Particle Entrainment under Turbulent Flow Conditions

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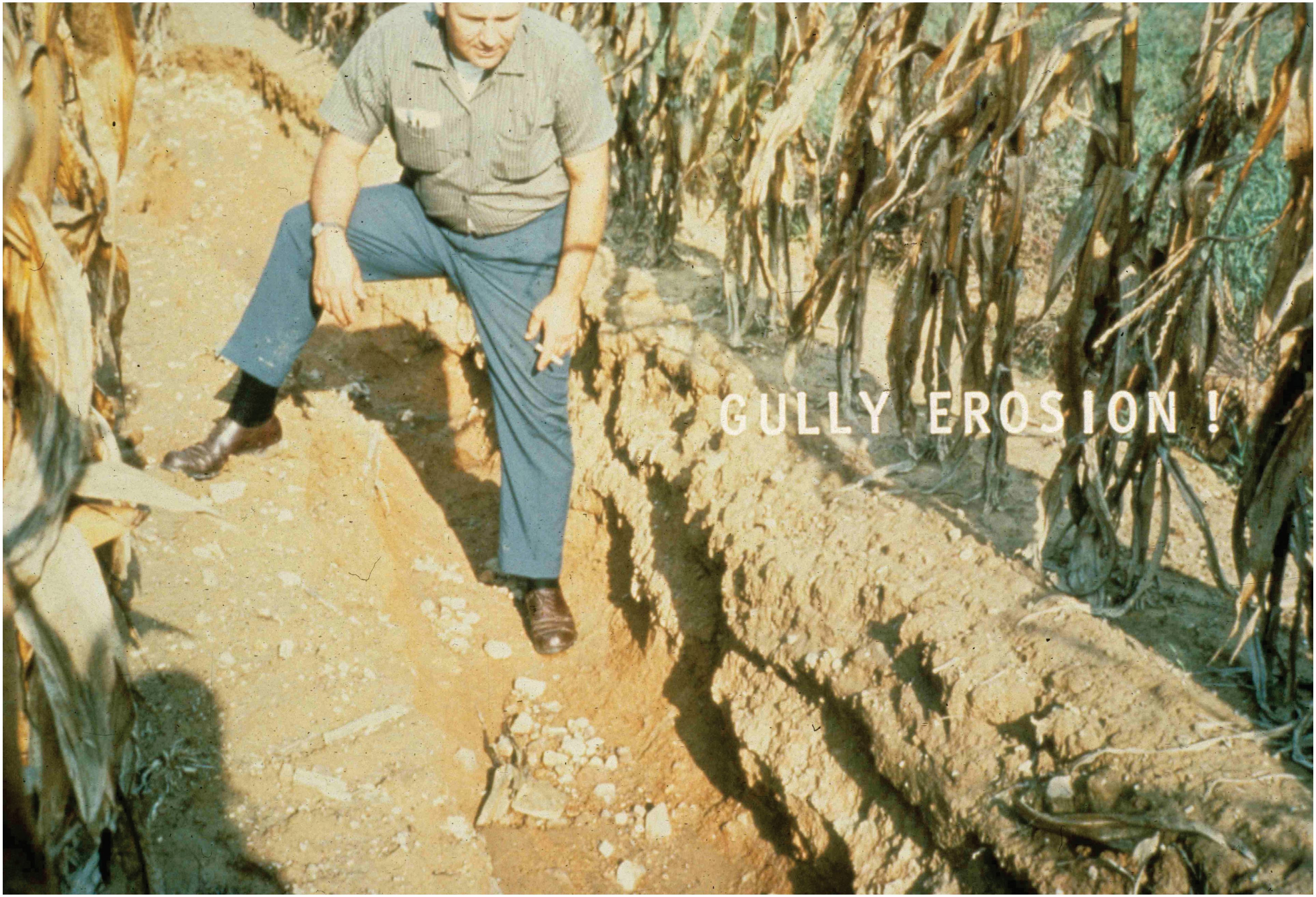
Backyard Erosion

Coastal Erosion

Gully Erosion

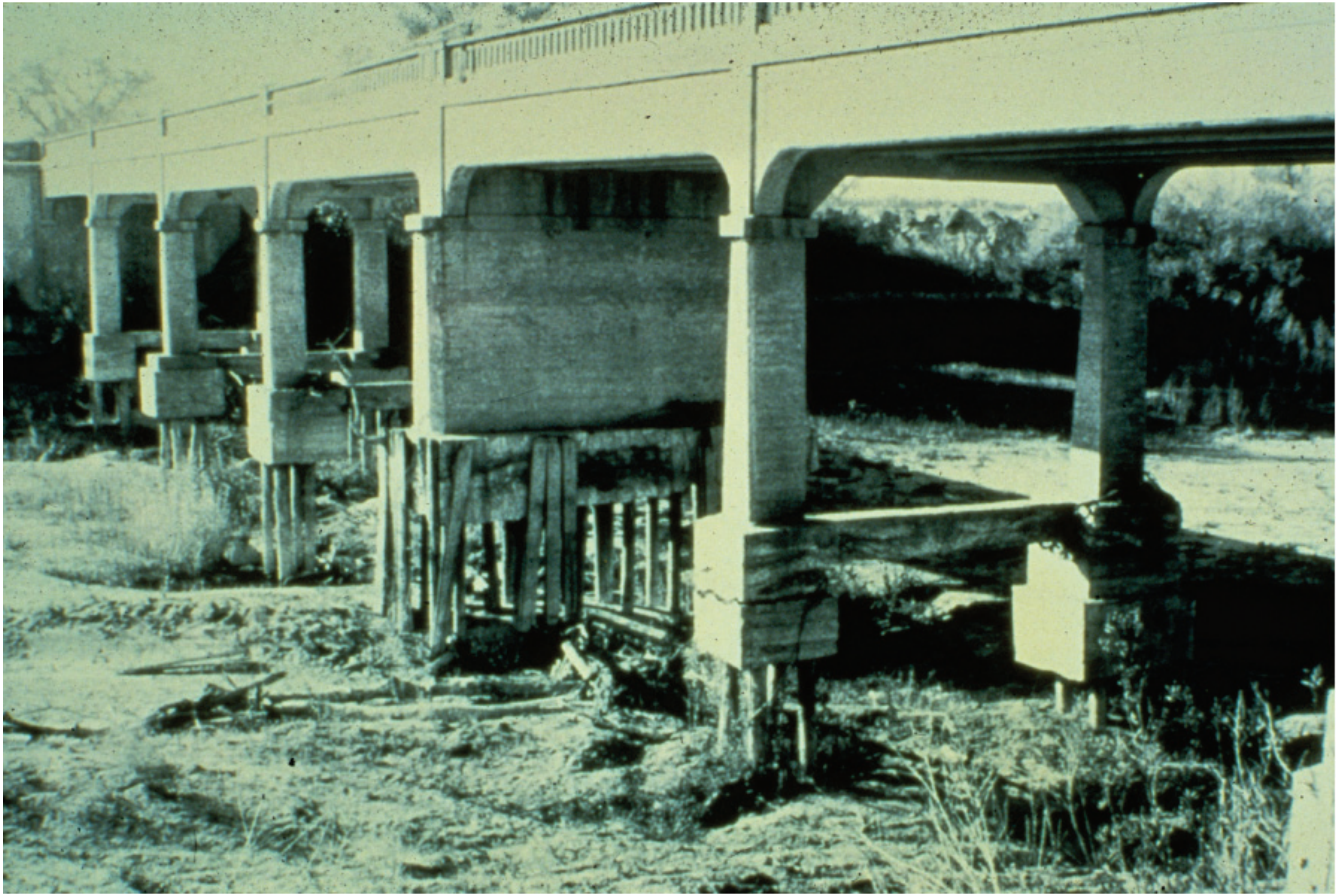


River with Heavy Sediment Load

2. Boulder deposited on the Hwy 35 roadbed. More of these bad boys went into Mineral Creek where they were dug out just today (1/23/07)

3. Hwy 35 bridge over White River completely plugged underneath by 25 ft of rock, and the bridge itself buried. This is the downstream side.

4. 200 yards north of the bridge, the river found a new route where iron Creek used to flow thru the 5 ft culvert. The river was later placed into two 8 ft culverts here to carry the water during the re-opening of the main channel and they will remain for future emergencies.



Pier foundation exposure due to river bed degradation, Cache River, CA

Soil Erosion/Contaminant Transport

- Overall erosion of the continental surface via water and wind amounts to 80 bn metric tones annually; 20 bn of the eroded sediment is delivered by rivers to the oceans
- The redistribution of material over the surface of the earth affects most of its physical, chemical and biological processes in ways that are not understood and which are exceedingly difficult to comprehend
- Dynamic interplay between fluctuating turbulent fluid forces and particle dislodgement for flows over an erodible boundary constitutes the **central problem in *earth surface dynamics* and many *industrial processes***

Early Laboratory Studies:

Bed Material Transport

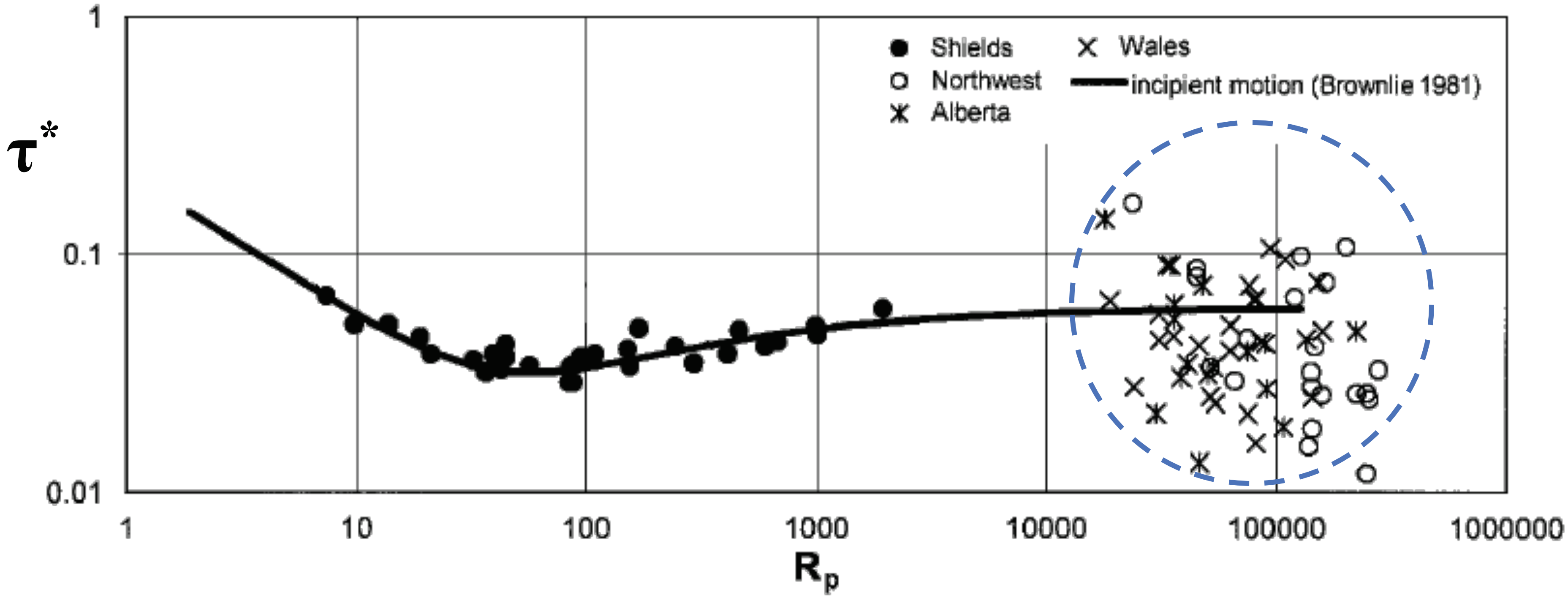
Outline

- Background – Need for a new threshold of motion criterion
- New hypothesis
- Particle dislodgement due to an instantaneous ***drag force*** – Electromagnet simulation experiments (fully exposed particle - rolling motion)
- Analytical solution to particle dislodgement
  - Due to instantaneous **lift force** (hidden particle - saltation)
  - Due to instantaneous **lift and drag forces** (exposed particle-rolling)
- Results from laboratory flume experiments
- Conclusion

Background

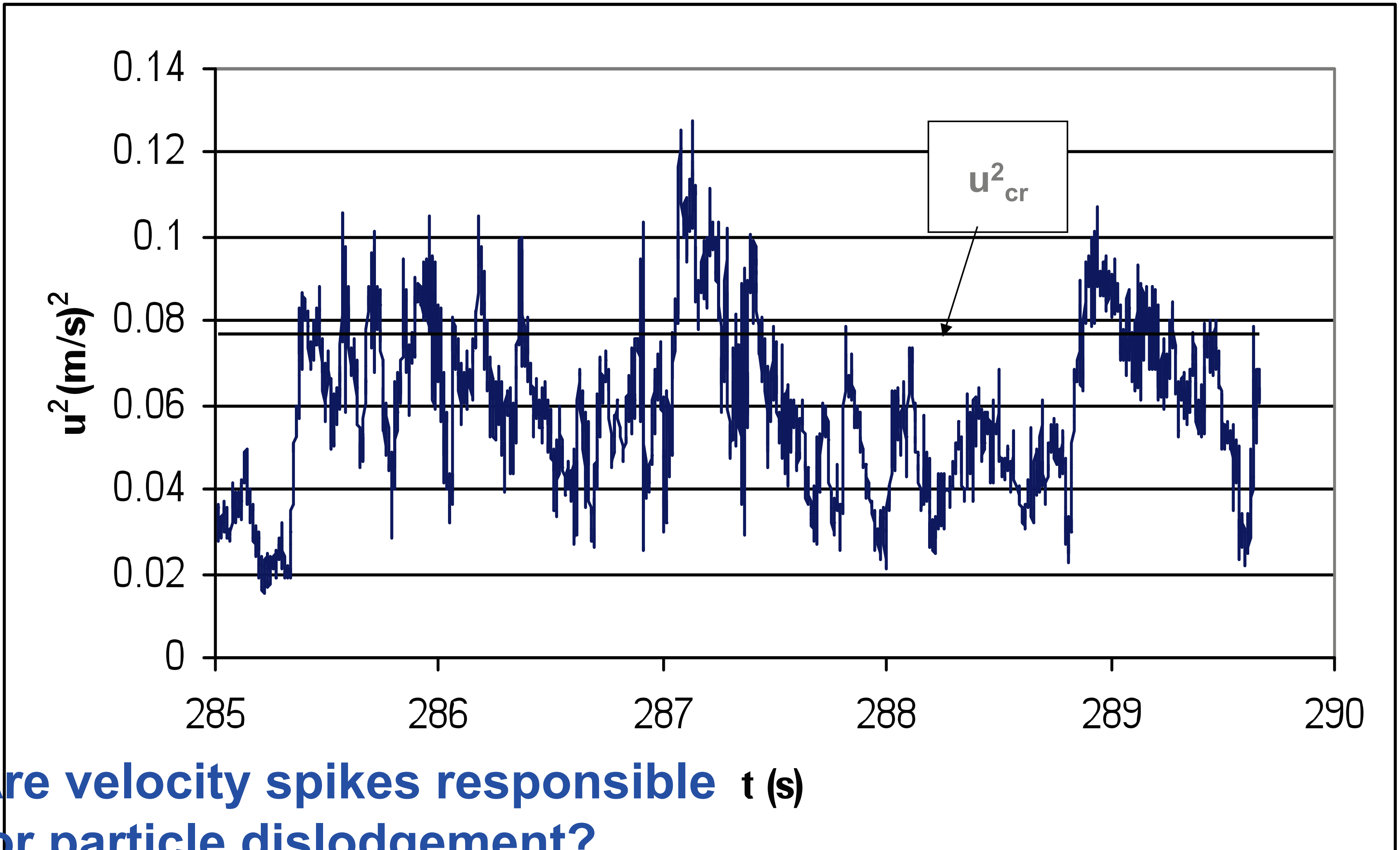
- Traditional approach for identifying threshold of motion conditions
  - Time-averaged characterization of boundary shear stress (Shields, 1936)
- Wide recognition of the role of instantaneous forces in turbulent flows on particle entrainment (Varenious 1650)
- Quantitative determination of the influence of turbulent fluctuations on threshold condition is rare

Present Initiation of Motion Criterion



Shields (1936)

Fluctuating turbulent fluid forces applied on a sediment particle located at the bottom of a channel flow



Are velocity spikes responsible for particle dislodgement?

Earlier VT study

Question

- Do ***all*** peak instantaneous turbulent events (higher than a critical value) result in particle entrainment?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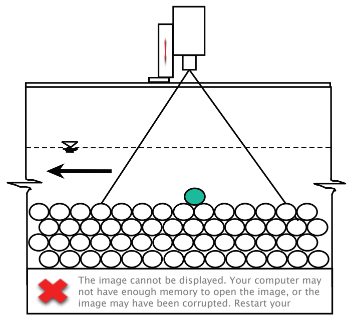
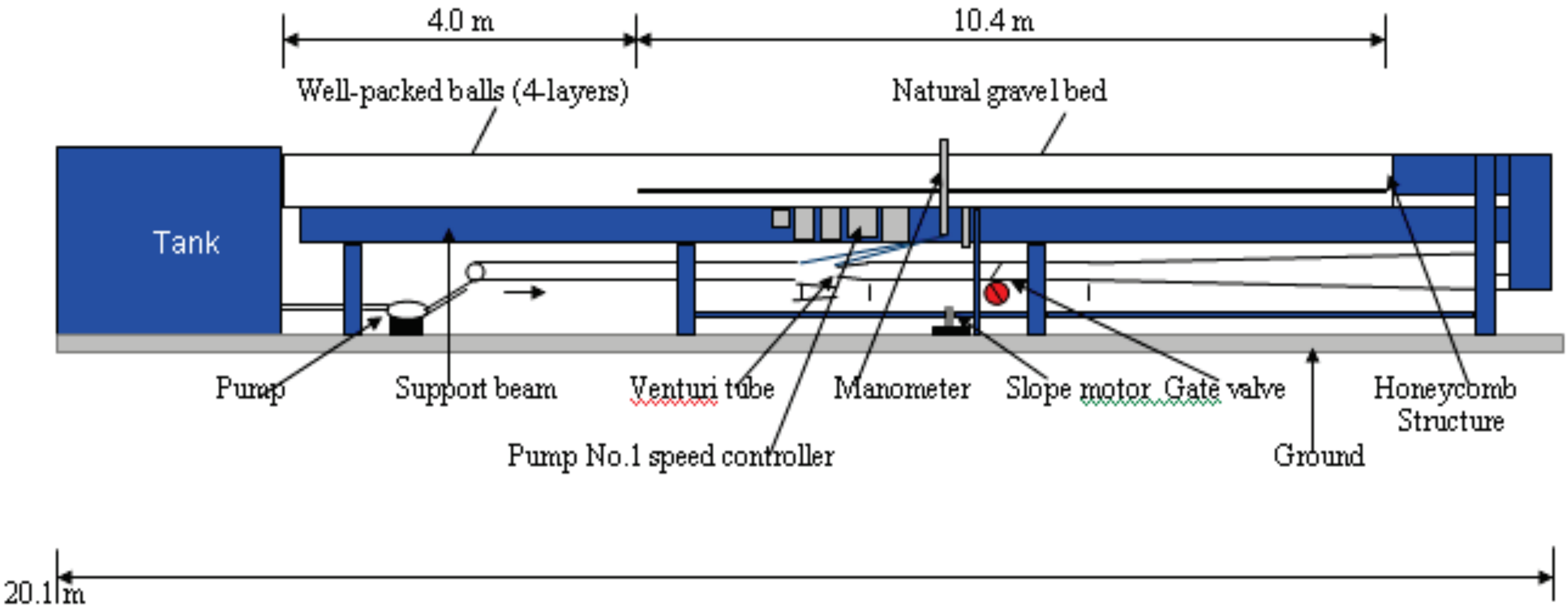
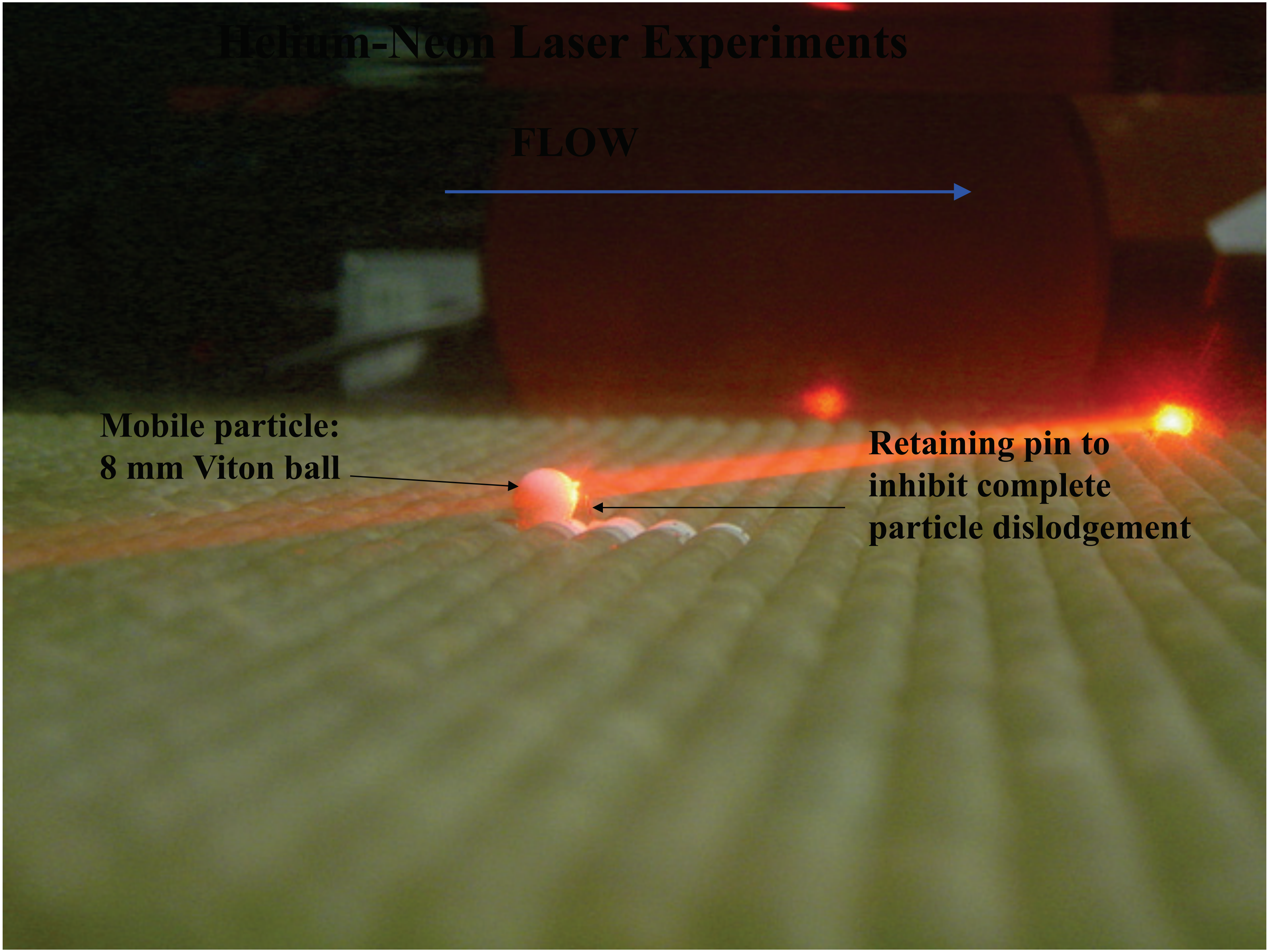
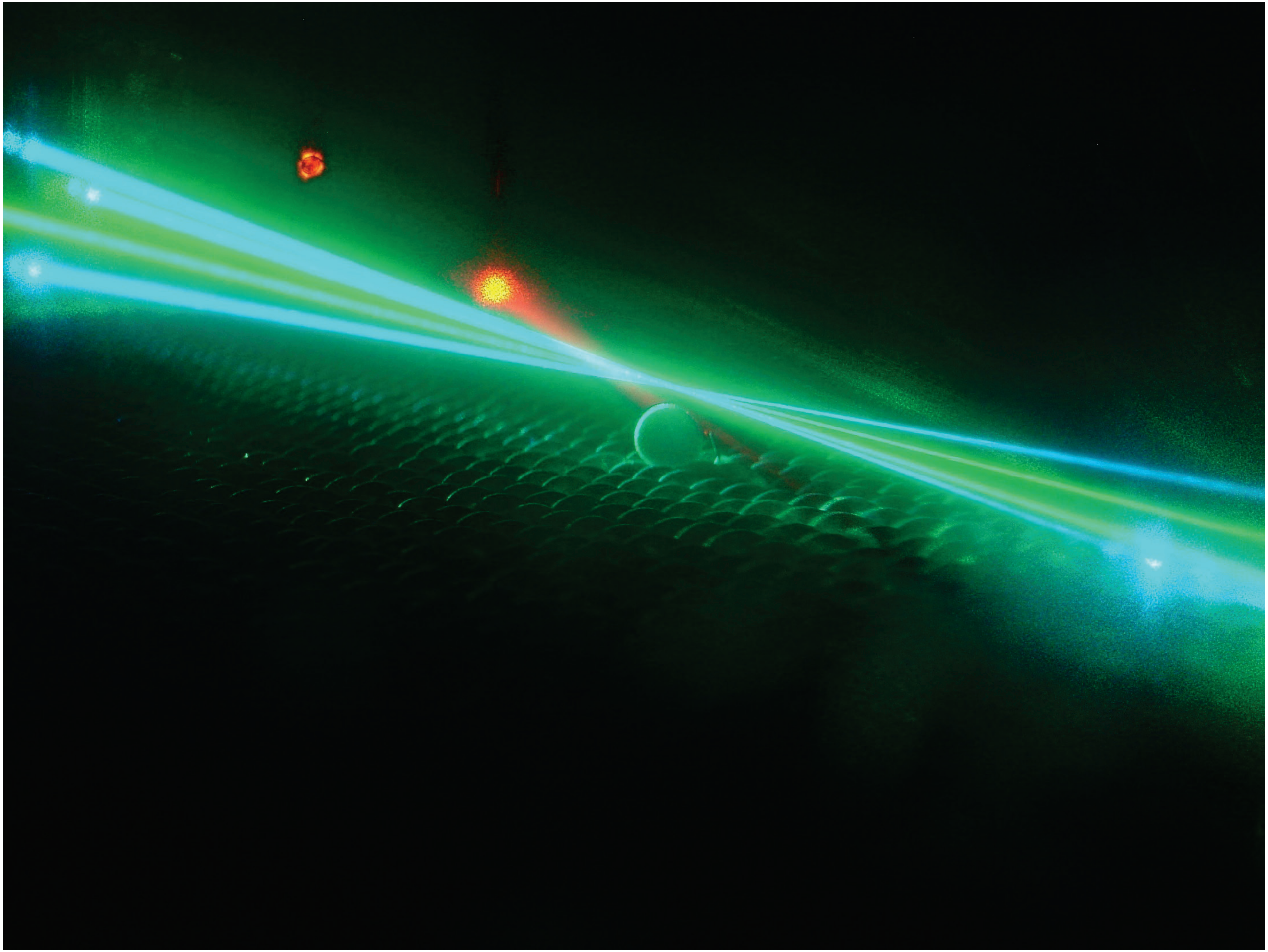
Experimental Set Up

Side view of test test section

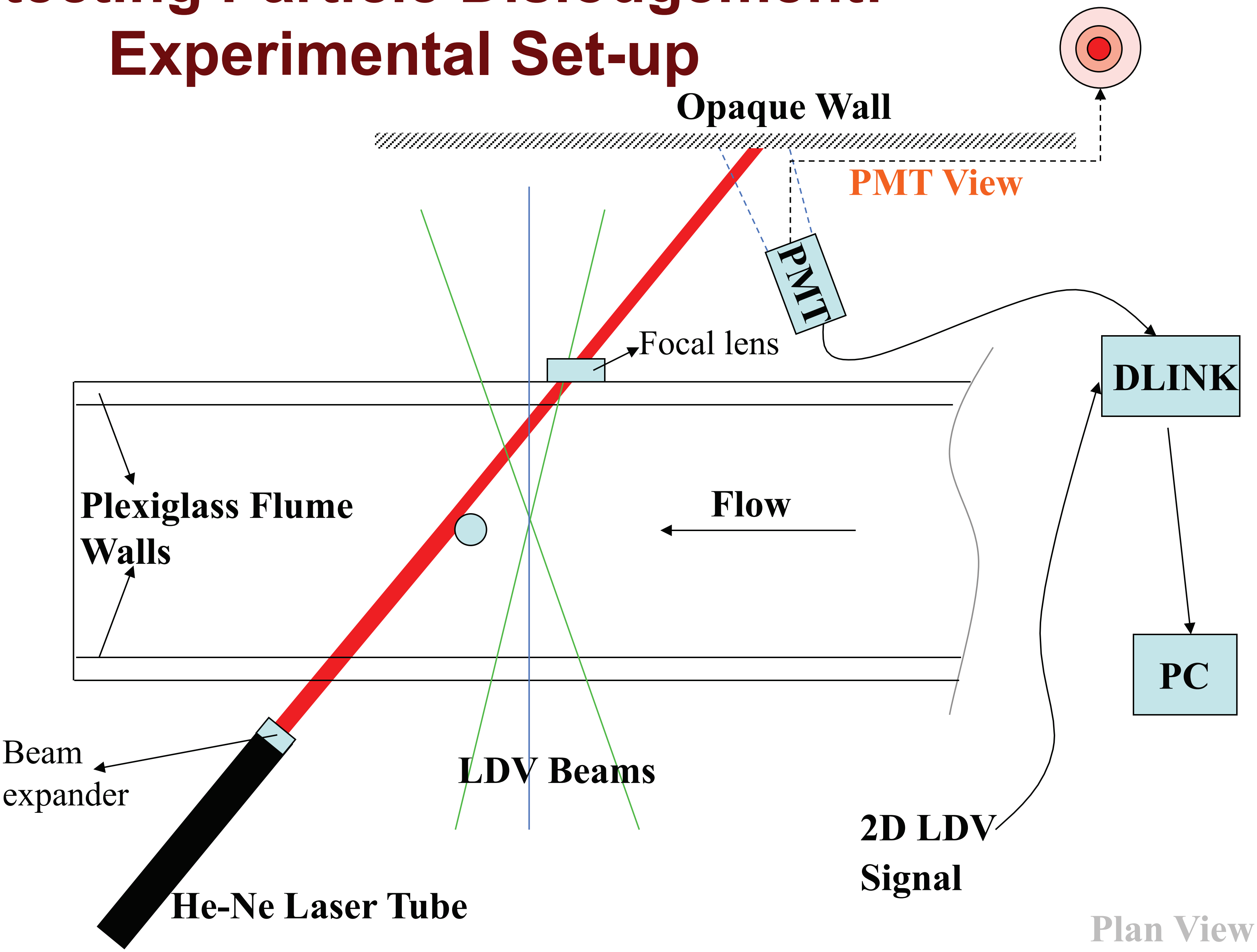





Helium-Neon Laser Experiments
FLOW
Mobile particle:
8 mm Viton ball
Retaining pin to
inhibit complete
particle dislodgement



Detecting Particle Dislodgement: Experimental Set-up



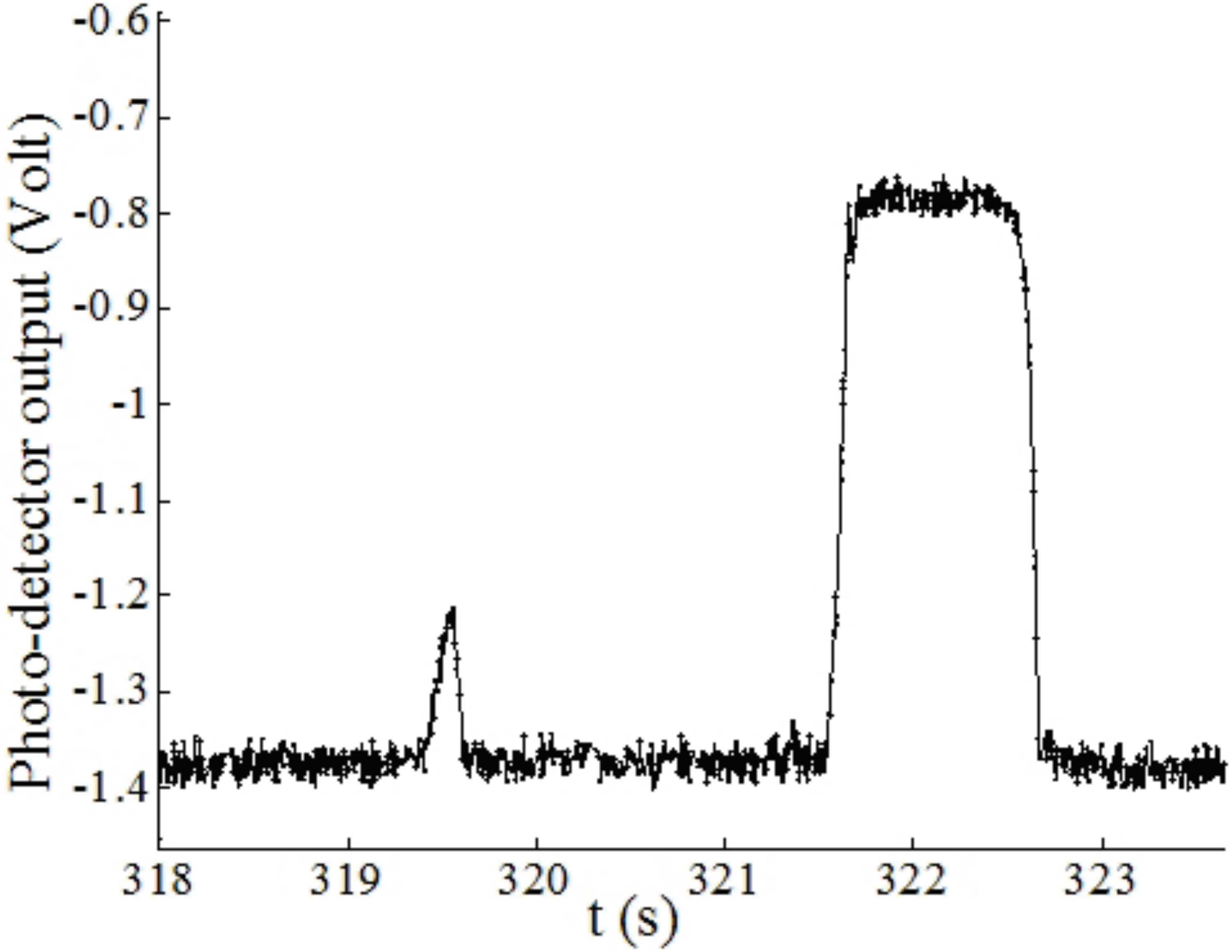
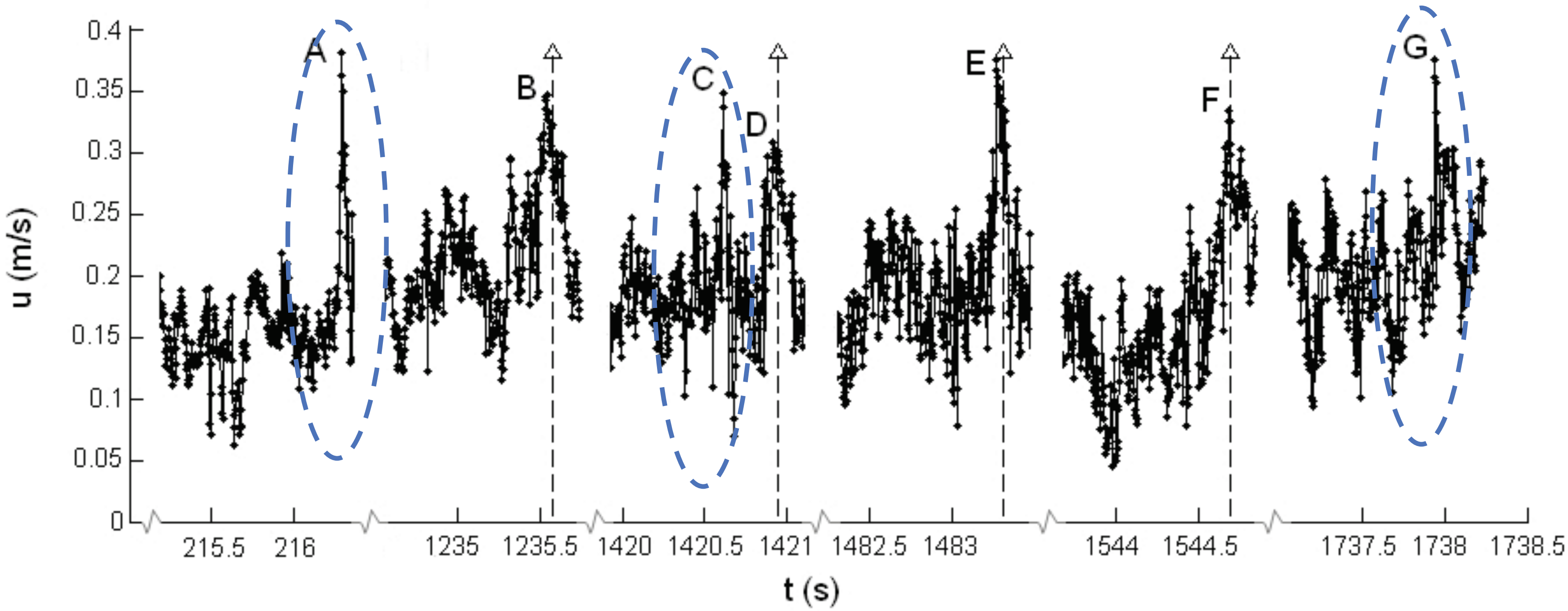


Photo-detector output (Volt)
-0.6
-0.7
-0.8
-0.9
-1
-1.1
-1.2
-1.3
-1.4
318
319
320
321
322
323
t (s)

Virginia Tech Experiments



Some *of the velocity spikes correspond to particle entrainment, but not all*

Early Laboratory Studies:

Bed Material Transport

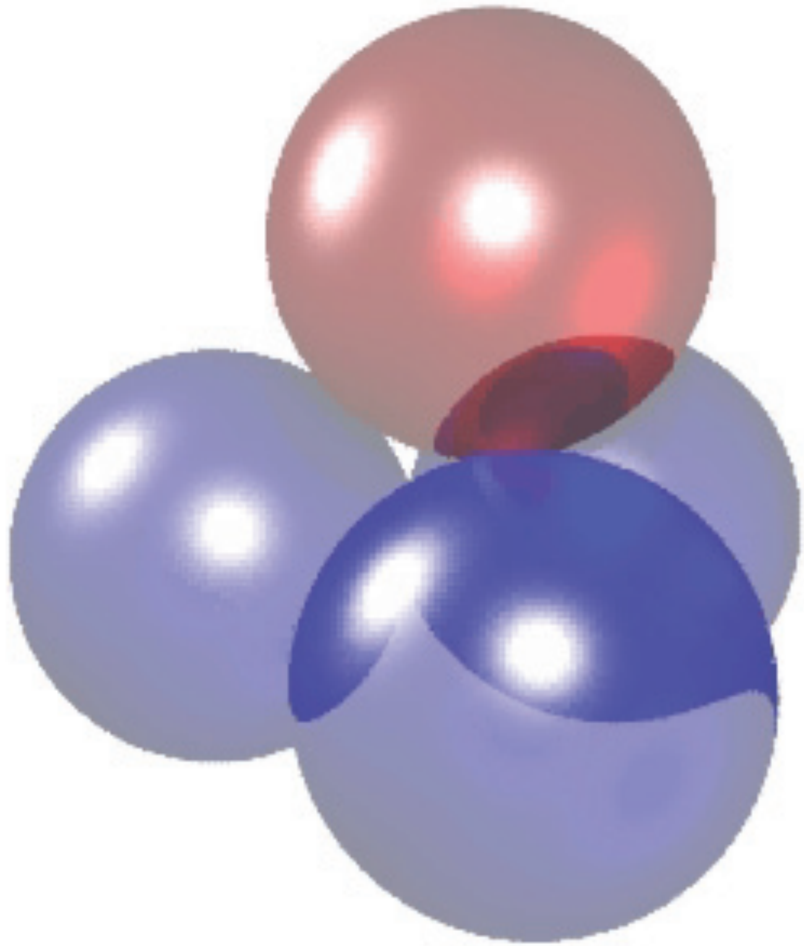
Result

- High instantaneous velocity values (which lead to large instantaneous drag forces) are ***necessary*** but ***not sufficient*** to dislodge a sediment particle

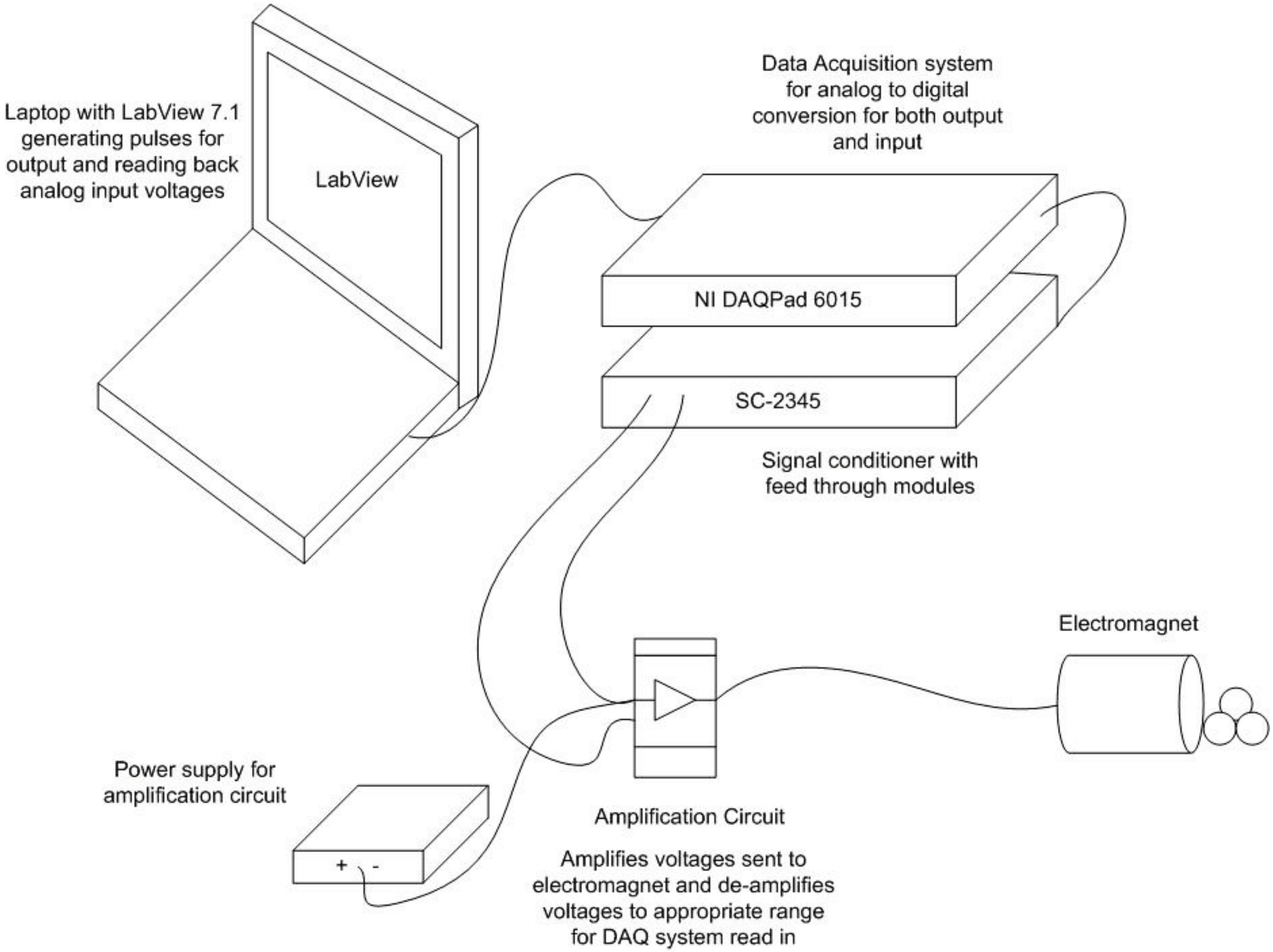
Hypothesis

- Force duration, besides force magnitude, is important in identifying threshold of motion conditions. A simple way to account for both aspects is to consider ***impulse*** as the appropriate parameter.

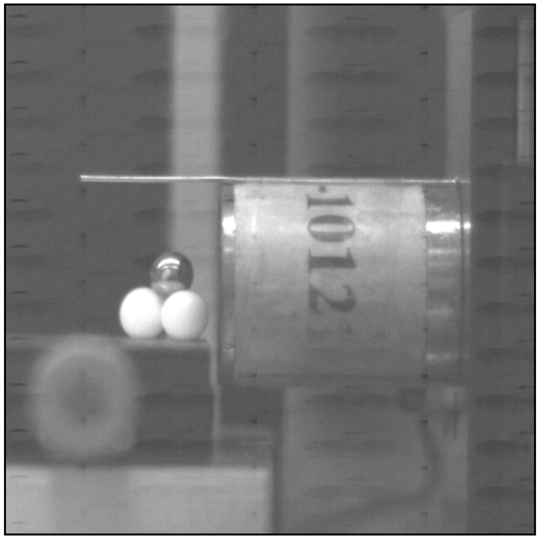
Simulation of Instantaneous Drag Force with an Electromagnet



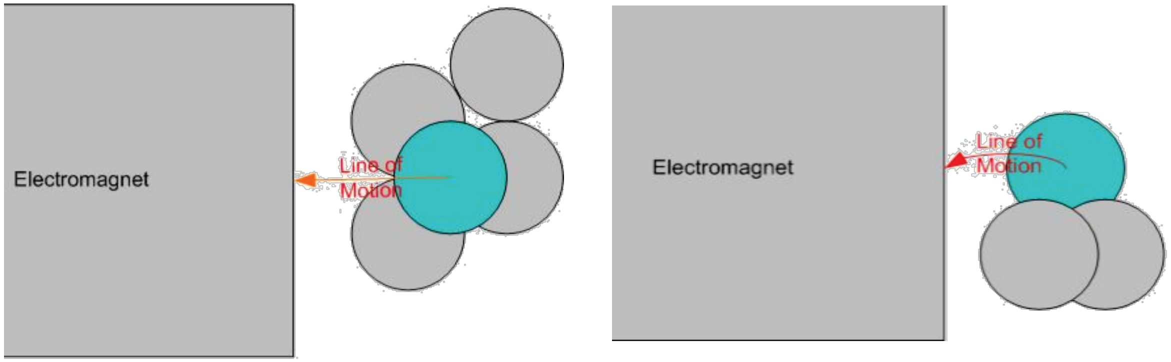
Electromagnet Experimental Setup

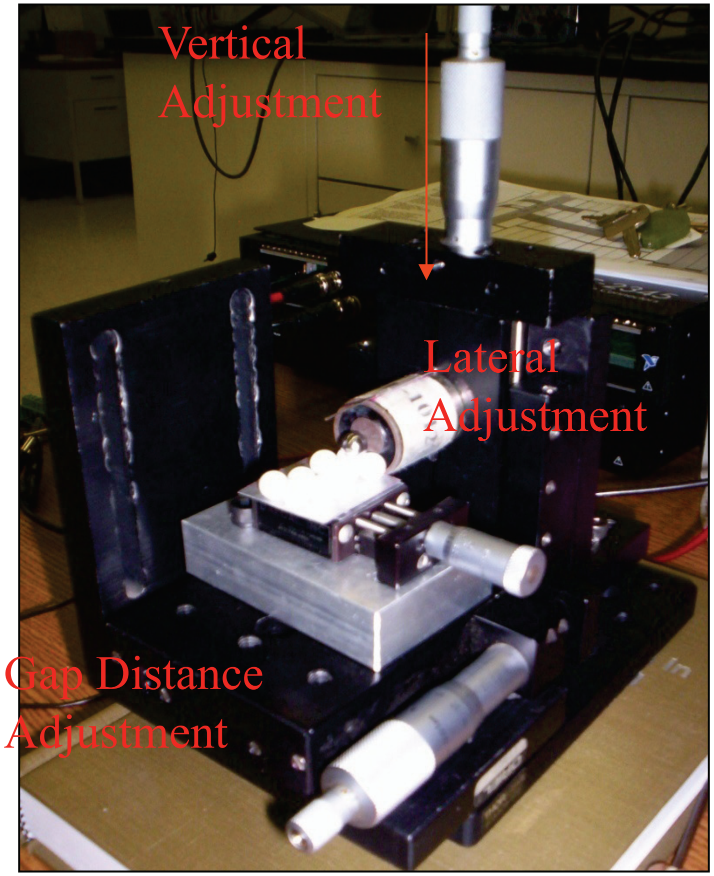


Experimental Setup



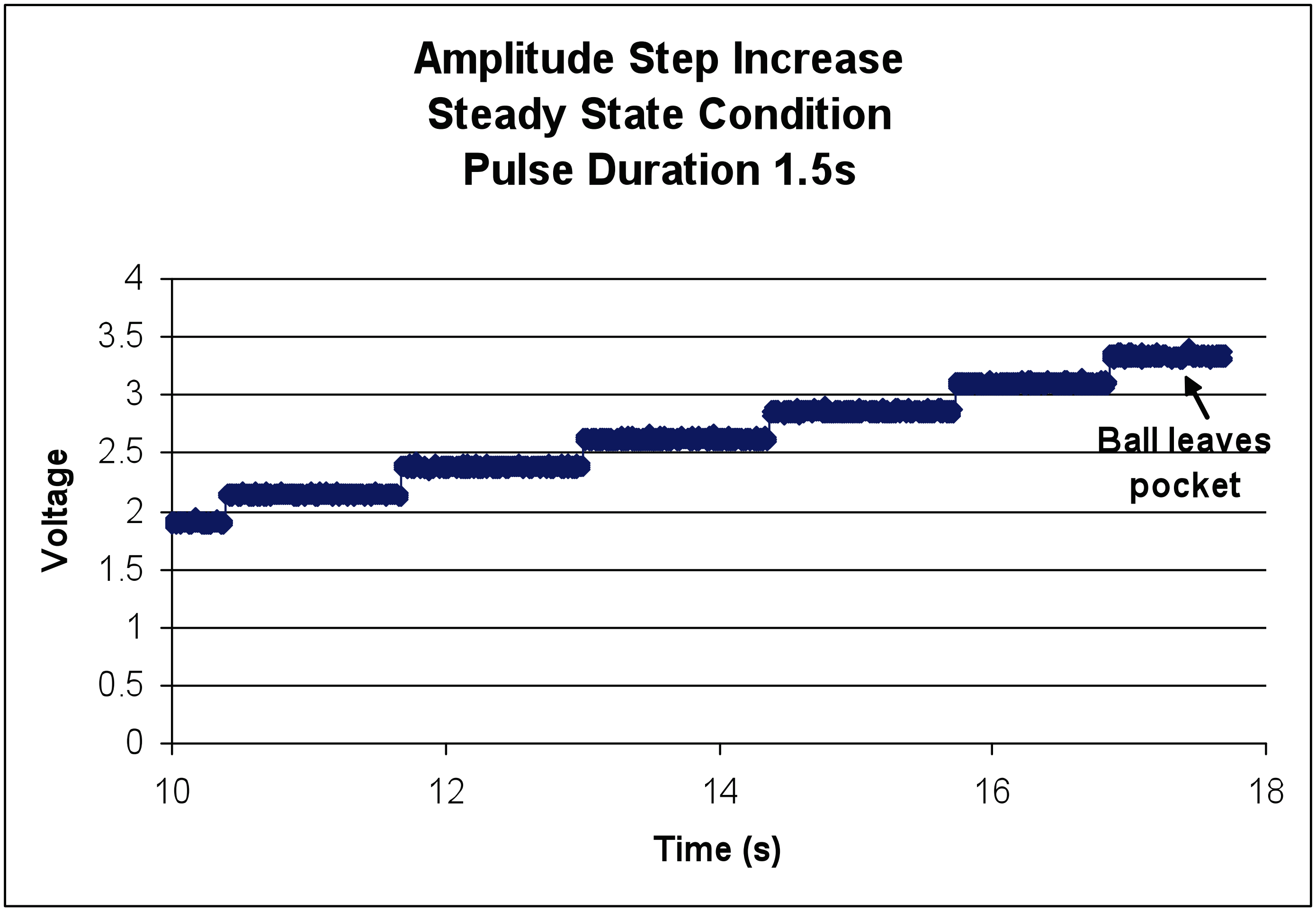
- Spherical particles
- Controllable magnetic forces
- Easiest path of motion
- “Drag” force only, no “lift”





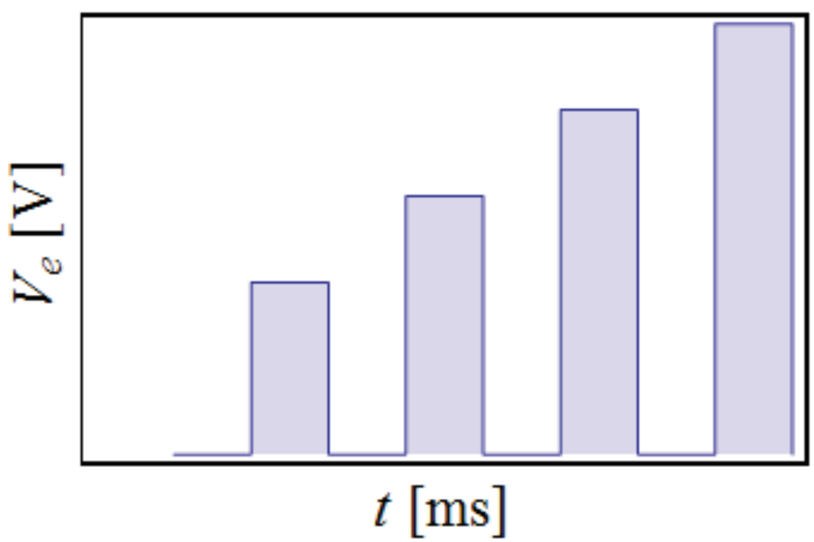
Experiment Objectives

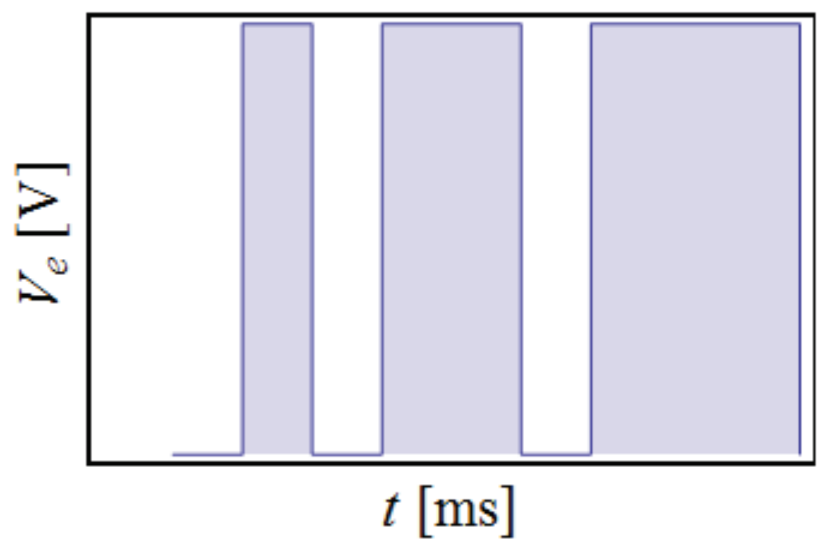
- Determine *steady state threshold* voltage value necessary to remove the ball from its pocket



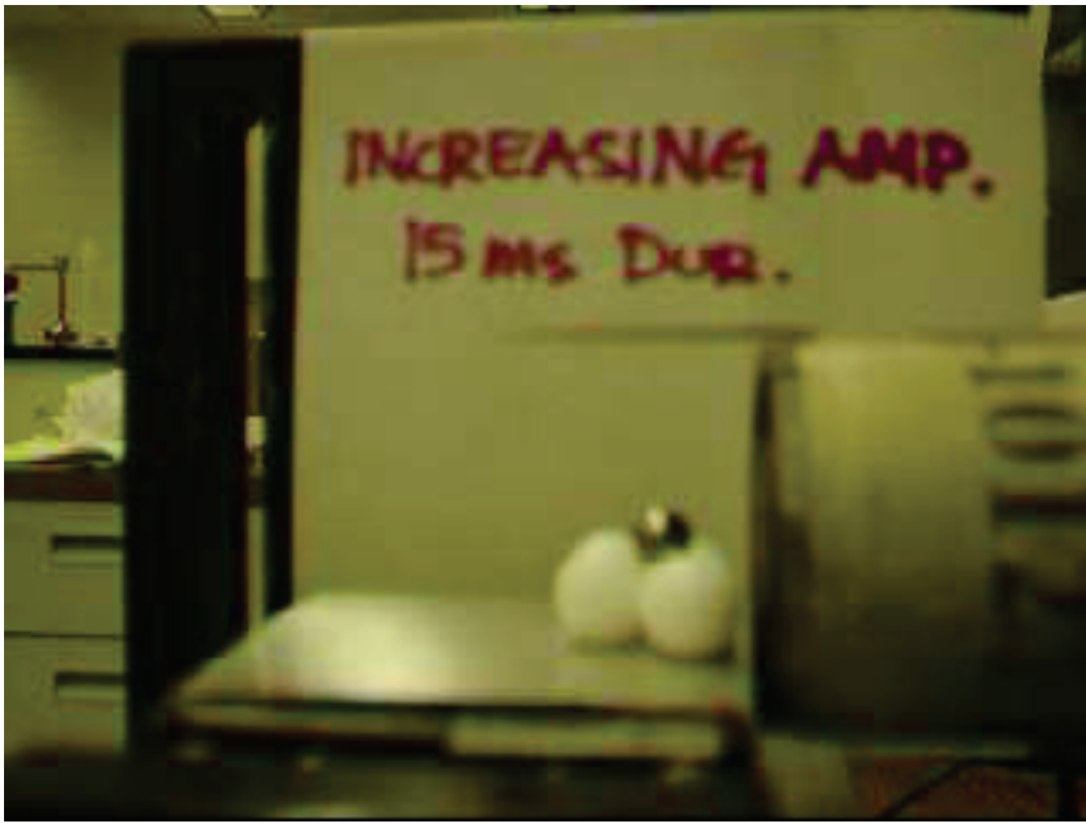
Experiment Objectives

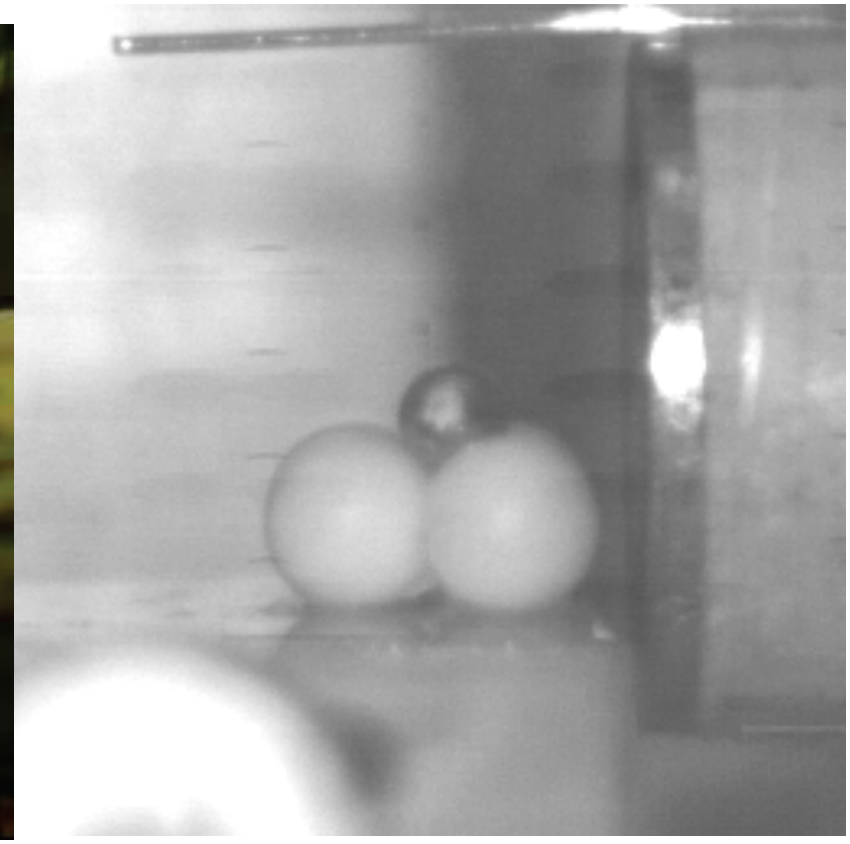
- Determine minimum voltage pulse duration and amplitude combinations necessary for dislodging the ball from its pocket





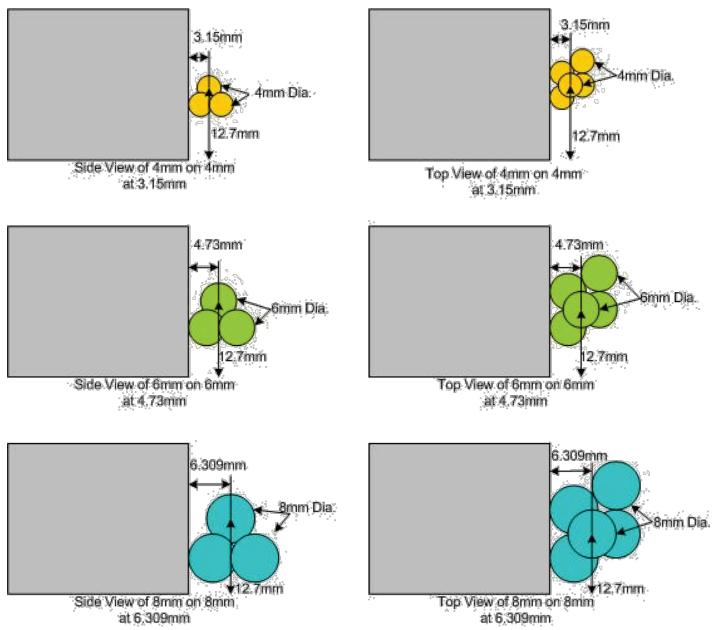
Pulse Duration: 15 ms; Increase amplitude until ball dislodgement occurs





Experiments

Same Geometry

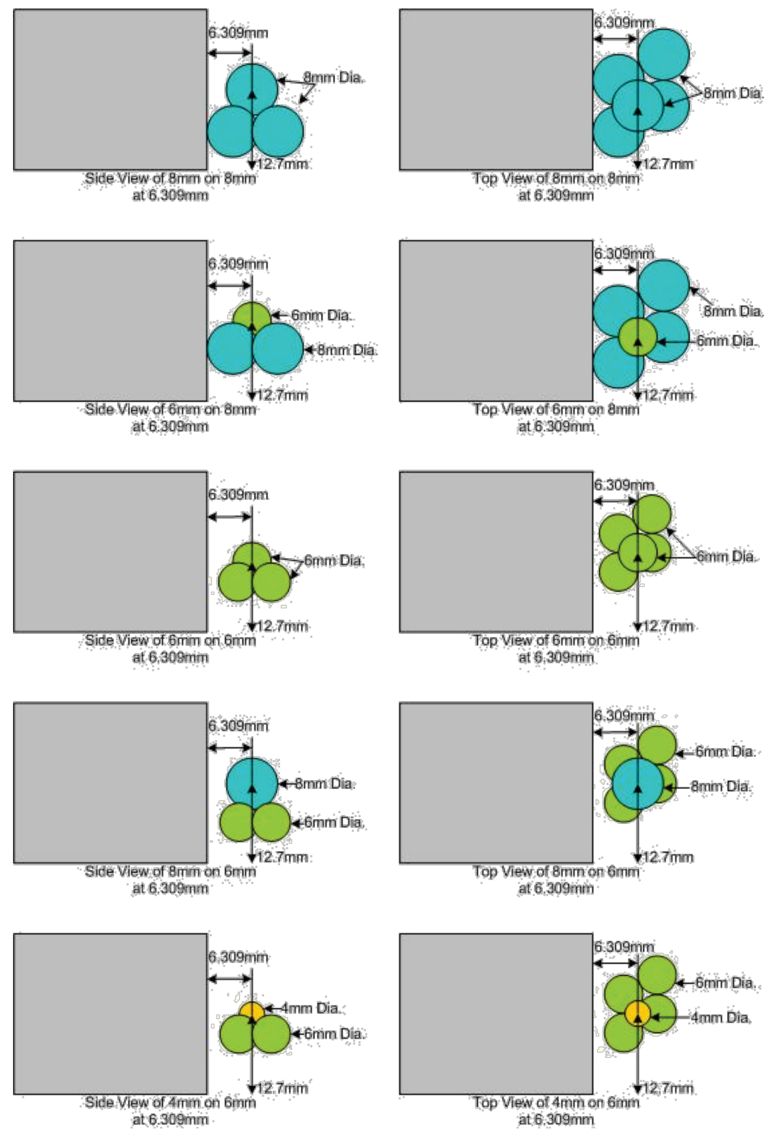


Side view

Top view

- 7 Setups
- 3 repeatable pulses
- 1709 experiments

Equal Distance



Experiment Objectives

- Relate voltages and pulse durations to impulse required to remove particle from pocket

Constant for magnet

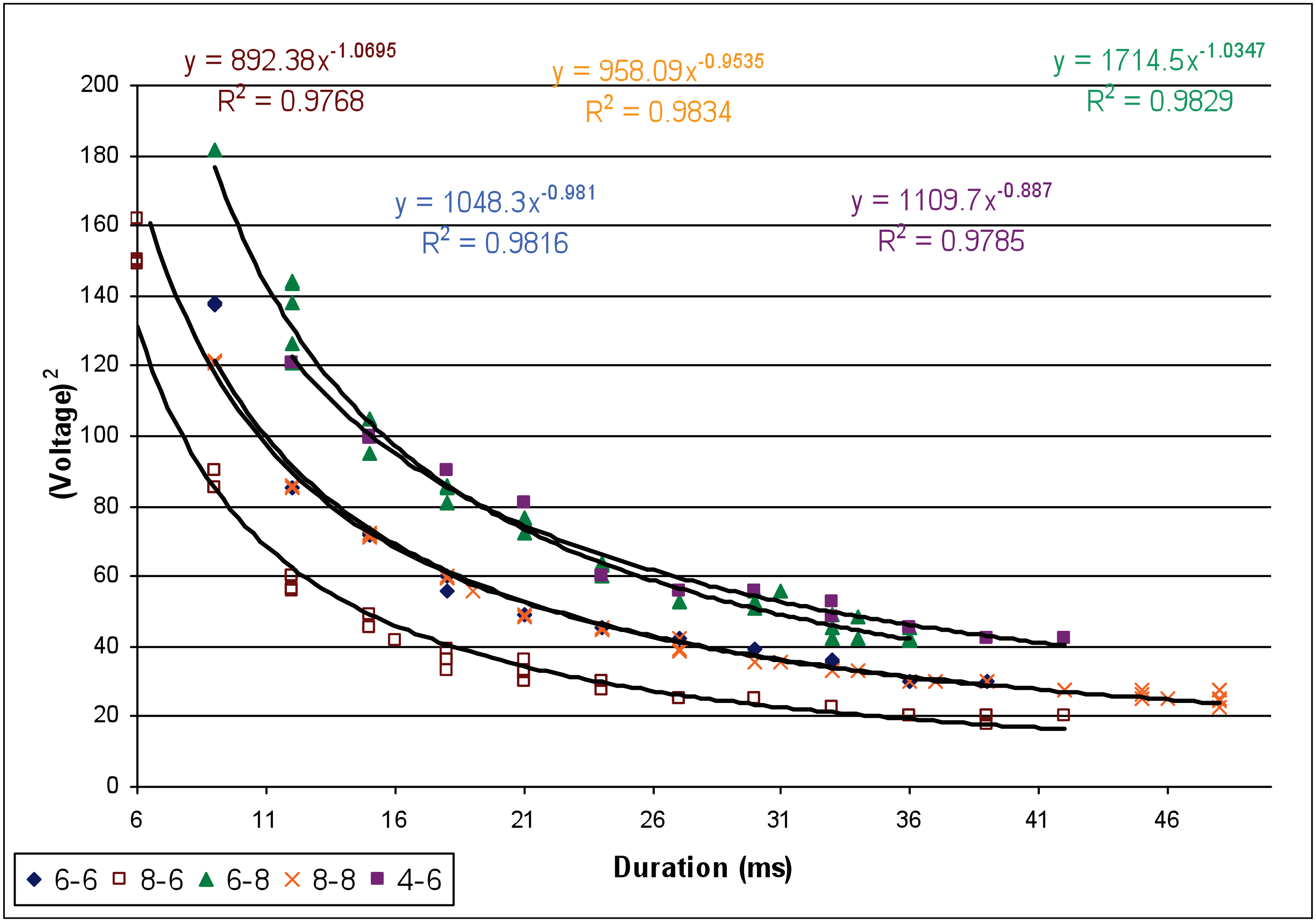
Electromagnetic Force
$$F = \frac{\mu A N^2 I^2}{h^2}$$

Constant for experiment

Ohm's Law
$$V = IR \rightarrow I = \frac{V}{R}$$

$$F \propto V^2$$

Equal Distance Experiments



Best Fit Results

Ball Size	Bed Size	Distance from Magnet	Best-fit Equation	R^2
8 mm	8 mm	6.31 mm	$V^2 = 958.09\ T^{-0.9535}$	0.9834
6 mm	6 mm	4.73 mm	$V^2 = 745.33\ T^{-1.0018}$	0.9821
4 mm	4 mm	3.15 mm	$V^2 = 449.27\ T^{-1.0316}$	0.9559
8 mm	6 mm	6.31 mm	$V^2 = 892.38\ T^{-1.0695}$	0.9768
6 mm	8 mm	6.31 mm	$V^2 = 1714.5\ T^{-1.0347}$	0.9829
6 mm	6 mm	6.31 mm	$V^2 = 1048\ T^{-0.9810}$	0.9816
4 mm	6 mm	6.31 mm	$V^2 = 1109.7\ T^{-0.887}$	0.9785

Best Fit Results

6mm on 6mm at a distance of 4.73mm Equation

$$V^2 = 745.33\ T^{-1.0018}$$

$$F \propto V^2$$

$$F = 745.33\ T^{-1.0018}$$

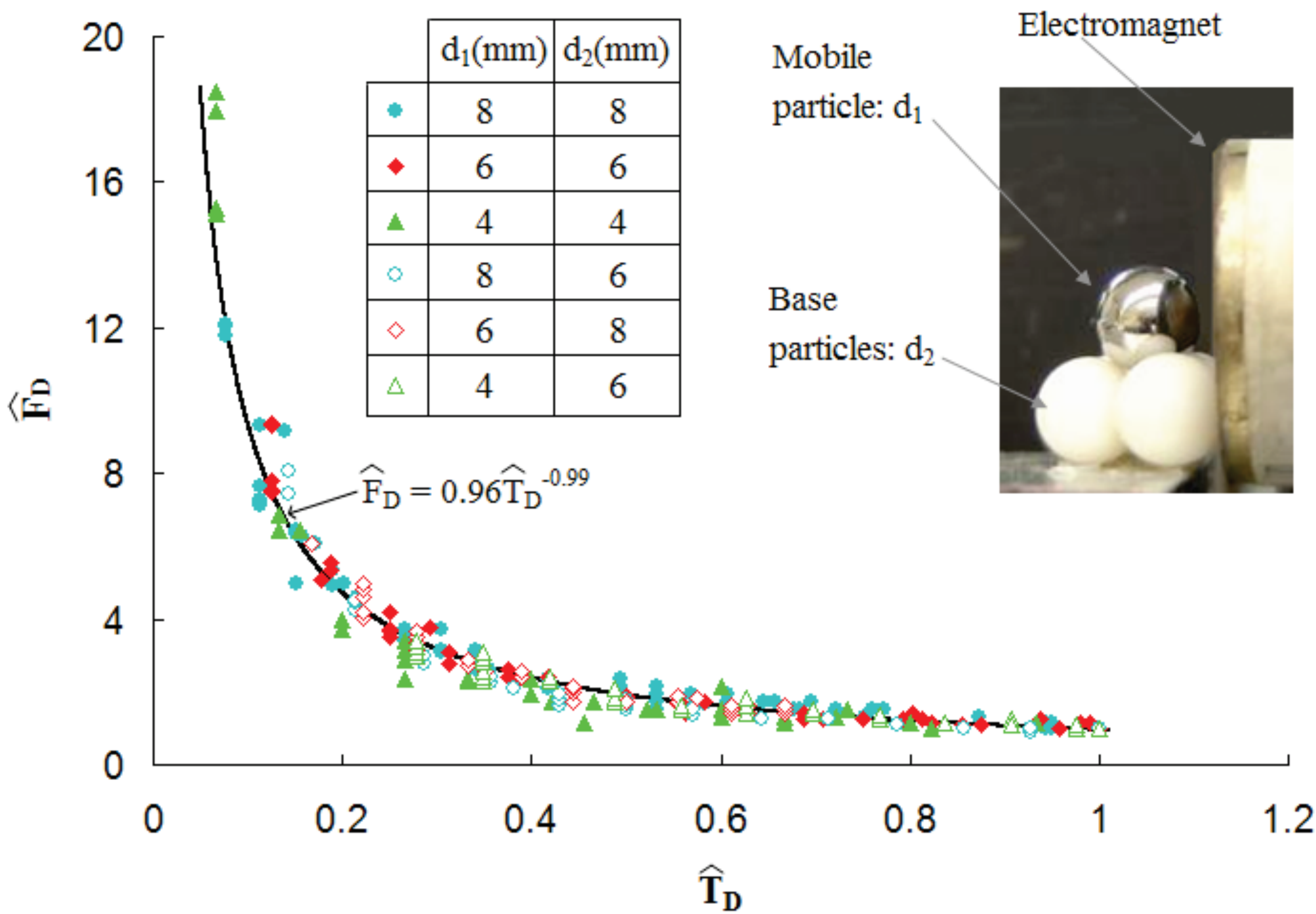
Substitute and Rearrange

$$F \cdot T^{1.0018} = 745.33$$

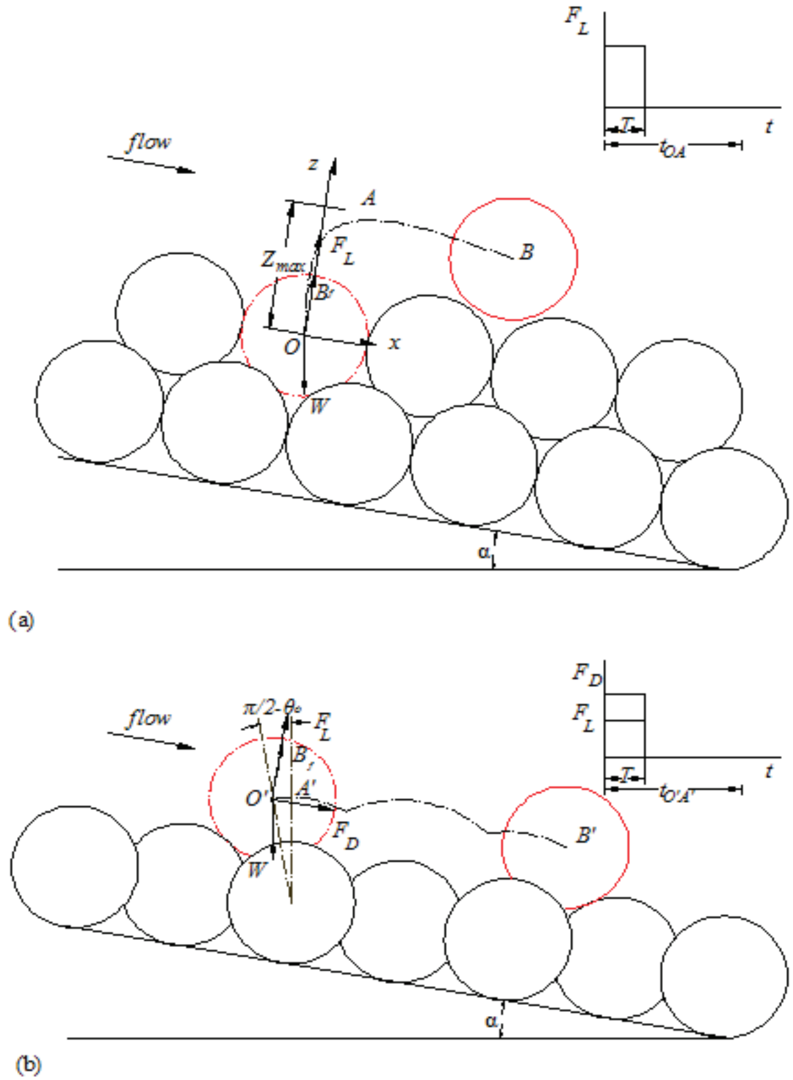
$$F \cdot T = \text{Impulse}$$

Impulse = Constant

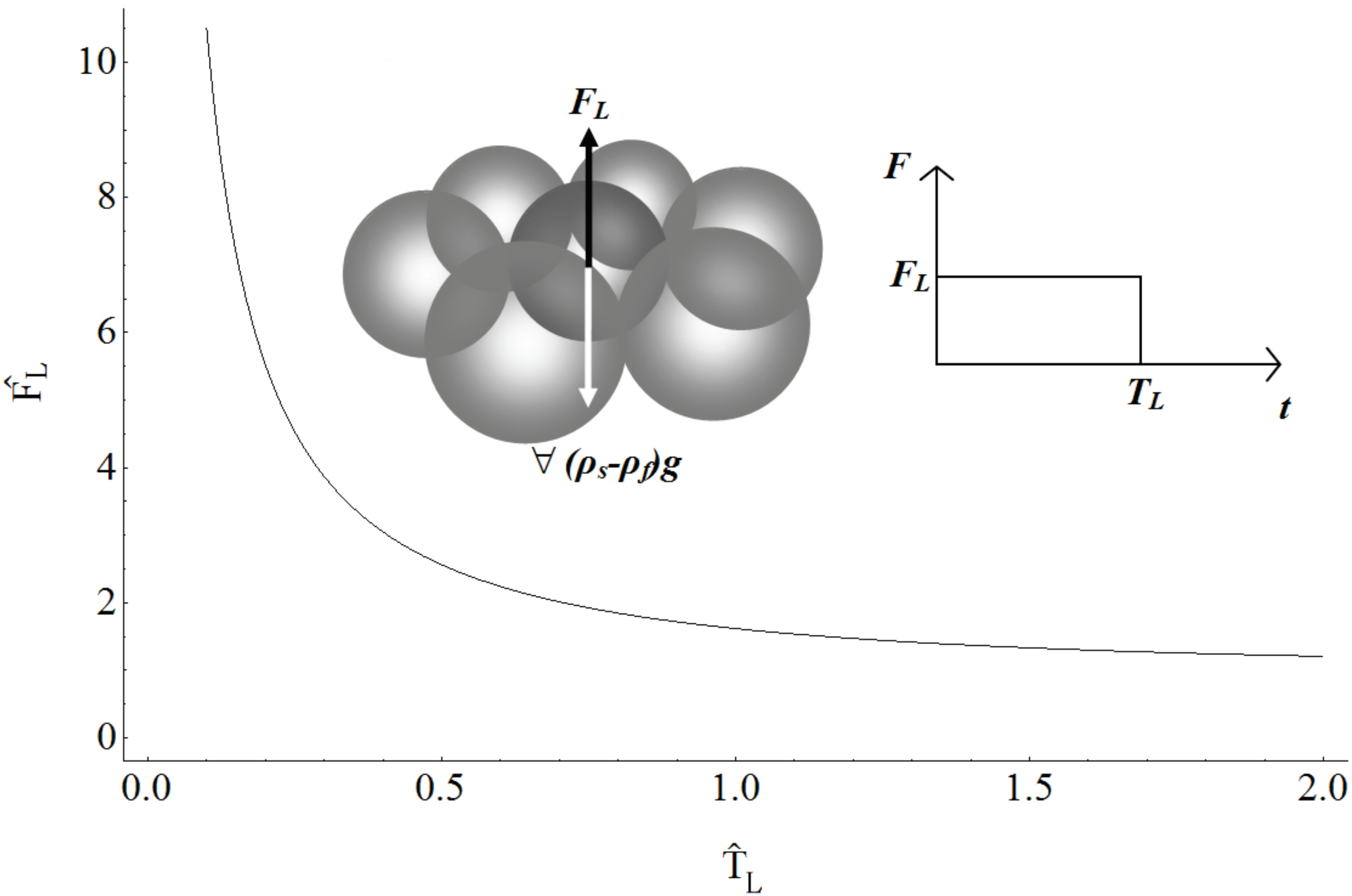
Electromagnet Experiments



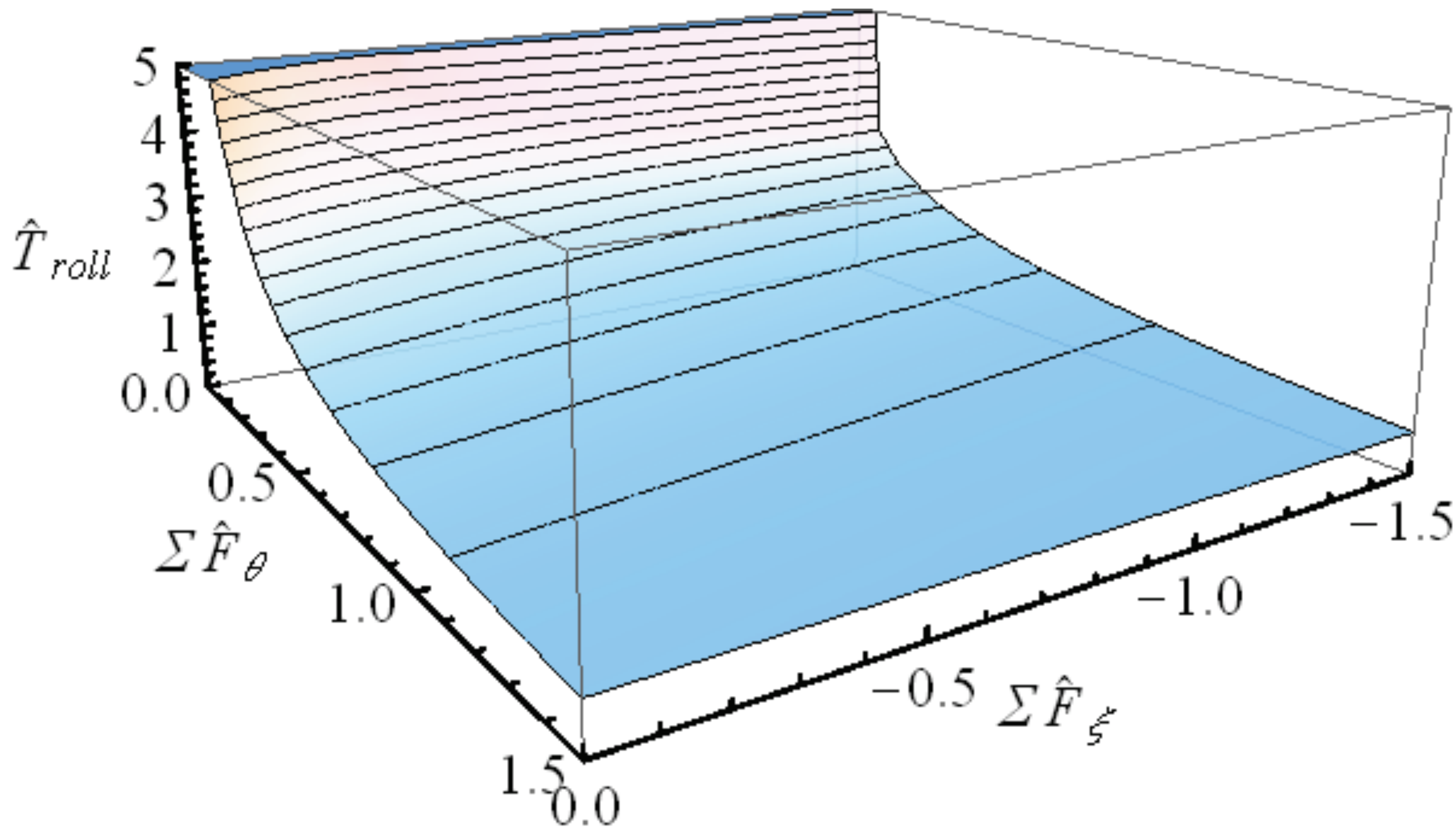
Grain Dislodgement via Saltation and Rolling Modes-Analytical Approaches



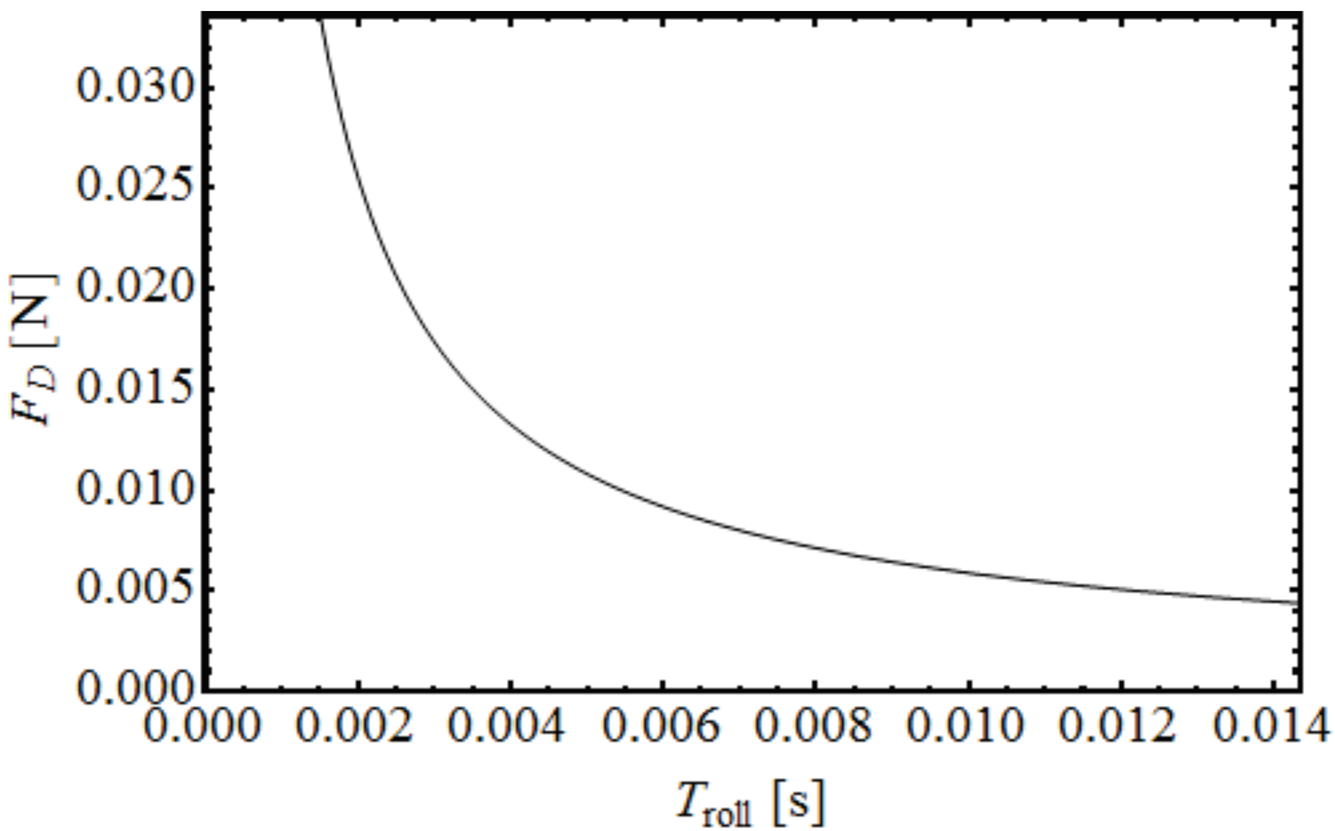
Theoretical Lift Analysis



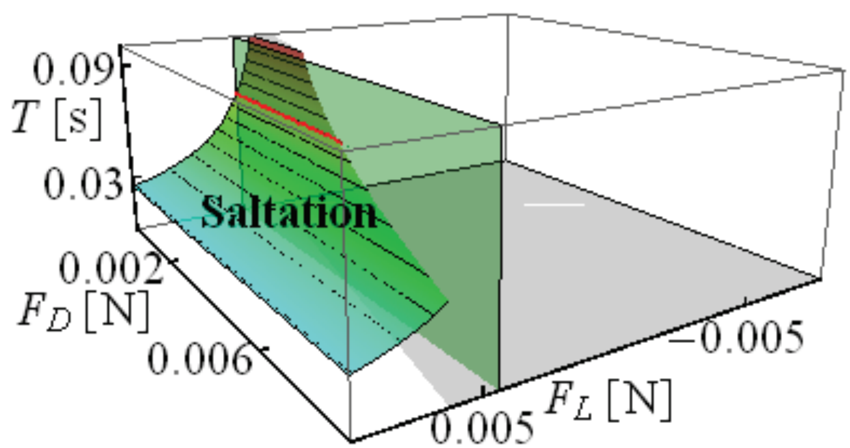
Theoretical Rolling Analysis with both Lift & Drag Forces Present

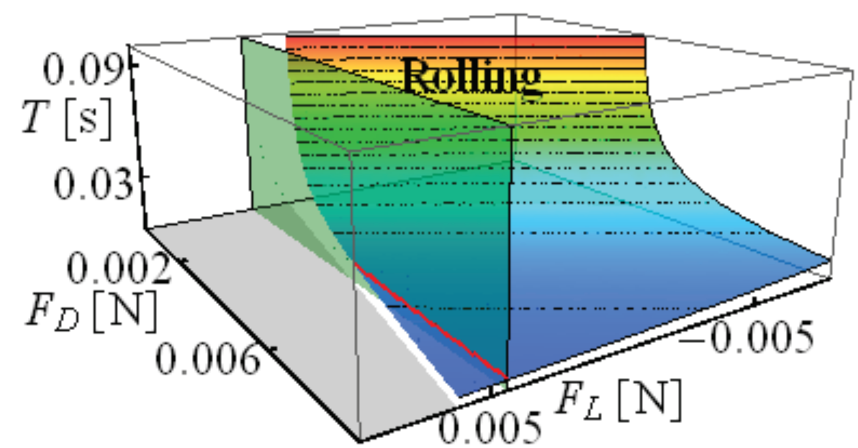


Theoretical Rolling Analysis with Zero Lift Force



Threshold Surfaces for Saltation & Rolling Motion for an Exposed Particle

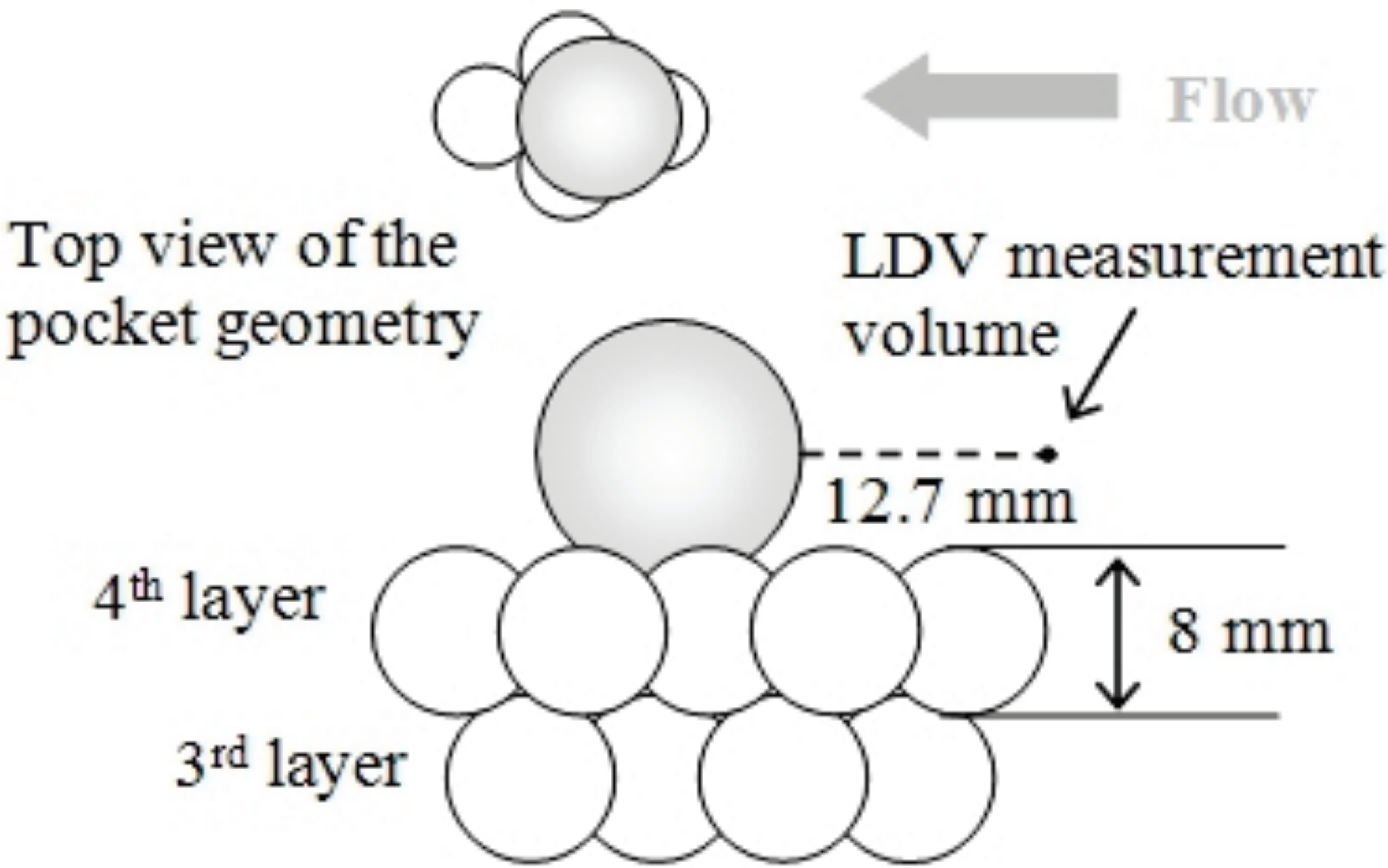




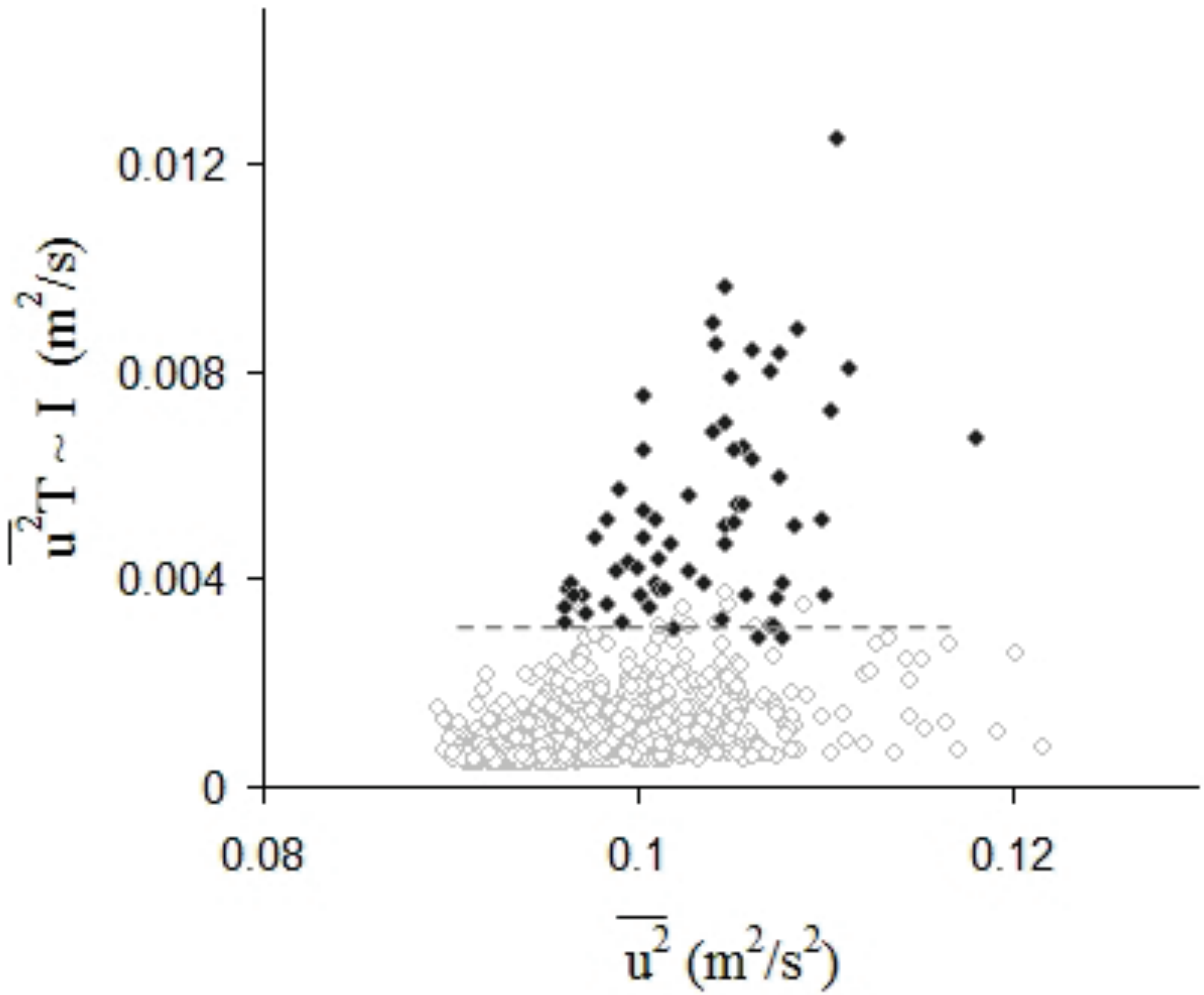
Flume Experiments

- Simultaneous measurements of *flow velocities with a 2D LDV system* and *test particle dislodgement* (as well as particle trajectory) using non-intrusive laser based techniques.

Flume Experiments



Flume Experiments



Conclusion

- The ***critical impulse*** concept is more fundamental than that of ***critical force*** in characterizing threshold of particulate motion.

Credits

- Dr. Clint Dancey
- Dr. Tanju Akar (Postdoc)
- Krista Greer (MS student)
- Manousos Valyrakis (PhD student)
- Ozan Celik (PhD student)
- Brad Dillon (MS student)
- National Science Foundation

How many years can a mountain exist
Before it's washed to the sea?

The answer, my friend, is blowin' in the wind,
The answer is blowin' in the wind.

“Blowin’ in the wind” Bob Dylan (1962)