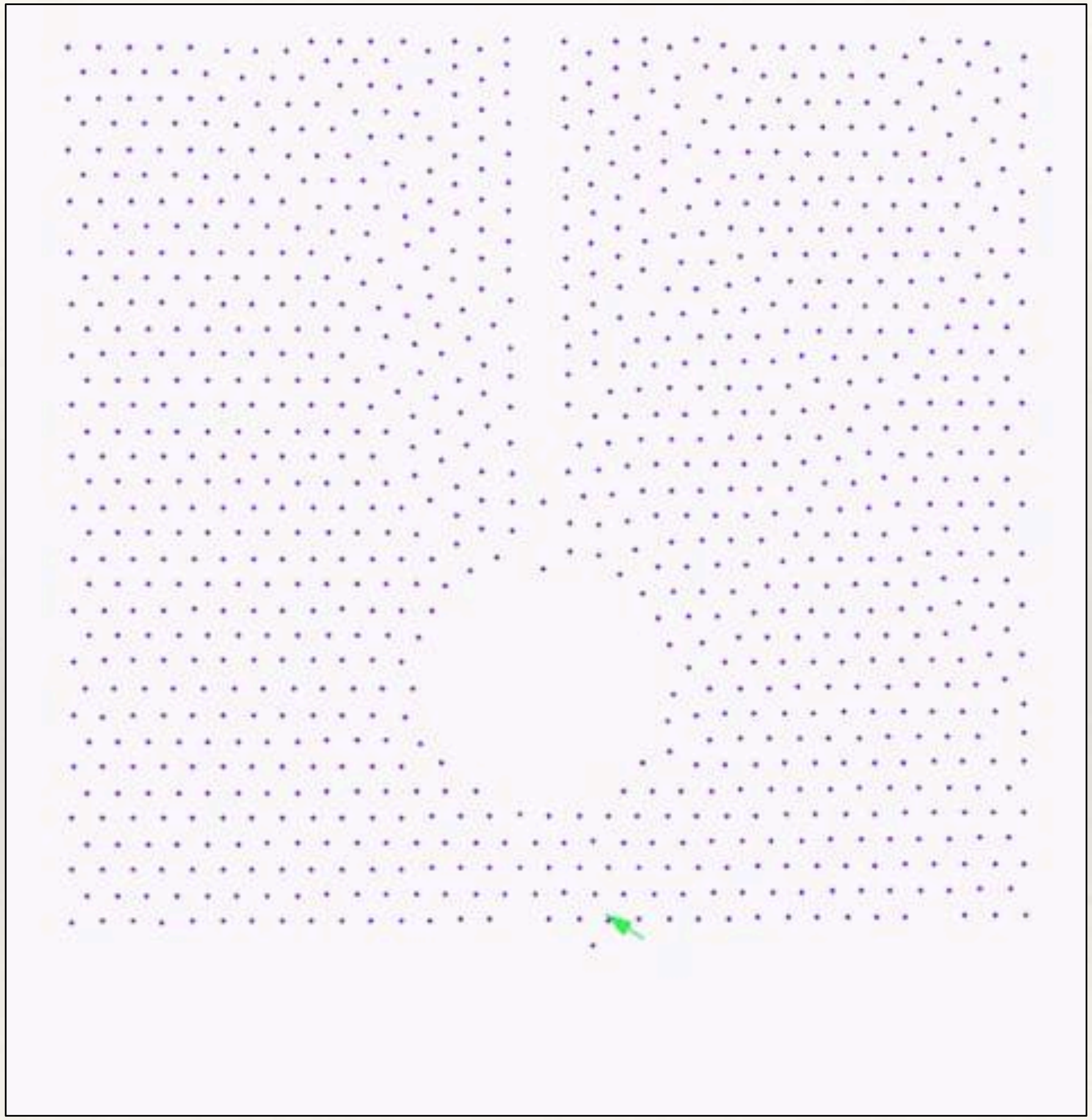
Obstacle shapes:



circle triangle

Circular obstacle

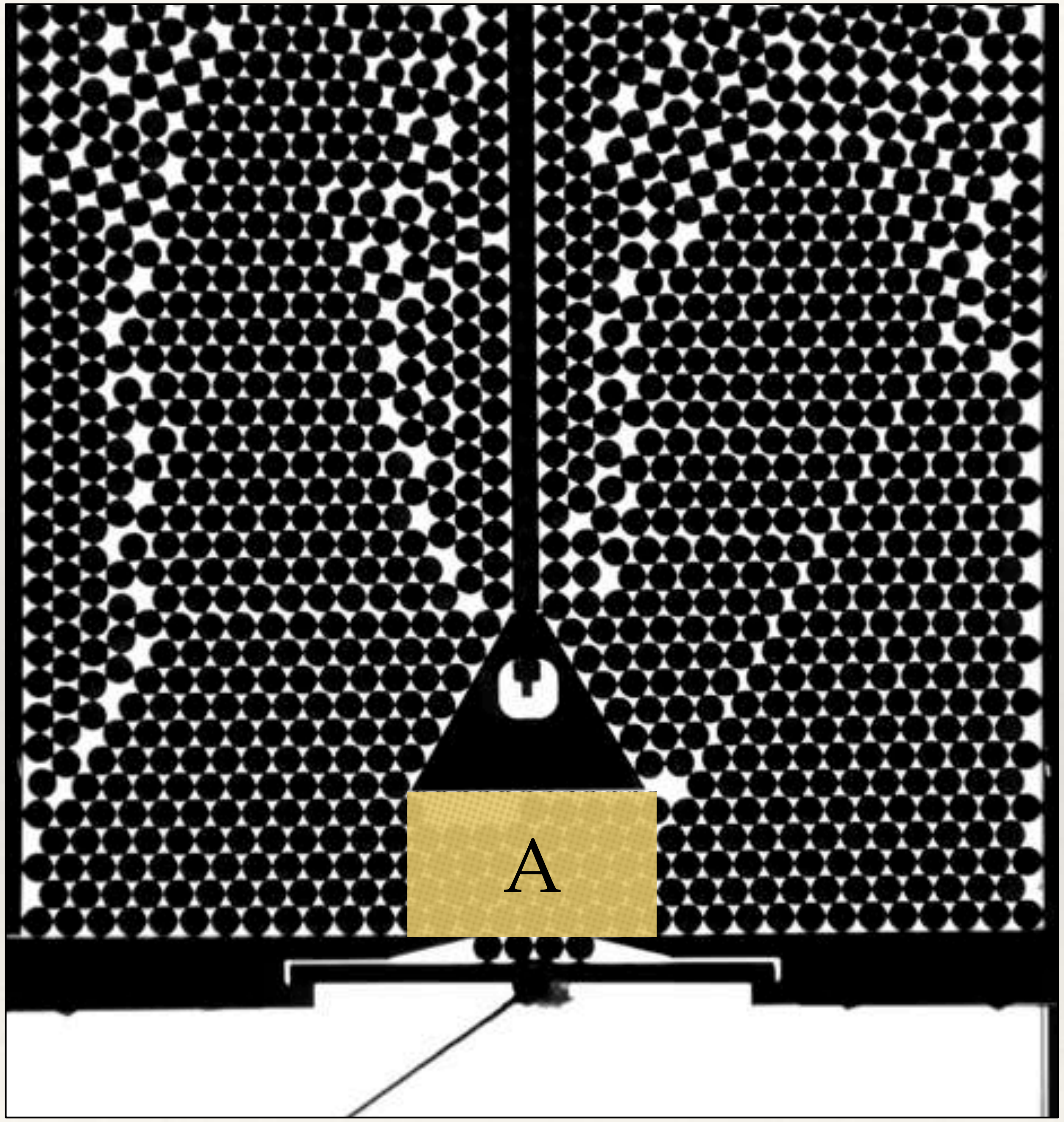


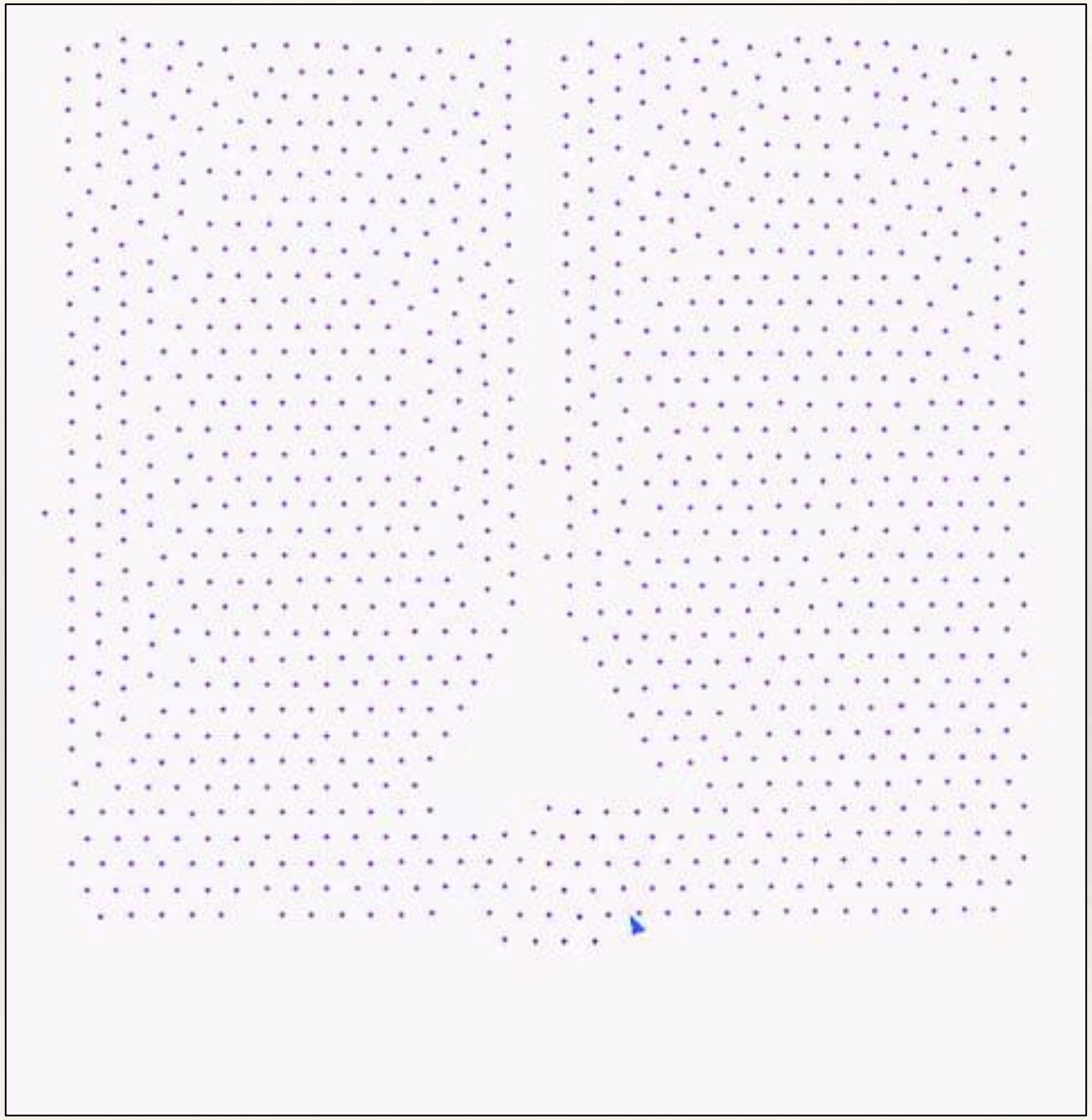


$W = 25 \text{ mm}$ $L = 30 \text{ mm}$

17 times slow movie

Triangular obstacle





$W = 25 \text{ mm} \qquad L = 30 \text{ mm}$

17 times slow movie

Summary of discharge flow experiment

- Granular discharge flow around an obstacle is captured by a high speed camera.
- PDF of velocity distribution obeys exponential form in vertical direction and (s[illegible]) Gaussian form in horizontal direction
- To prevent the clogging, sufficient void space is much more crucial than the grain activity (fluctuation or granular temperature).

Please visit POSTER 7 (by K. Endo) for more details!

Thank you