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



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1. Context & Objectives

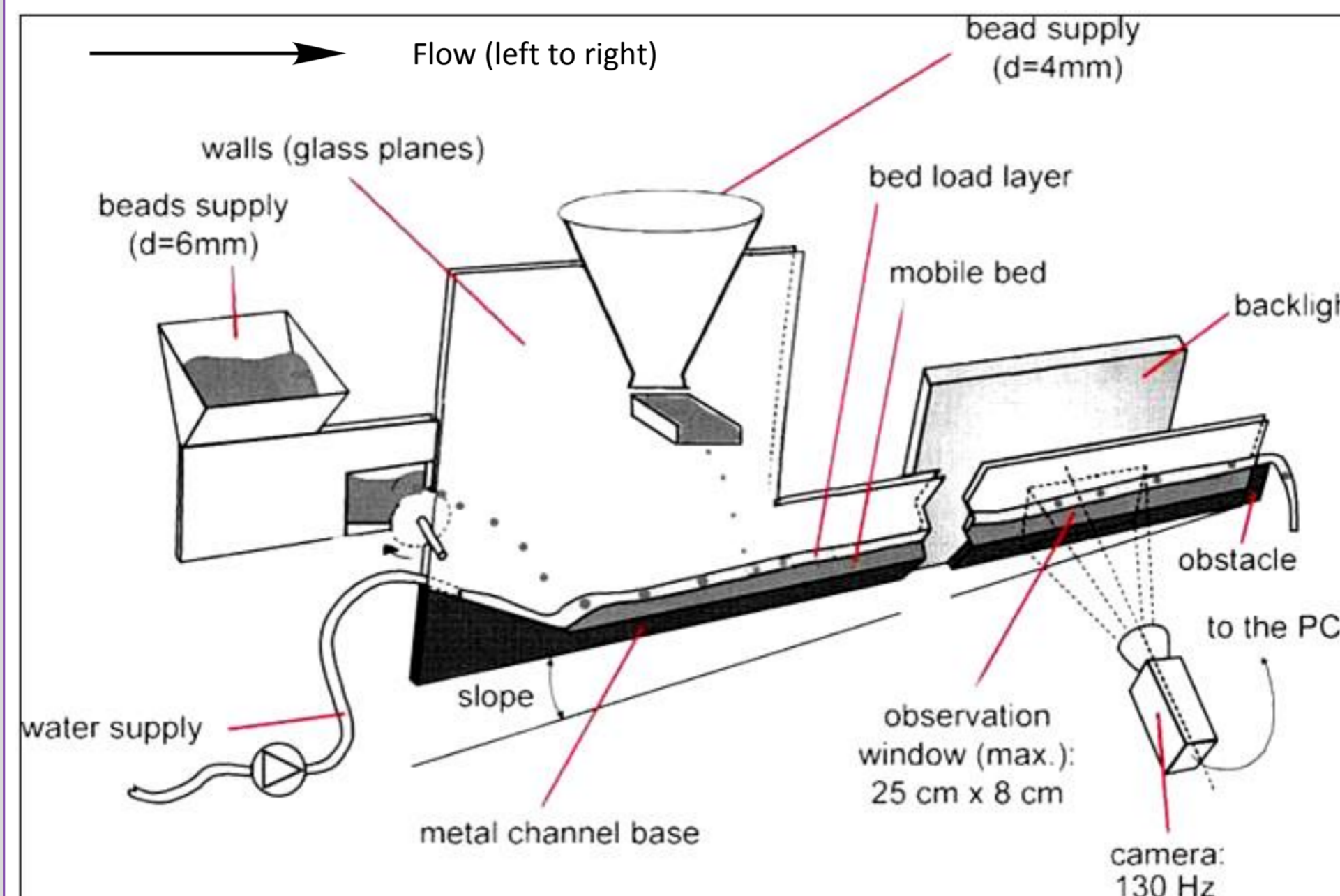
Global aim: studying bedload transport thanks to experiments with two-size beads in a water flow.

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

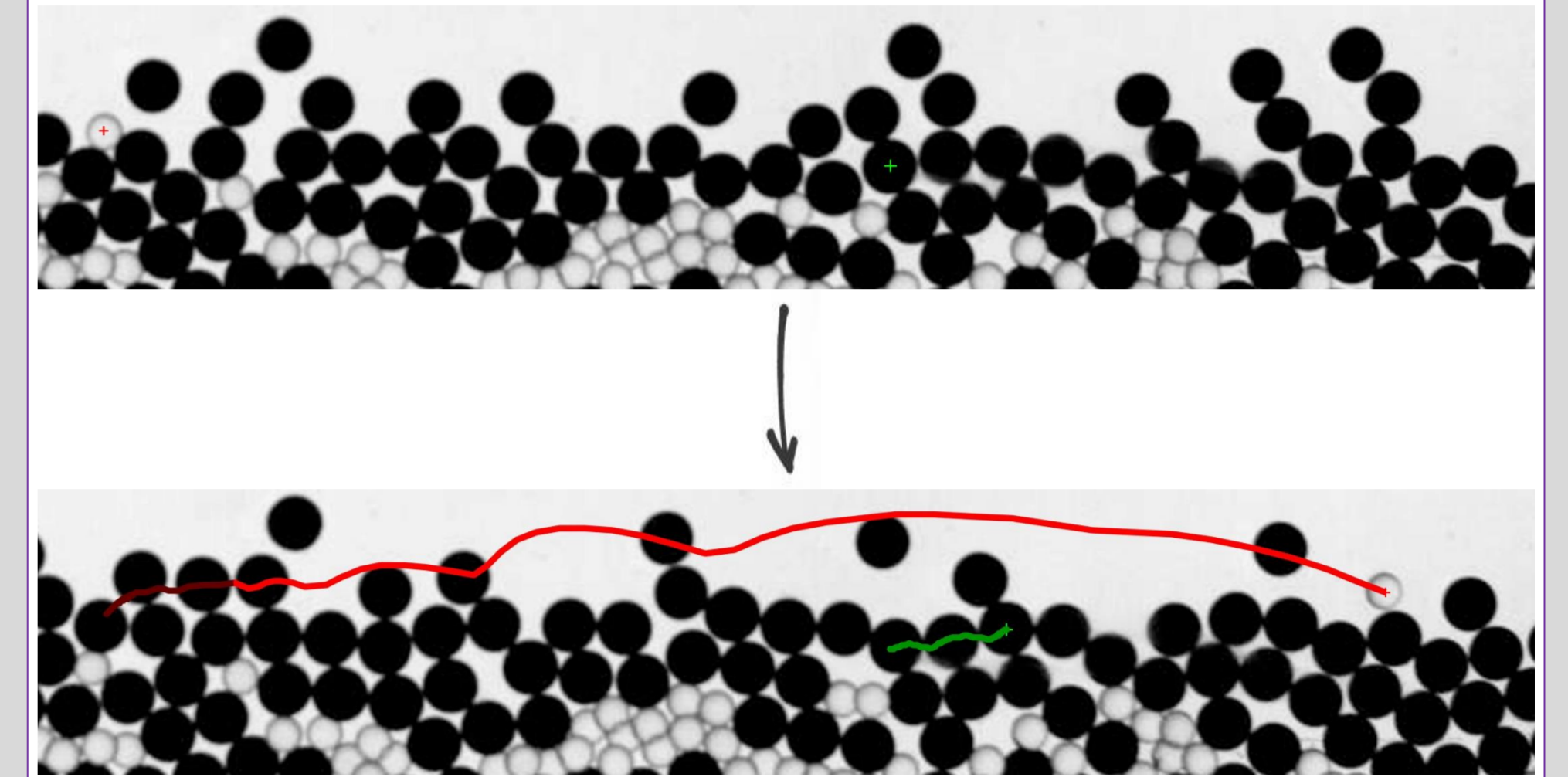
1. Include an adapted multiple motion models with known mechanical dynamics to better anticipate bead locations.
2. Exploit detector confidence to handle missing detections.

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

$$c(tr, d) = \alpha \frac{\|x_d - x_{tr}\|}{r_s} + \beta \frac{|v_d|}{|v_{max}|}$$

distance term 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

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

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**

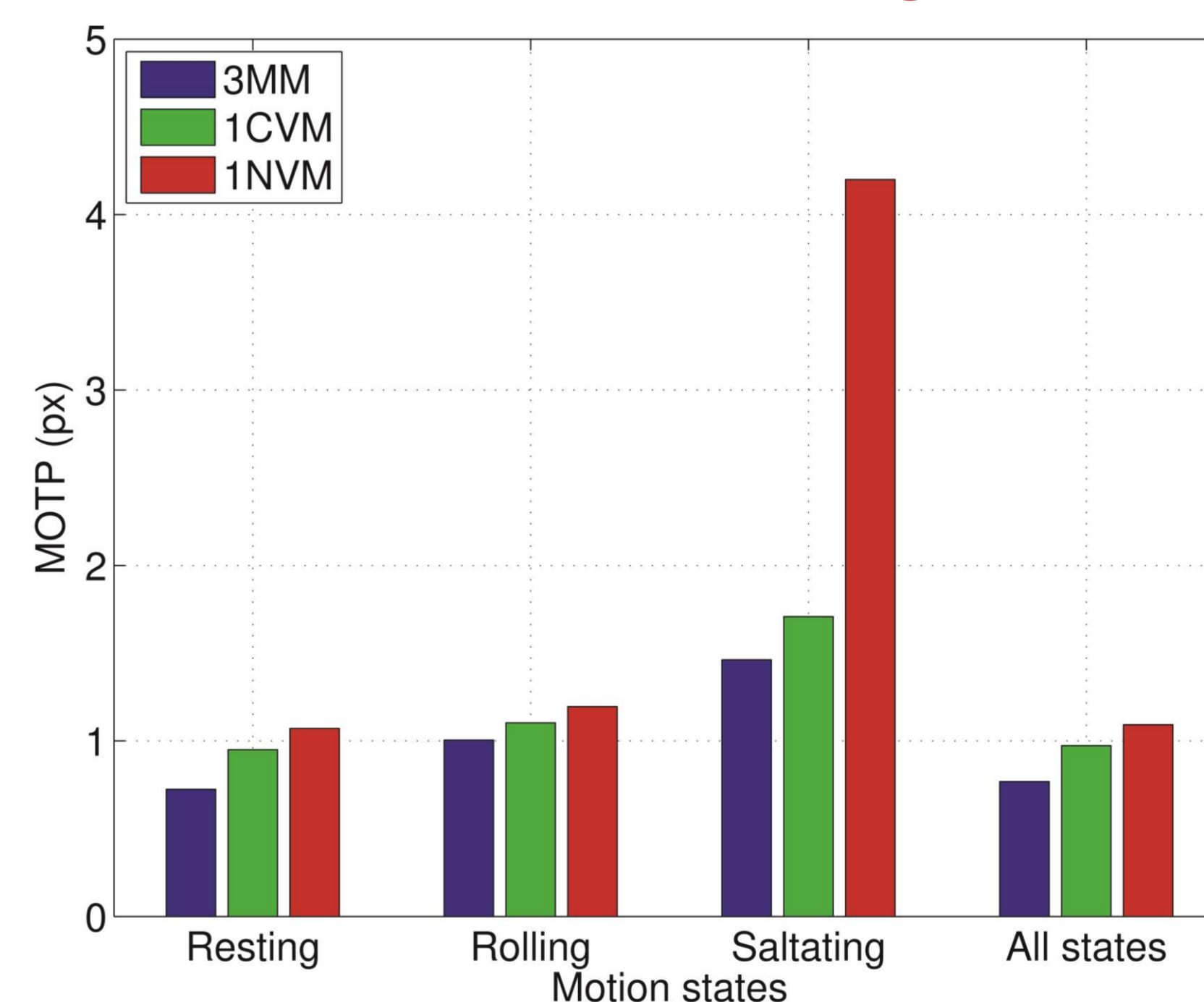
↳ Parameters are fixed on half of the dataset

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

Algo. Models	% Correct Tracks	MOTP	FN	FP	Id Sw.	MOTA
3MM	98.35%	0.64px	0.07%	0.16%	4	99.77%
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%

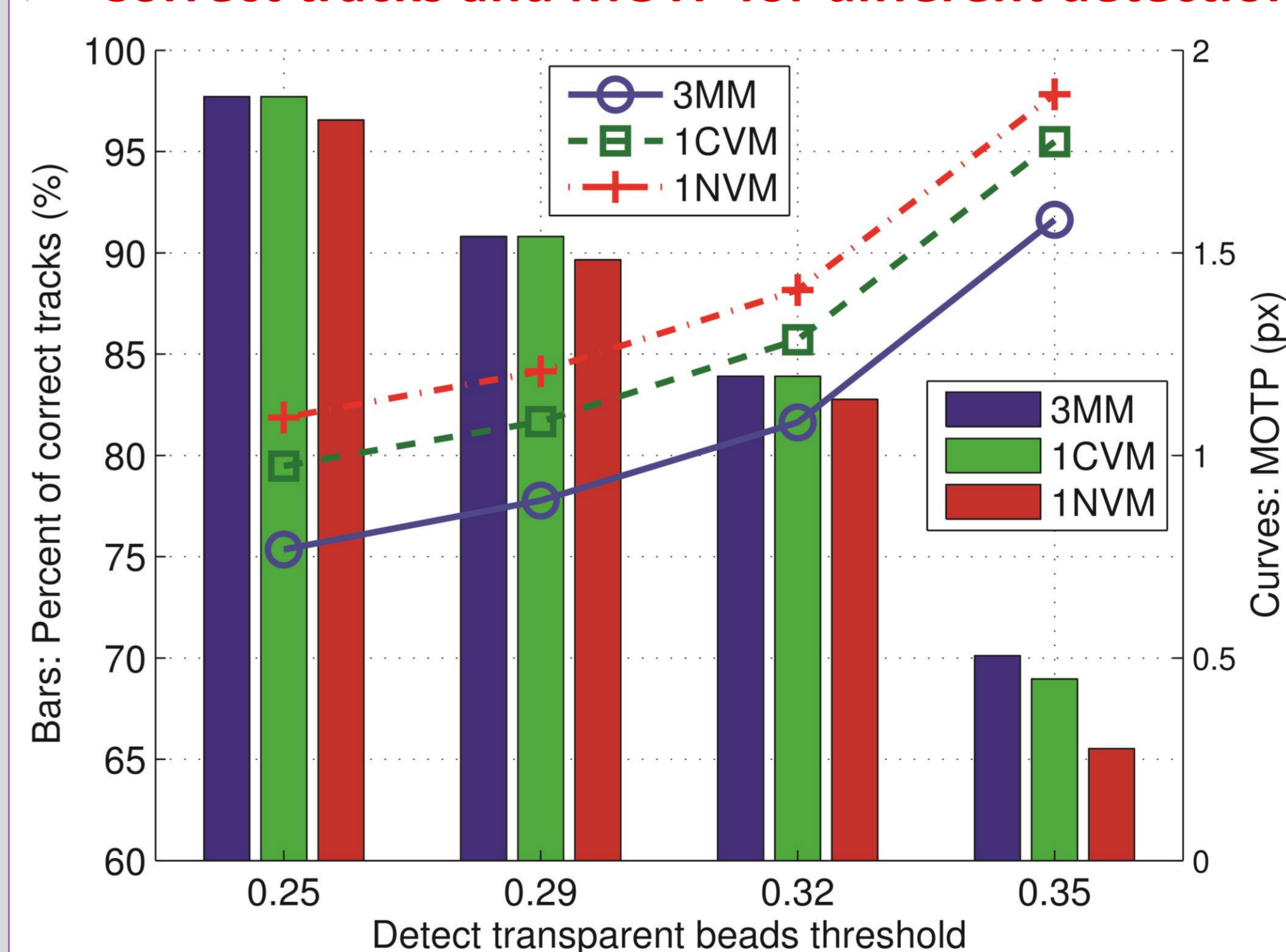
3MM = 3 motion models ; 1CVM = 1 constant velocity model ; 1NVM = 1 null velocity model

➤ **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

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