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# ONLINE MULTI-MODEL PARTICLE FILTER-BASED TRACKING TO STUDY BEDLOAD TRANSPORT



UMR • CNRS • 5516 • SAINT-ÉTIENNE



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## 1. Context & Objectives

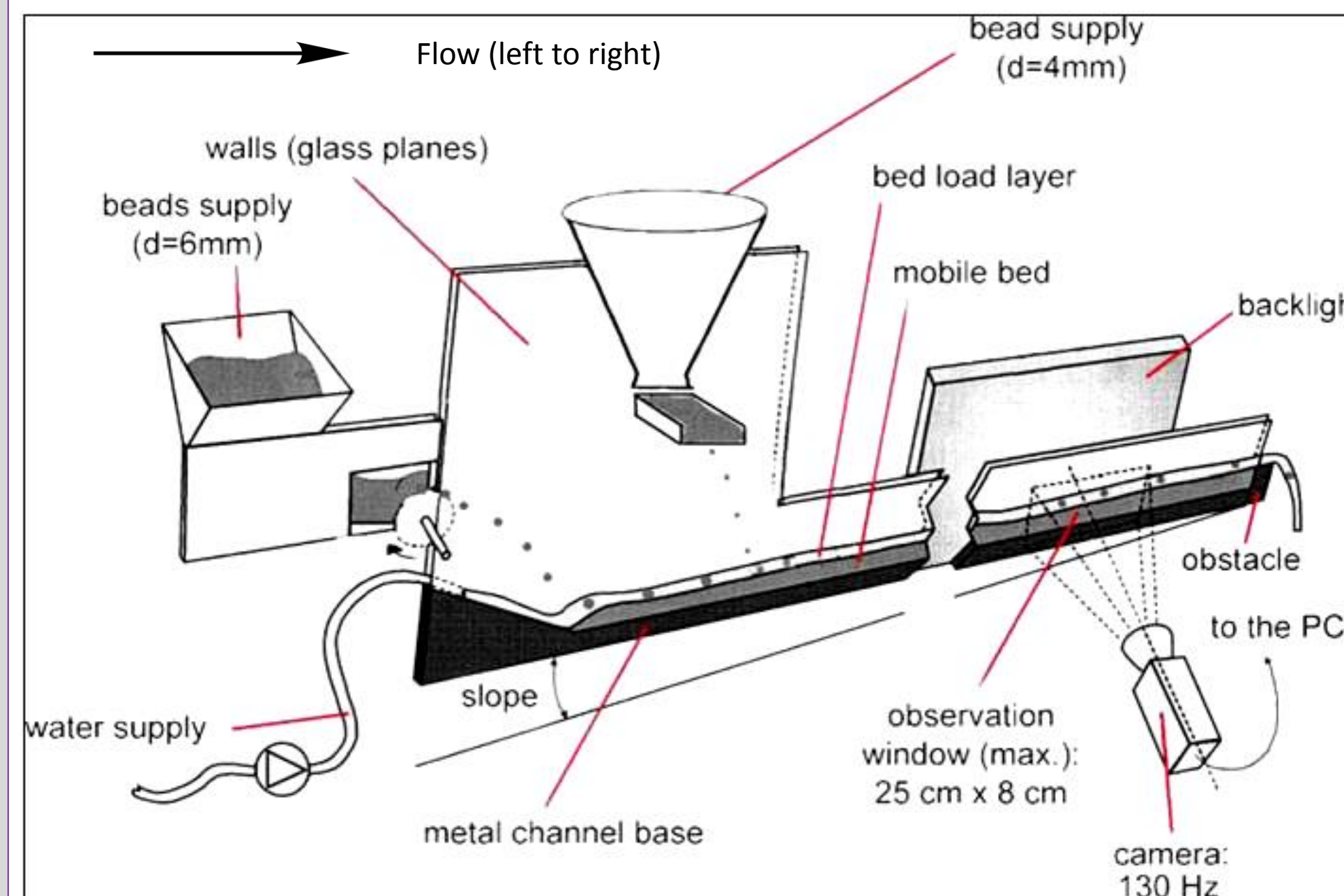
**Global aim:** studying bedload transport thanks to experiments with two-size beads in a water flow.

**Main objective:** track beads over long time sequences to better understand size segregation responsible for complex morphology structures.

The idea: propose an **online particle filter-based algorithm** integrating several improvements

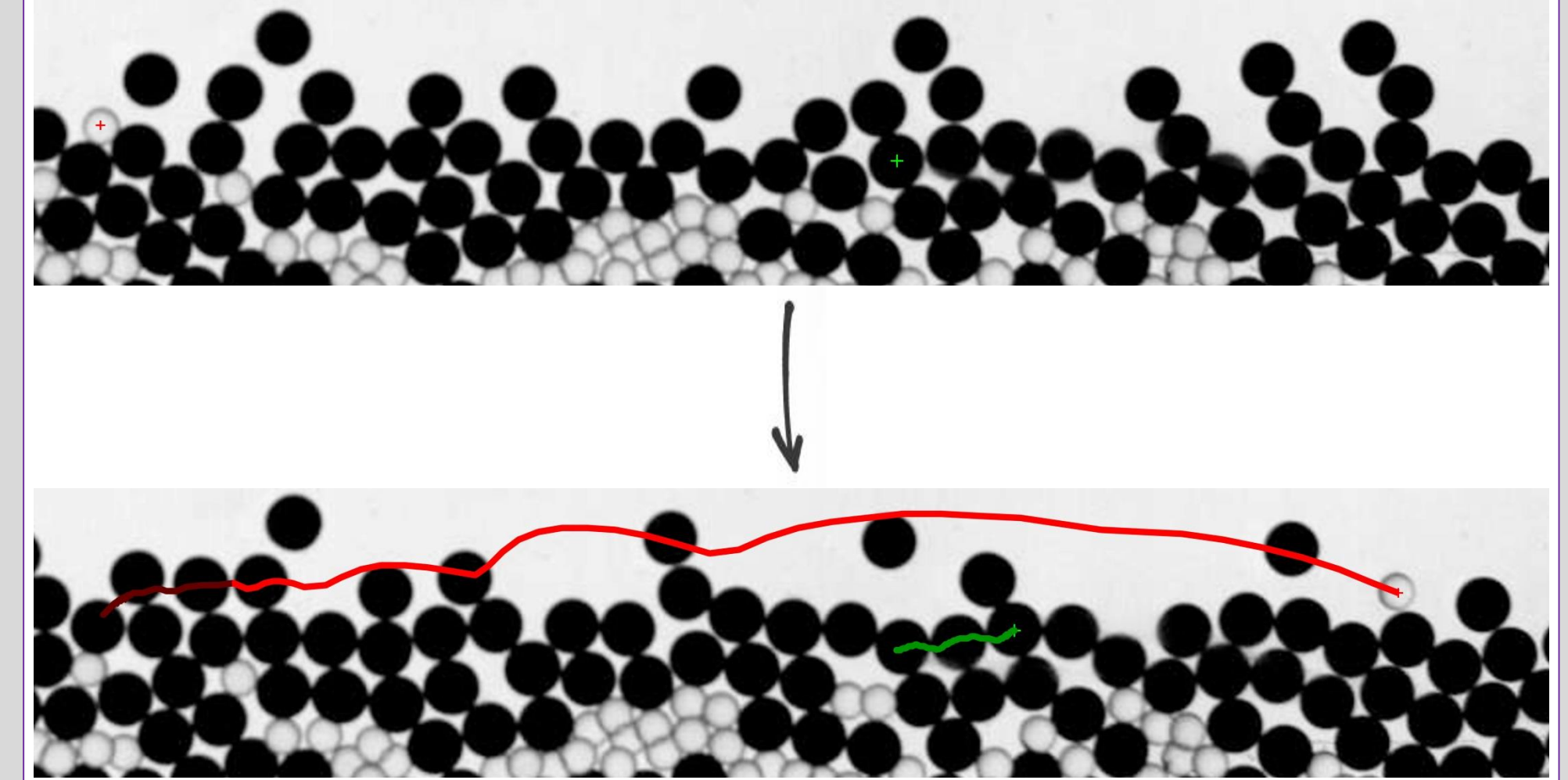
1. **Include an adapted multiple motion models** with known mechanical dynamics to better anticipate bead locations.
2. Exploit detector confidence to handle missing detections.

## 2a. Experimental setup



Sketch of the experimental arrangement (modified from [1])

## 2b. Tracking & bedload transport



Example of 2 trajectories from the experiment

**Tracking bedload sediment transport to study:**

- Velocities and concentrations
- Bedload granular rheology
- Size segregation and associated morphology

## 3. Multi-model tracking algorithm

### Stage 1: Object detector

- Use specific morphological operations (hconvex, cross-correlation, ...)
- Exploit detector confidence to handle miss-detections (based on [2])

$$d_c(x) = \frac{1}{k_D} \sum_{d \in D} \text{xcorr}(d) \exp(-\lambda \|x - x_d\|)$$

### Stage 2: Data association

- Perform greedy algorithm on matching costs

$$c(tr, d) = \alpha \underbrace{\frac{\|x_d - x_{tr}\|}{r_s}}_{\text{distance term}} + \beta \underbrace{\frac{|v_d|}{|v_{max}|}}_{\text{velocity term}}$$

### Stage 3: Particle filtering

**Principle:** use Sequential Importance Resampling (SIR) with an internal state including motion state, position  $(x, y)$  and velocity  $(u, v)$ :

1. Draw a new state according to conditional probability table
2. Propagate the particles using a motion-based stochastic tracking (as in [3]) with 3 motion models:
  - Resting - *not moving* -  $(x, y)_t = (x, y)_{t-1} + \varepsilon_{(x,y)}^{rest}$
  - Rolling - *sliding on other* -  $(x, y)_t = (x, y)_{t-1} + (u)_{t-1} \Delta t + \varepsilon_{(x,y)}^{roll}$   
 $(u)_t = (u)_{t-1} + \varepsilon_{(u)}^{roll}$
  - Saltating - *bouncing on others* -  $(x, y)_t = (x, y)_{t-1} + (u, v)_{t-1} \Delta t + \varepsilon_{(x,y)}^{salt}$   
 $(u, v)_t = (u, v)_{t-1} + \varepsilon_{(u,v)}^{salt}$

3. Compute particle weighting

$$w_{tr,p} = \mathcal{I}(tr) \underbrace{\delta p_{\mathcal{N}}(x_p - x_{d^*})}_{\text{particle position}} + \underbrace{\gamma p_{\mathcal{N}}(v_p - v_{d^*})}_{\text{particle velocity}} + \underbrace{\eta d_c(x_p)}_{\text{det. conf}}$$

4. Normalize weights and resample particles with SIR method
5. Estimate position and velocity by averaging resampled particles

## 5. Conclusions & Perspectives

- **New online particle filter-based tracking algorithm based on multiple dynamic models:**
  - Input of object mechanical dynamics helps approaching real trajectories.
  - Allows studying bedload transport with higher confidence.
- **Our multiple motion model based algorithm provides high tracking precision and accuracy with different detector qualities:**
  - Outperforms single dynamic models.
  - Effect of inaccurate detections reduced by detector confidence.

**Perspectives:** Use configuration and state of neighboring objects as an information to help choosing between motion states.

## 4. Results

### ➤ Creation of a ground truth dataset of 1000 images for the tests

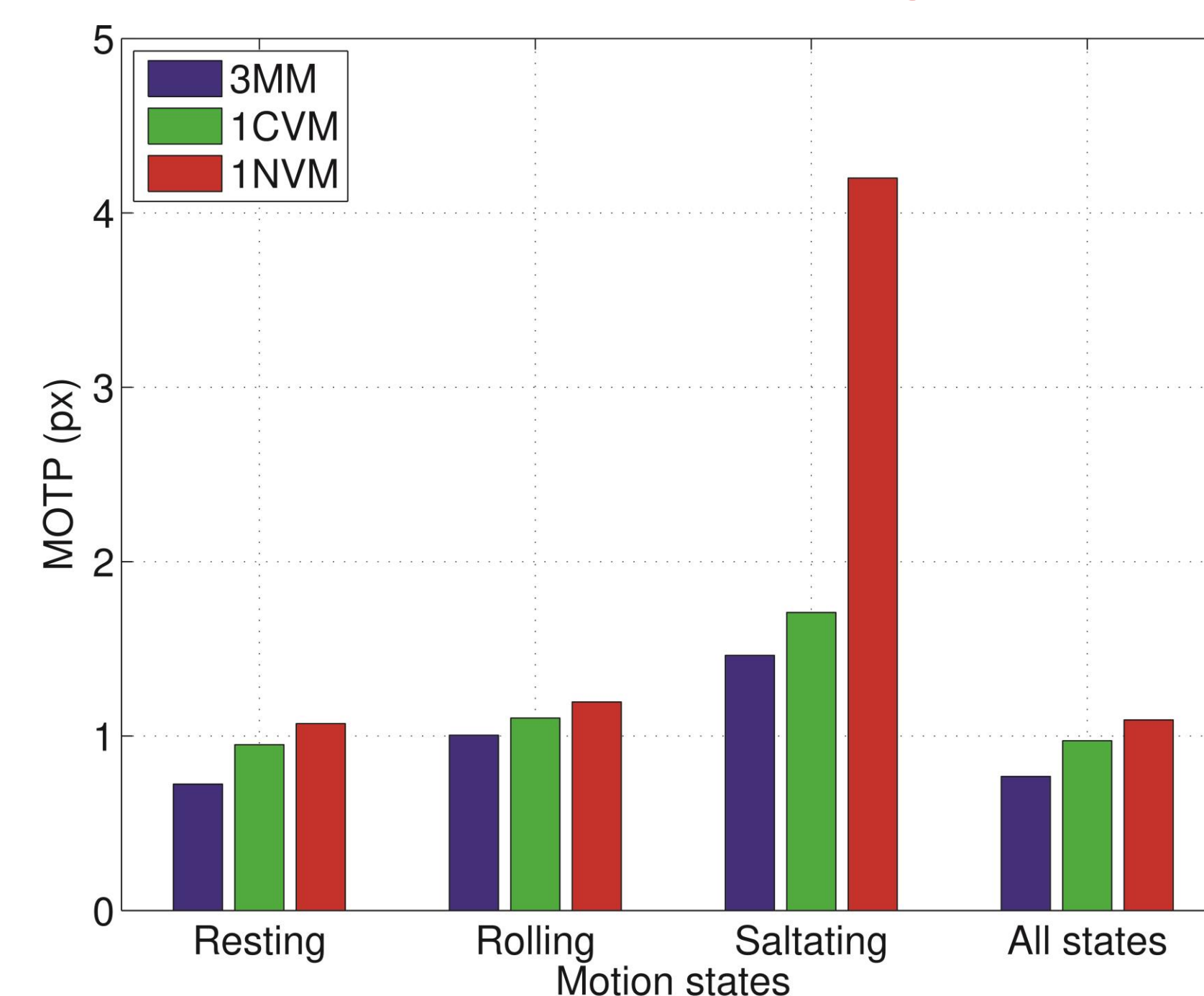
Parameters are fixed on half of the dataset

### ➤ Tracking evaluation results on 3 algorithm configurations:

Algo. Models	% Correct Tracks	MOTP	FN	FP	Id Sw.	MOTA
3MM	<b>98.35%</b>	<b>0.64px</b>	<b>0.07%</b>	<b>0.16%</b>	<b>4</b>	<b>99.77%</b>
1CVM [2]	95.05%	0.77px	0.09%	0.17%	23	99.72%
1NVM	89.90%	0.89px	0.14%	0.54%	84	99.28%

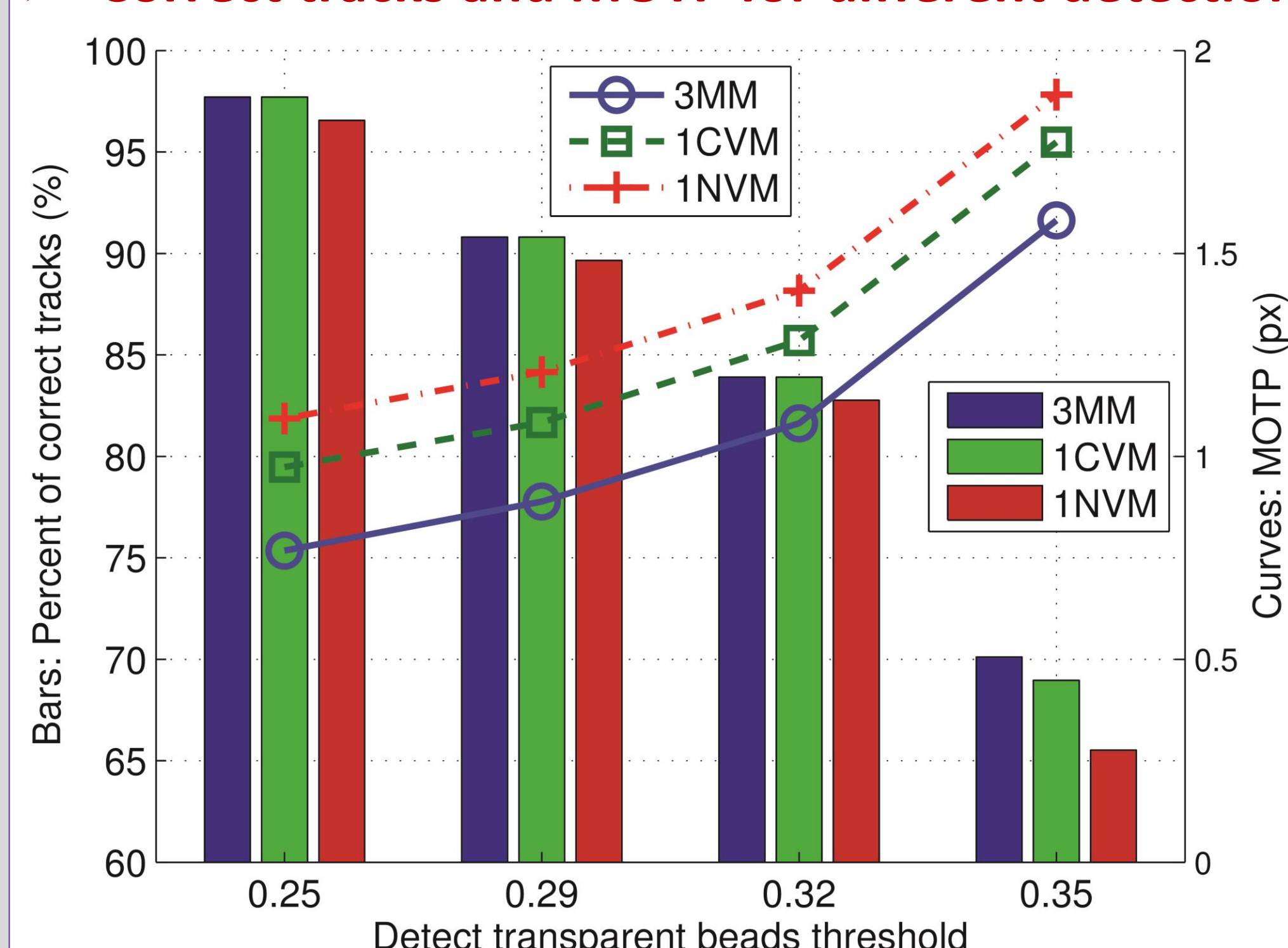
3MM = 3 motion models ; 1CVM = 1 constant velocity model ; 1NVM = 1 null velocity model

### ➤ Precision score MOTP according to motion state:



**MOTP:**  
precision to ground  
truth in pixels

### ➤ Correct tracks and MOTP for different detection thresholds:



**Correct track:**  
>95% of the track  
without FN or  
mismatches

## References

- [1] Hergault, V., Frey, P., Métivier, F., Barat, C., Ducottet, C., Böhm, T. & Ancey, C. (2010). Image processing for the study of bedload transport of two-size spherical particles in a supercritical flow. *Experiments in fluids*, 49, 1095-1107.
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- [3] Odobez, J.-M., Gatica-Perez, D. & Ba, S. O. (2006). Embedding motion in model-based stochastic tracking. *IEEE TIP*, 15(11), 3514-3530.

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