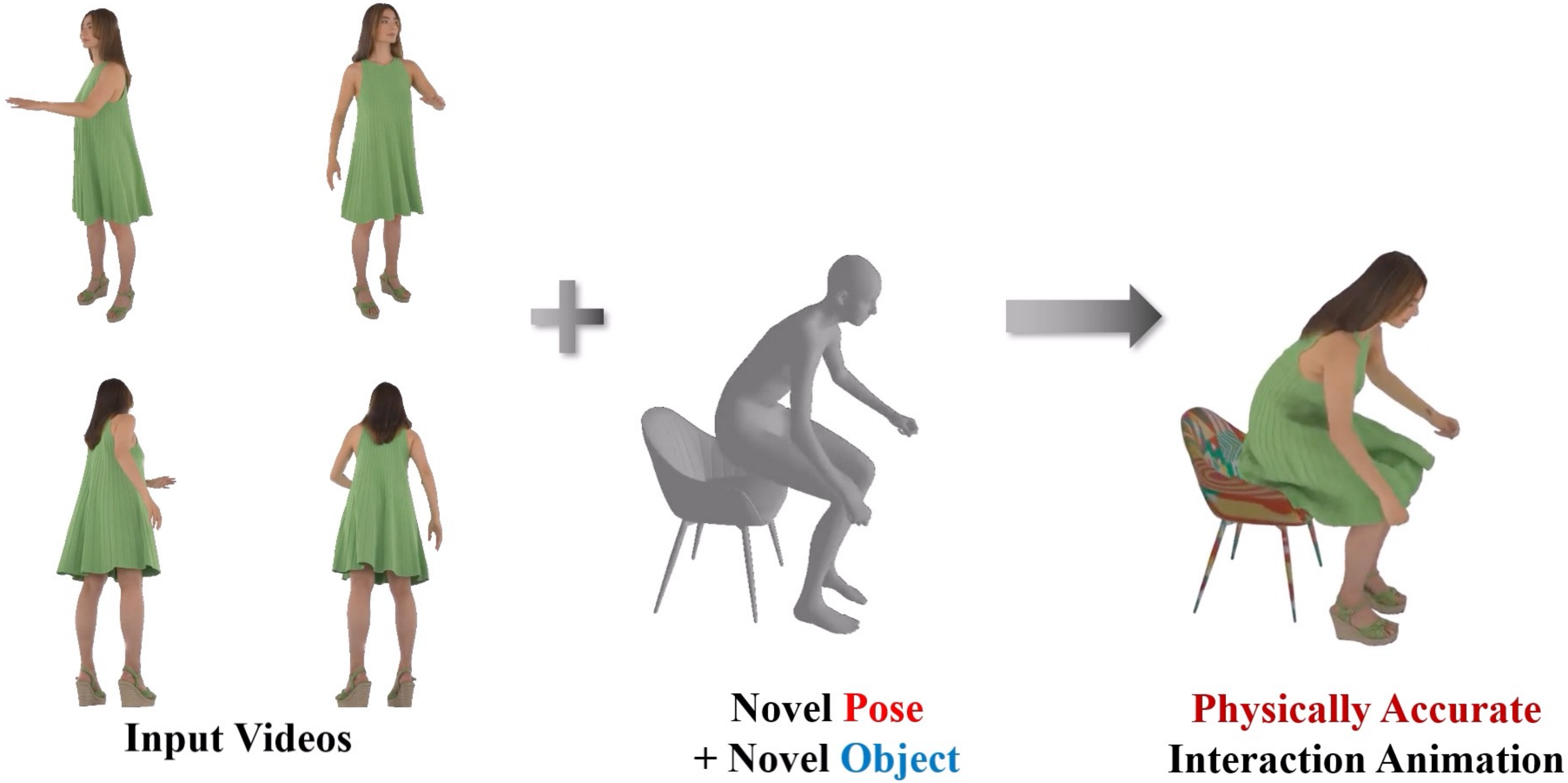
MPMAvatar: Learning 3D Gaussian Avatars with Accurate and Robust Physics-Based Dynamics

Multi-view video input Novel pose driving Zero-shot scene interactions

Changmin Lee, Jihyun Lee, Tae-Kyun Kim

KAIST KCVL NEURAL INFORMATION PROCESSING SYSTEMS

Overview



Create **3D Gaussian avatars** from **multi-view videos**, that support **physically accurate** and **robust animations**, especially for loose garments

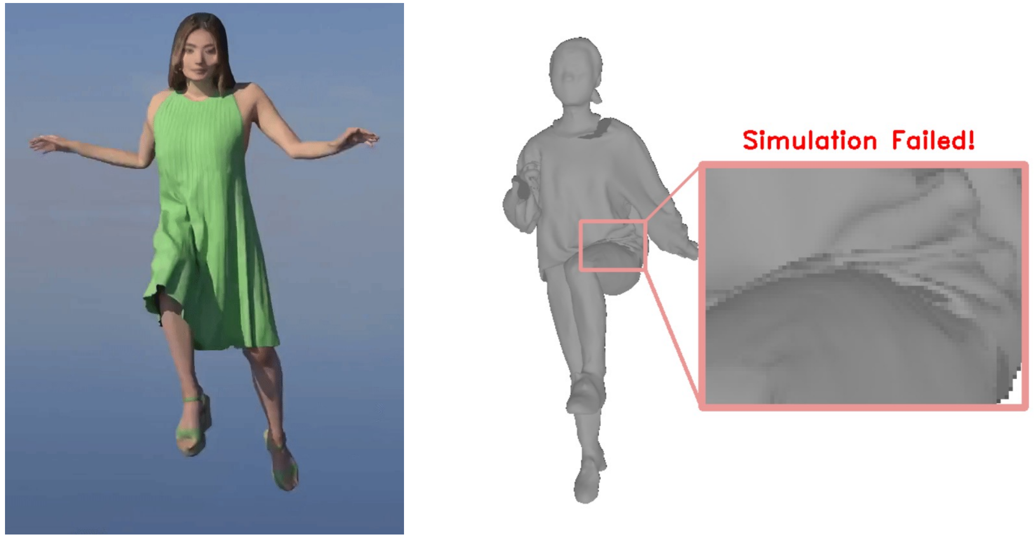
Motivation

- Realistic Avatars require both **photorealistic rendering** and **physically plausible motion**.
- However, existing methods achieve **only one** — either realistic appearance *or* physical accuracy.

❌ **Physical** ✅ **Photorealistic**

MMLPHuman [1]

✅ **Physical** ⚠️ **Photorealistic** ❌ **Robust**



PhysAvatar [2]

[1] Zhan *et al.*, Real-time High-fidelity Gaussian Human Avatars with Position-based Interpolation of Spatially Distributed MLPs, In *CVPR*, 2025.
[2] Zheng *et al.*, PhysAvatar: Learning the Physics of Dressed 3D Avatars from Visual Observations, In *ECCV*, 2024.

Key Idea

We need avatars that are:

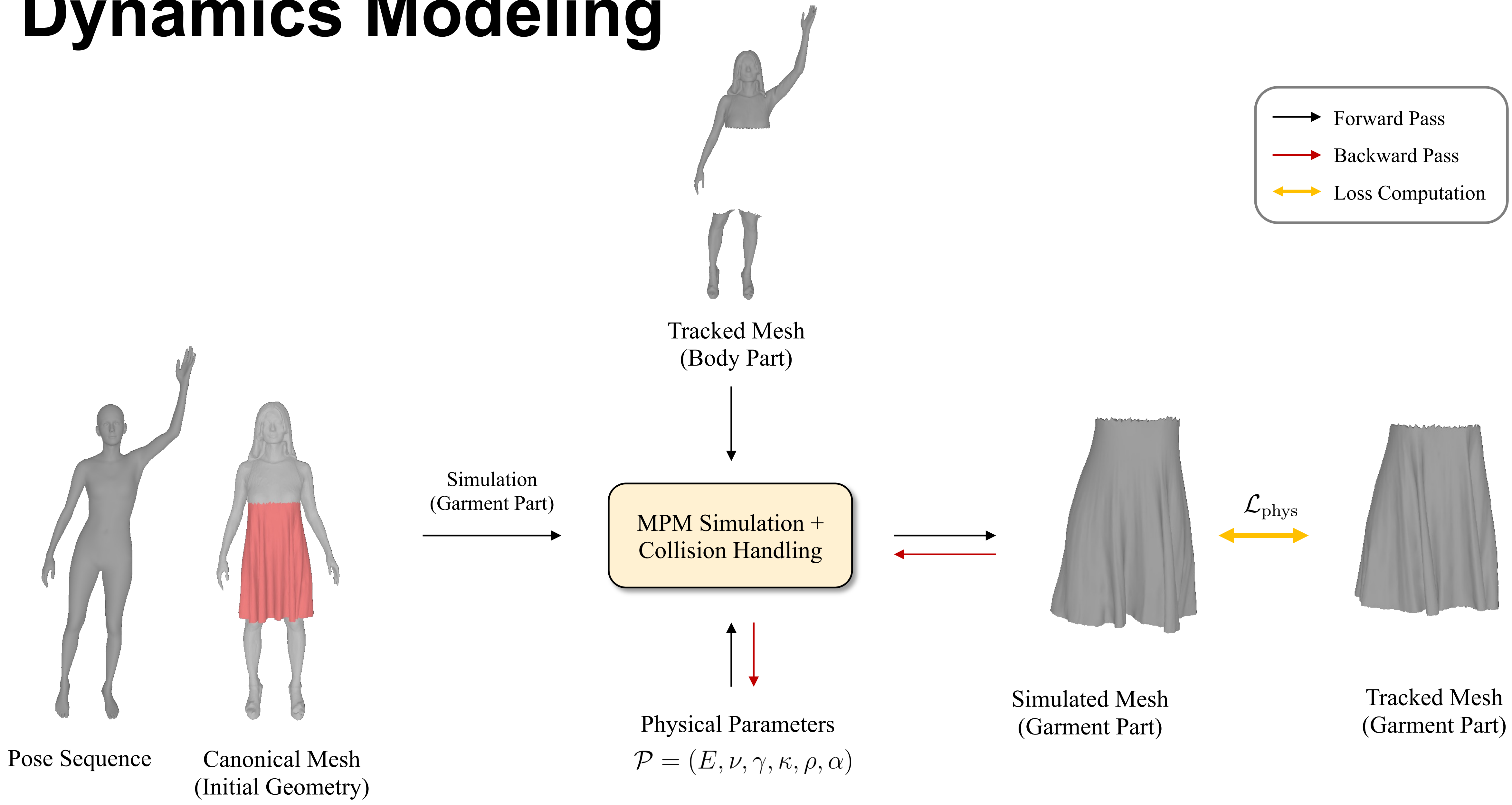
1. **Physically accurate**
2. **Simulation-robust**
3. **Photorealistically rendered**

We achieve this by:

1. **Physics-based simulation for garments**
   - ➢ MPM [3] with anisotropic constitutive model [4]
2. **Robust mesh-based collision handling**
   - ➢ Robust collision with arbitrary meshes
3. **Hybrid representation (Mesh + 3DGS [5])**
   - ➢ Mesh for dynamics, 3DGS for appearance

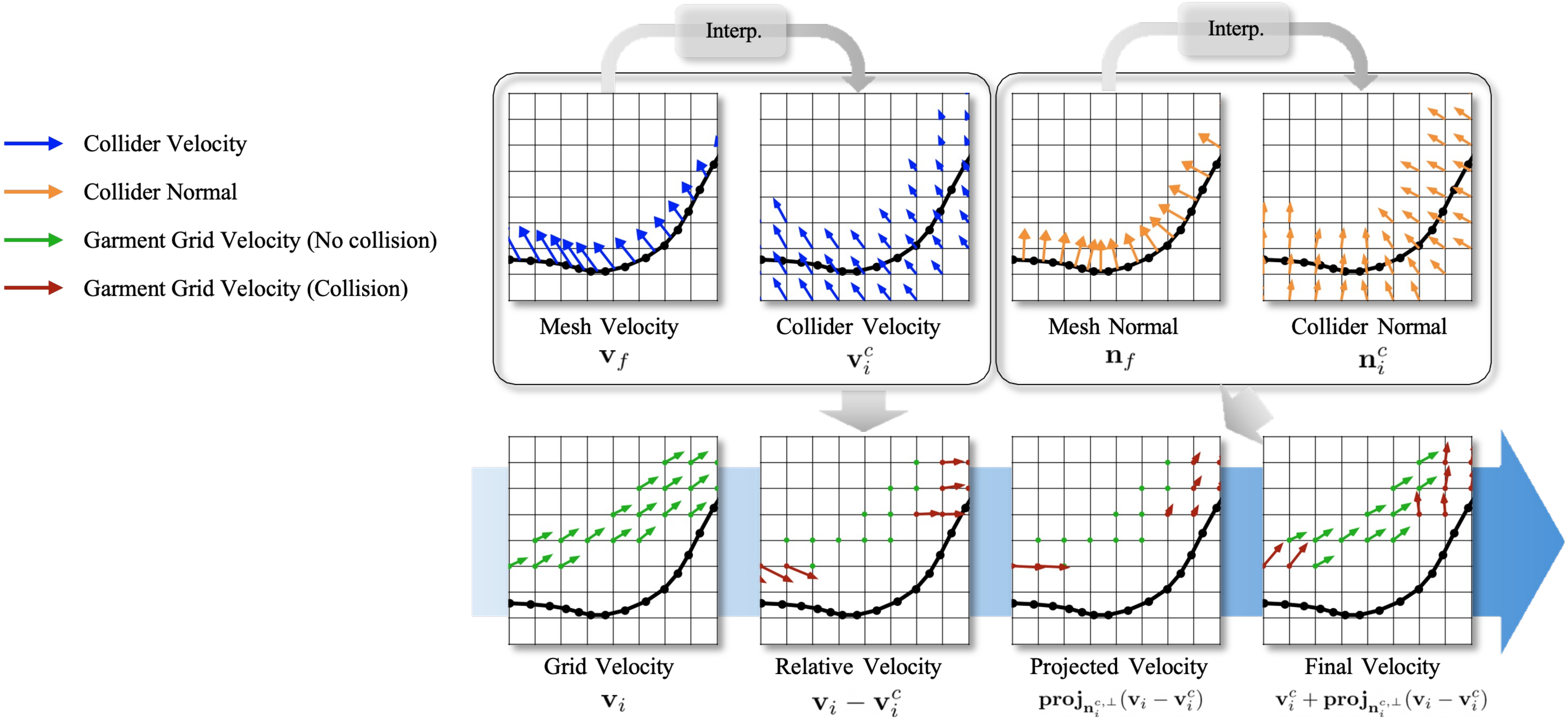
[3] Jiang *et al.*, The material point method for simulating continuum materials., In *SIGGRAPH 2016 Course*, 2016.
[4] Jiang *et al.*, Anisotropic elastoplasticity for cloth, knit and hair frictional contact., In *SIGGRAPH*, 2017.
[5] Kerbl *et al.*, 3D Gaussian Splatting for Real-Time Radiance Field Rendering, In *SIGGRAPH*, 2023.

Dynamics Modeling

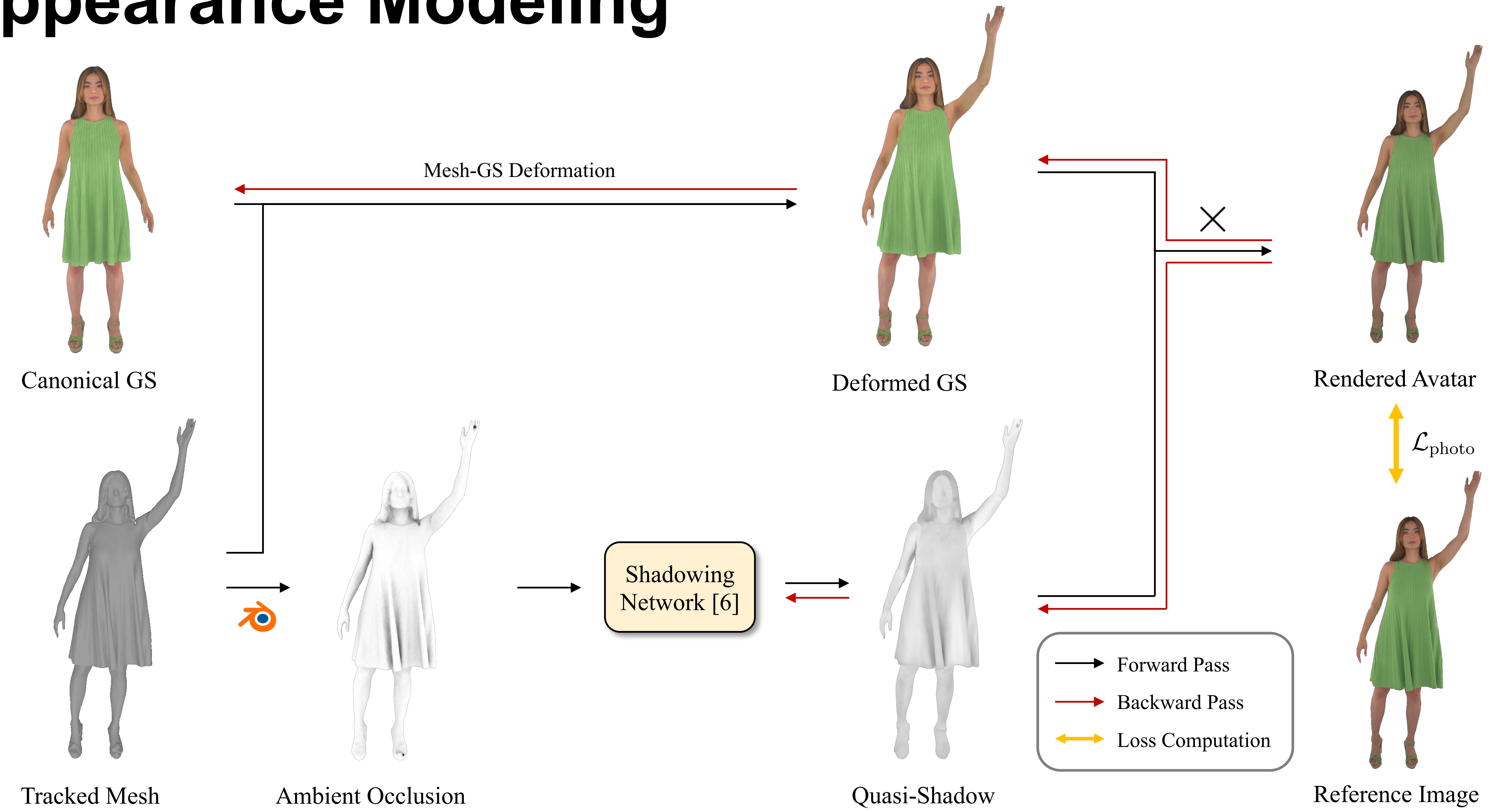


[2] Zheng *et al.*, PhysAvatar: Learning the Physics of Dressed 3D Avatars from Visual Observations, In *ECCV*, 2024.

Dynamics Modeling



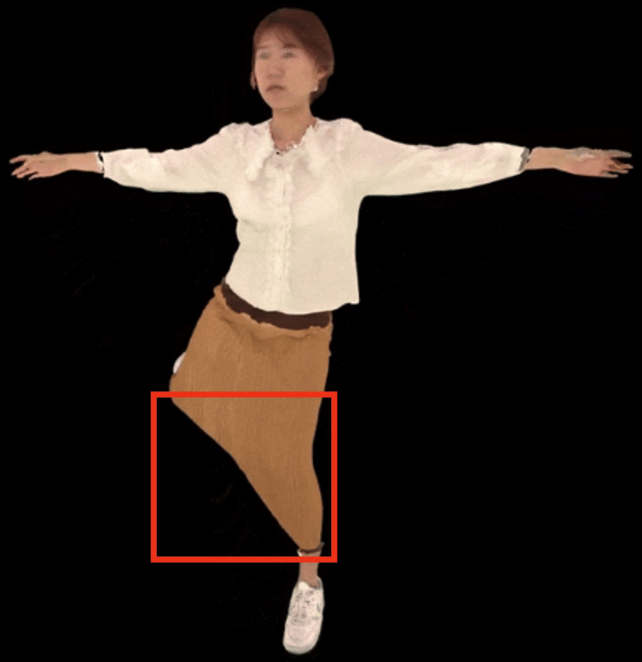
Appearance Modeling



[6] Bagautdinov *et al.*, Driving-signal aware full-body avatars, In *SIGGRAPH*, 2021.

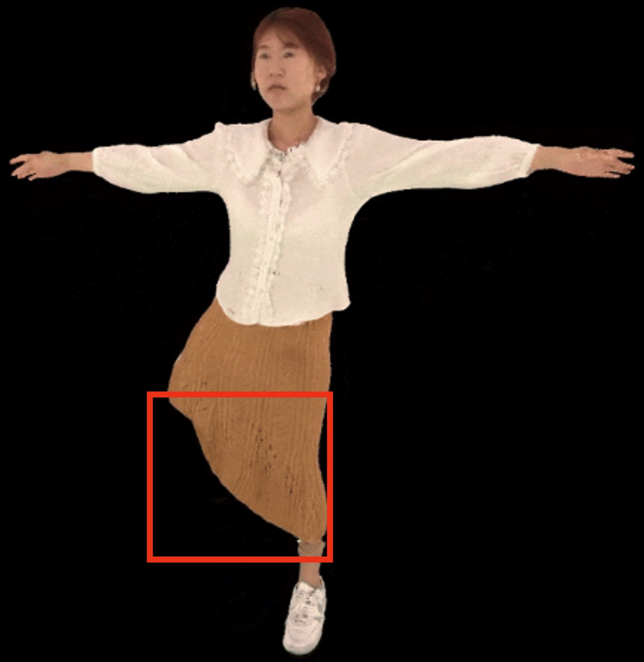
Experimental Comparisons

PhysAvatar[2]



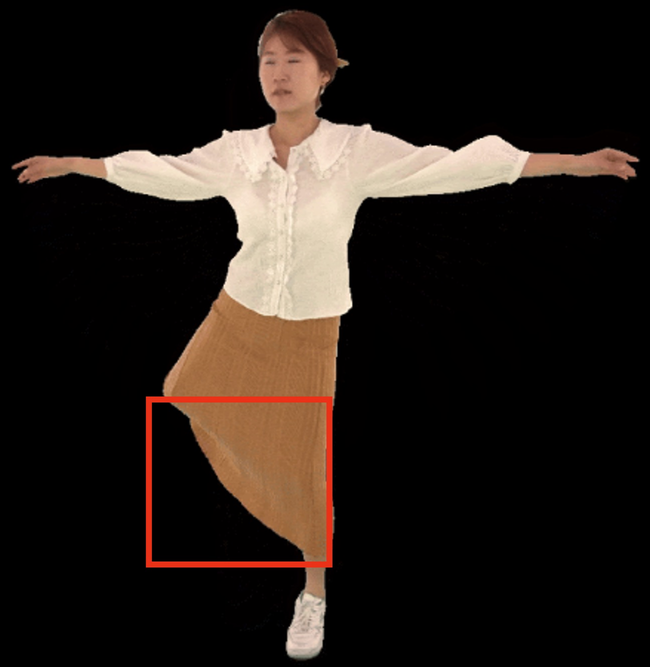
👎 Less natural cloth motion

MPMAvatar (Ours)

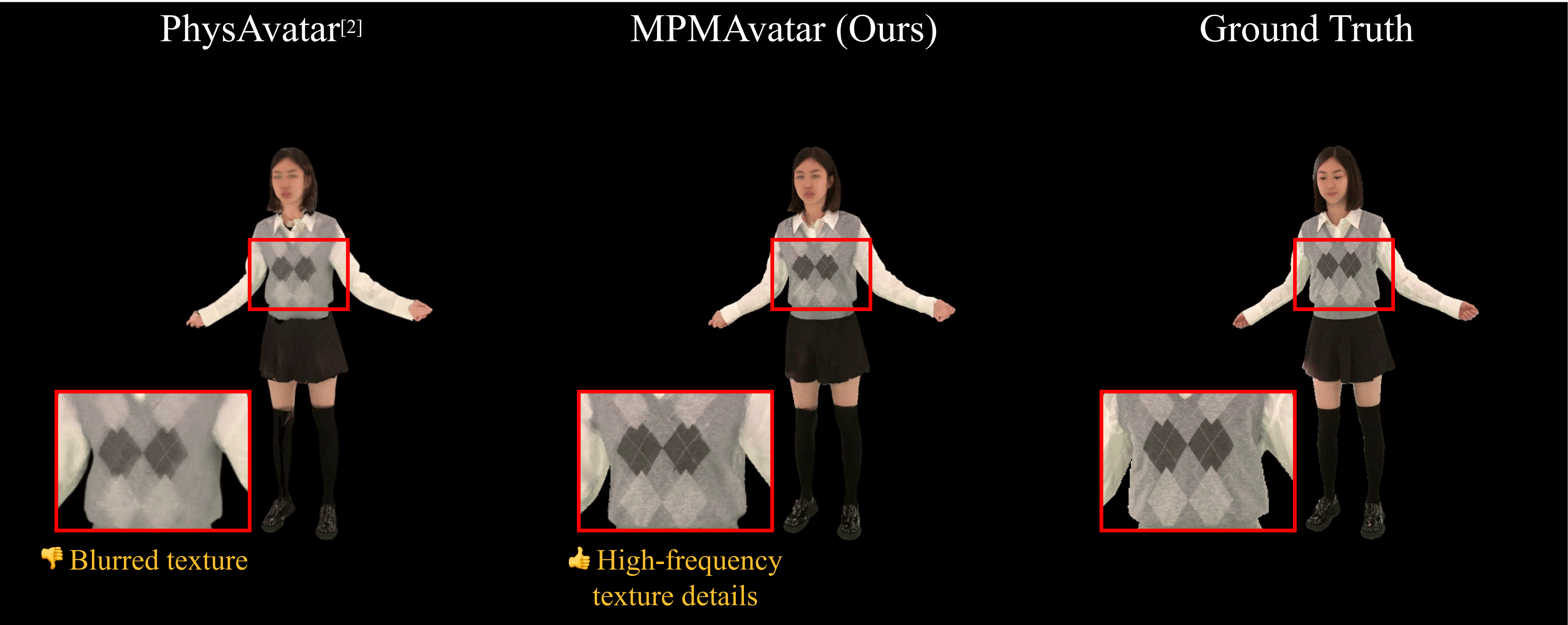


👍 Fluttering cloth motion similar to the ground truth

Ground Truth



Experimental Comparisons

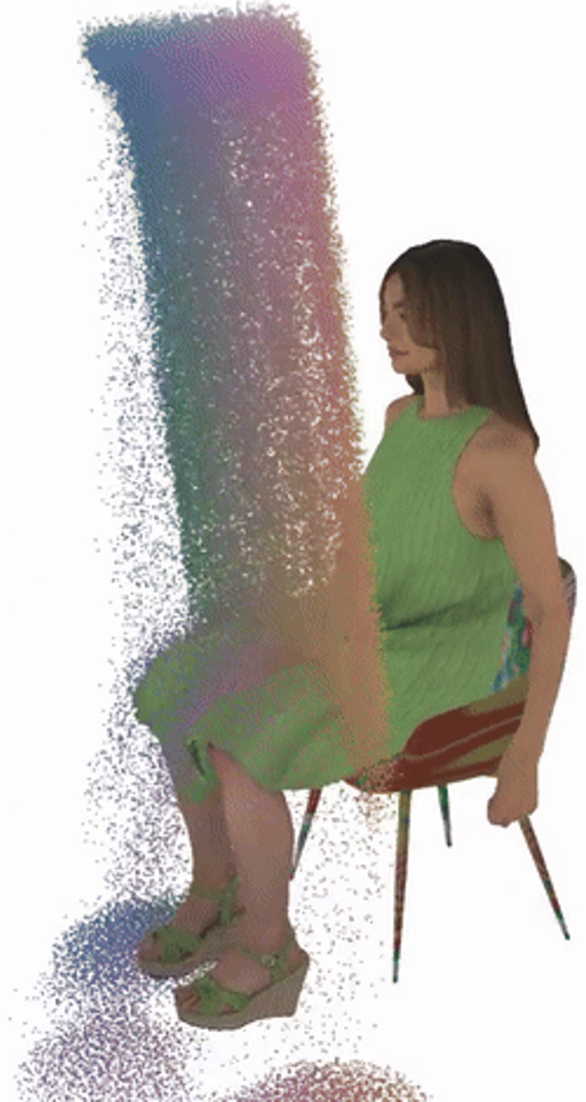


Experimental Comparisons

Method	Geometry		Appearance		
	CD ($\times 10^3$) ↓	F-Score ↑	LPIPS ↓	PSNR ↑	SSIM ↑
(a) Results on ActorsHQ dataset.					
ARAH	1.12	86.1	0.055	28.6	0.957
TAVA	0.66	92.3	0.051	29.6	0.962
GS-Avatar	0.91	89.4	0.044	30.6	0.962
PhysAvatar	0.55	92.9	0.035	30.2	0.957
MPMAvatar (Ours)	**0.42**	**95.7**	**0.033**	**32.0**	**0.963**
(b) Results on 4D-DRESS dataset.					
PhysAvatar	0.37	96.6	0.022	33.2	0.976
MPMAvatar (Ours)	**0.33**	**97.2**	**0.018**	**34.1**	**0.977**

Method	Success Rate (%) ↑	Simulation Time (s) ↓
PhysAvatar	37.6	170.0
MPMAvatar (Ours)	**100.0**	**1.1**

Application: Zero-Shot Scene Interaction



Chair: Mesh collider
Sand: MPM particles (granular material)

Conclusion

- We presented **MPMAvatar**, a framework for creating **3D human avatars from multi-view videos** that supports (1) **physically accurate and robust animation**, as well as (2) **high-fidelity rendering**.
- Our **Gaussian Splat-based avatar** is animated based on a **carefully tailored MPM-based simulator** designed for **effective garment dynamics modeling**, enabling **physically grounded animations.**

💃MPMAvatar: Learning 3D Gaussian Avatars with Accurate and Robust Physics-Based Dynamics

KAIST

NEURAL INFORMATION PROCESSING SYSTEMS

Project Page