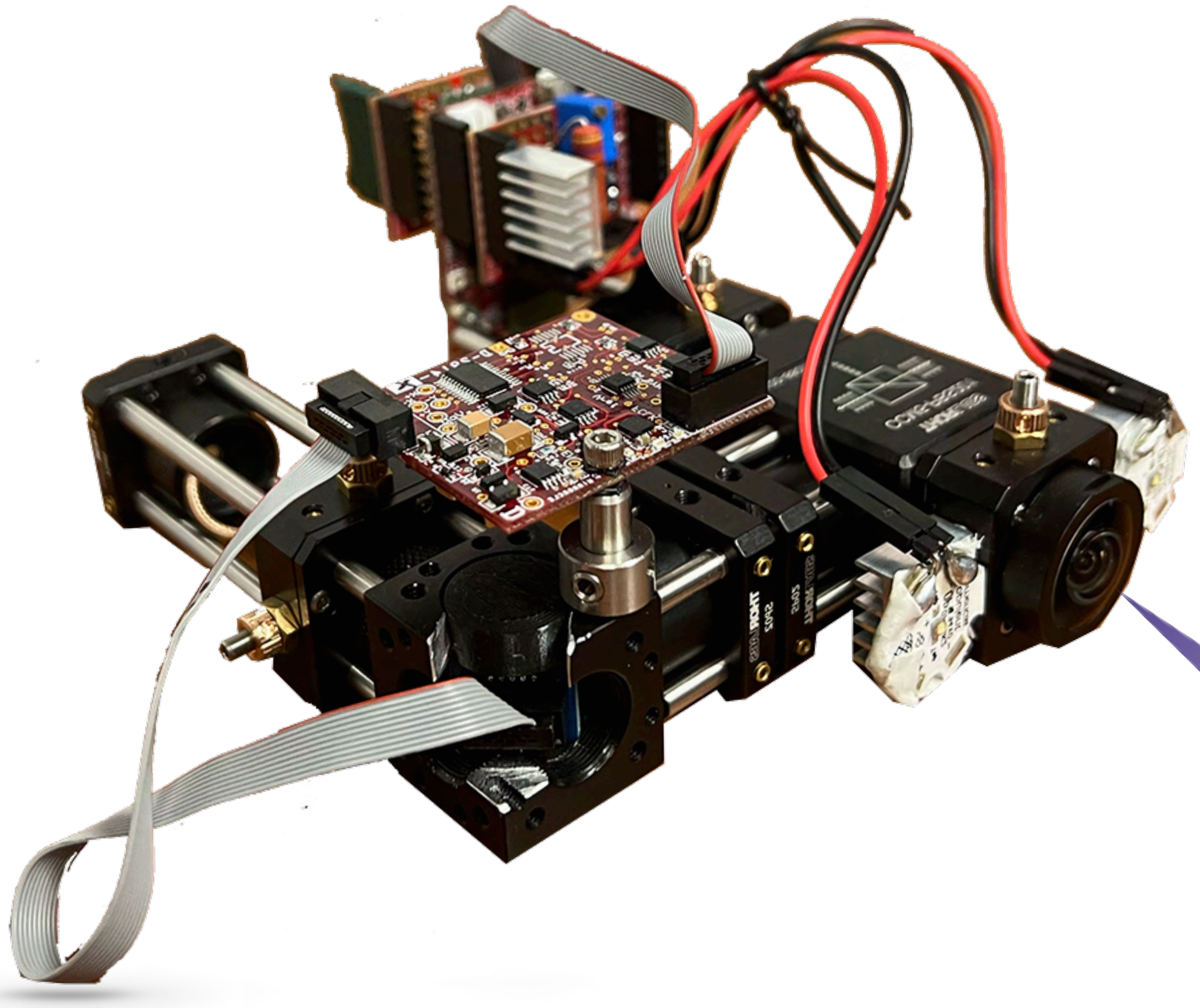
Catch Me If You Can: Laser Tethering with Highly Mobile Targets



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Emerging Laser-Based Mobile Applications

✔ **Drone Communication** ✔ **Laser VR** ✔ **Wireless Power Delivery**

Enabled by alignment with a directional, narrow beam

Emerging Laser-Based Mobile Applications

✗ **Drone Communication**

✗ **Laser VR**

✗ **Wireless Power Delivery**

How do we maintain a laser tether in **mobile** scenarios?

Prior Work

- Long range applications
- Bulky hardware
- Predetermined target trajectories

Optical module of NASA's Laser Communications Relay Demonstration (LCRD)

Emerging Laser-Based Mobile Applications

Drone Communication **Laser VR** **Wireless Power Delivery**

Requirements:

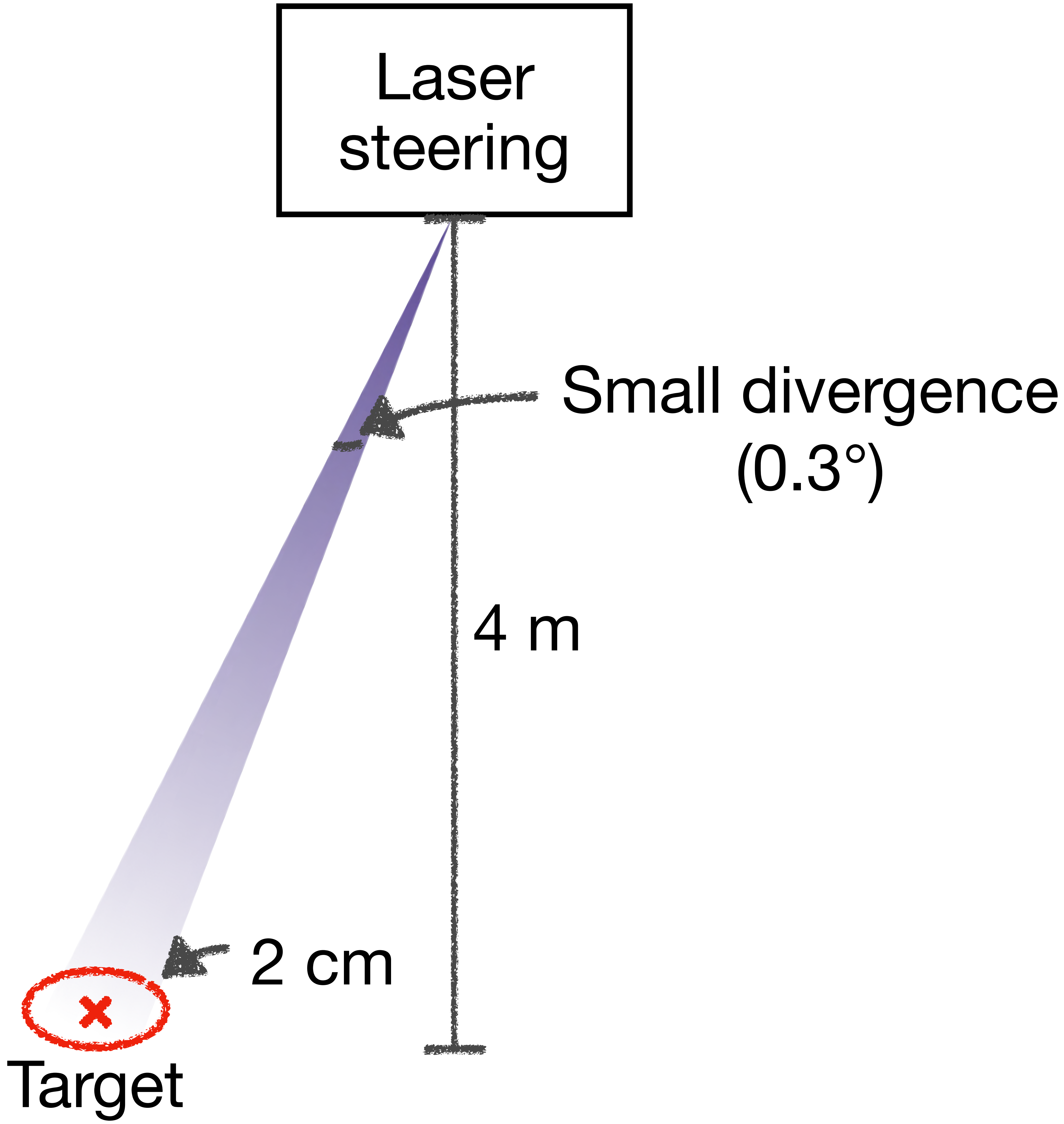
- ✔ Near range (meter-level)
- ✔ Arbitrary target trajectories
- ✔ Portable hardware

Lasertag


Mobile target→
Laser light
System→

Challenges

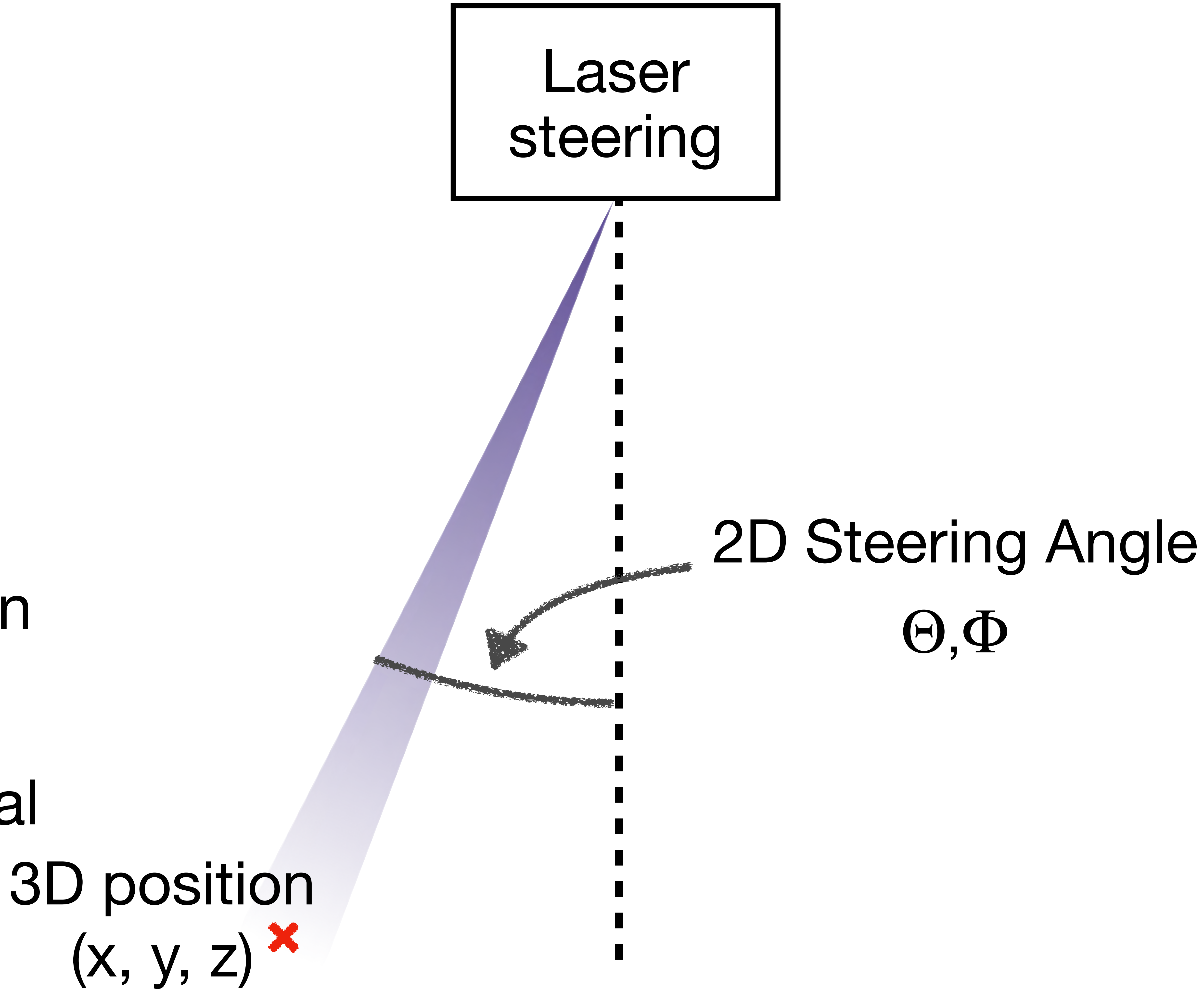
❶ Low tolerance for localization error



Challenges

1. Low tolerance for localization error

2. Integration of tracking and laser steering
   - ✗ Unknown steering and localization device origins
   - ✗ Geometry changes from additional optics



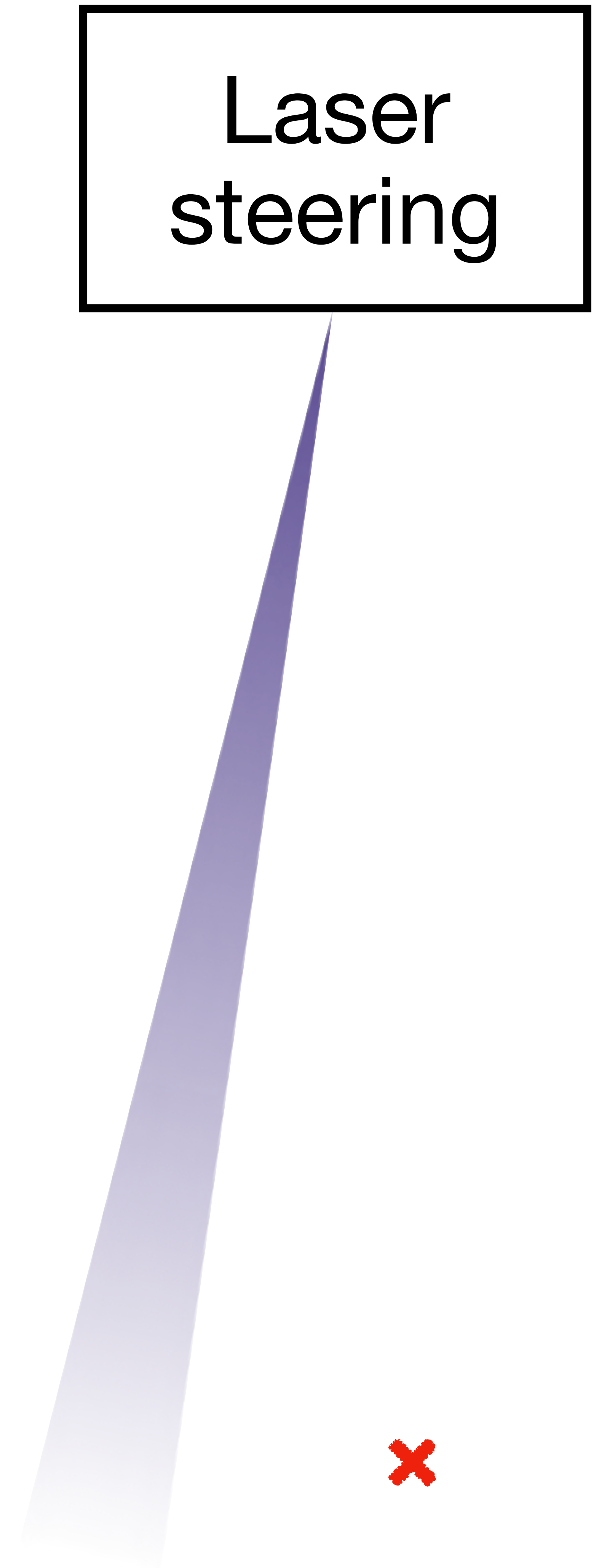
Challenges

1. Low tolerance for localization error

2. Integration of tracking and laser steering

3. Demanding angular tracking rates (e.g., 47°/s for a 6.5 m/s target 6 m away)

✗ Inevitable tracking and steering delays



Lasertag Design Components

1. Low tolerance for localization error
2. Integration of tracking and laser steering

→ Optical design for streamlined tracking and laser steering

3. Demanding angular tracking rates (e.g., 47°/s for a 6.5 m/s target 6 m away)

→ Predictive steering for high mobility

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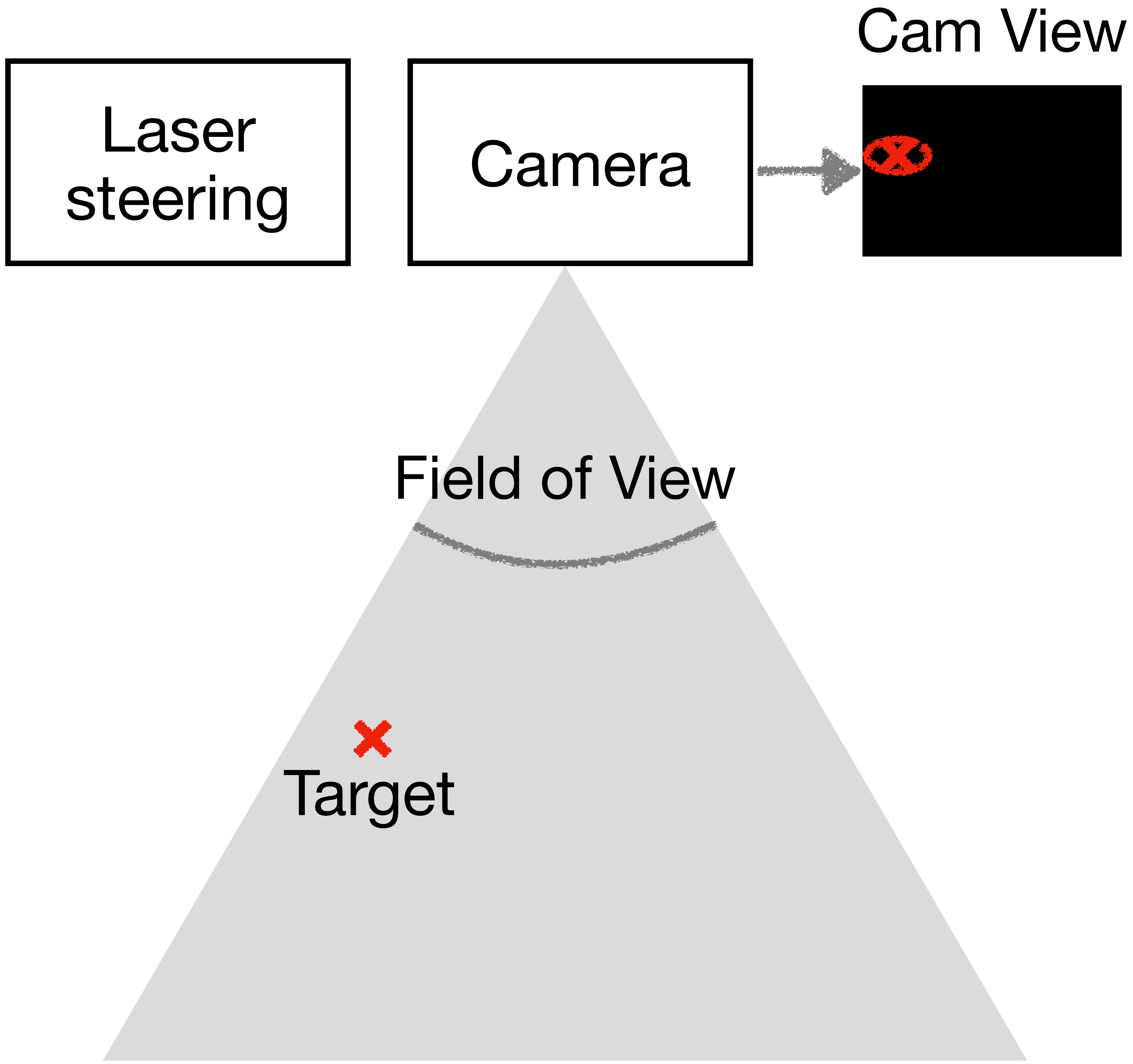
Optical Design

Camera-Based Tracking

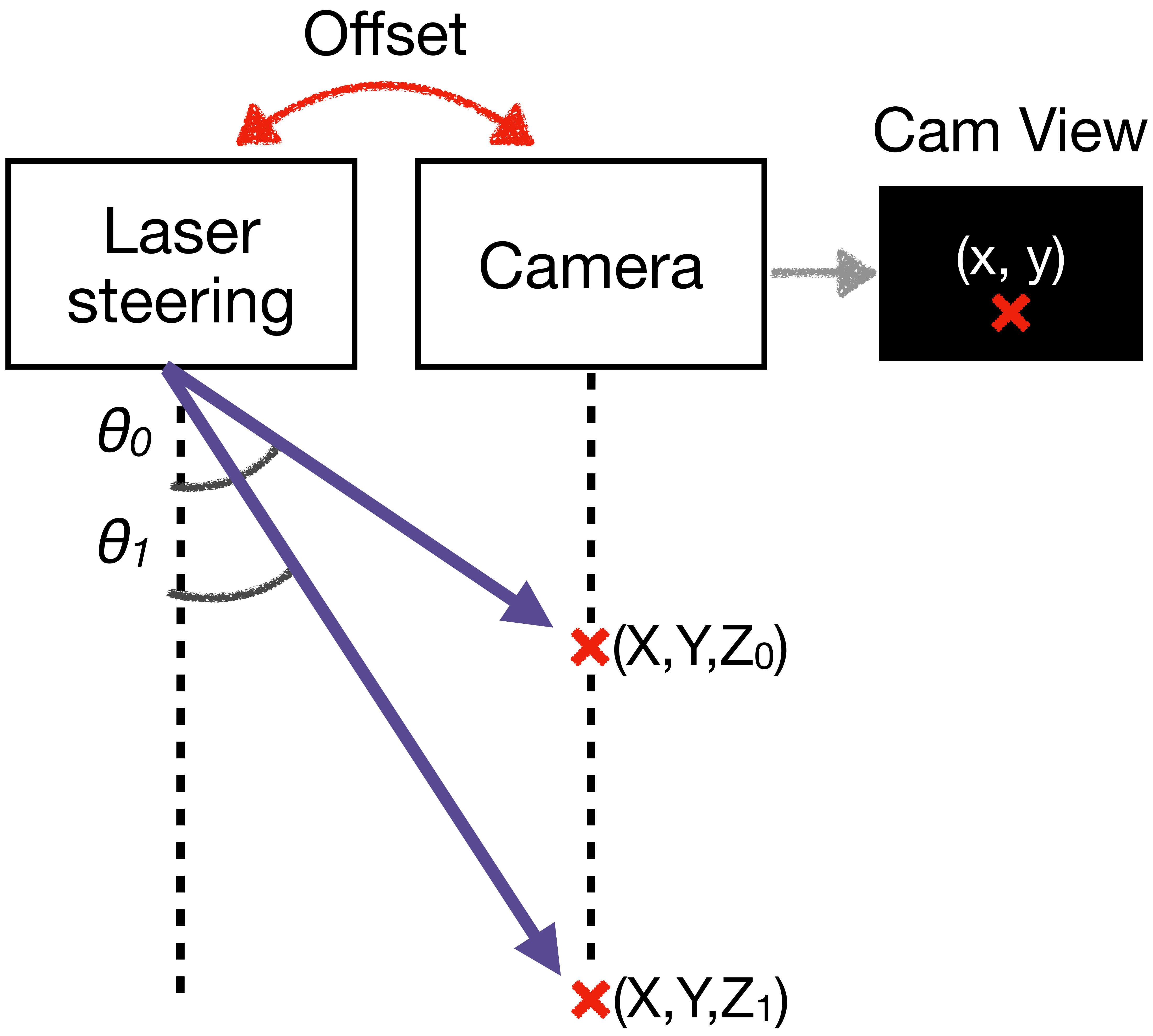
- ✔ Accurate (constrained by image sensor resolution)
- ✔ Ease of co-location with steering



Optical Design

Camera-Based Tracking

- ✔ Accurate (constrained by image sensor resolution)
- ✔ Ease of co-location with steering
- ✗ Offset introduces **depth ambiguity** when translating position to angle



Optical Design

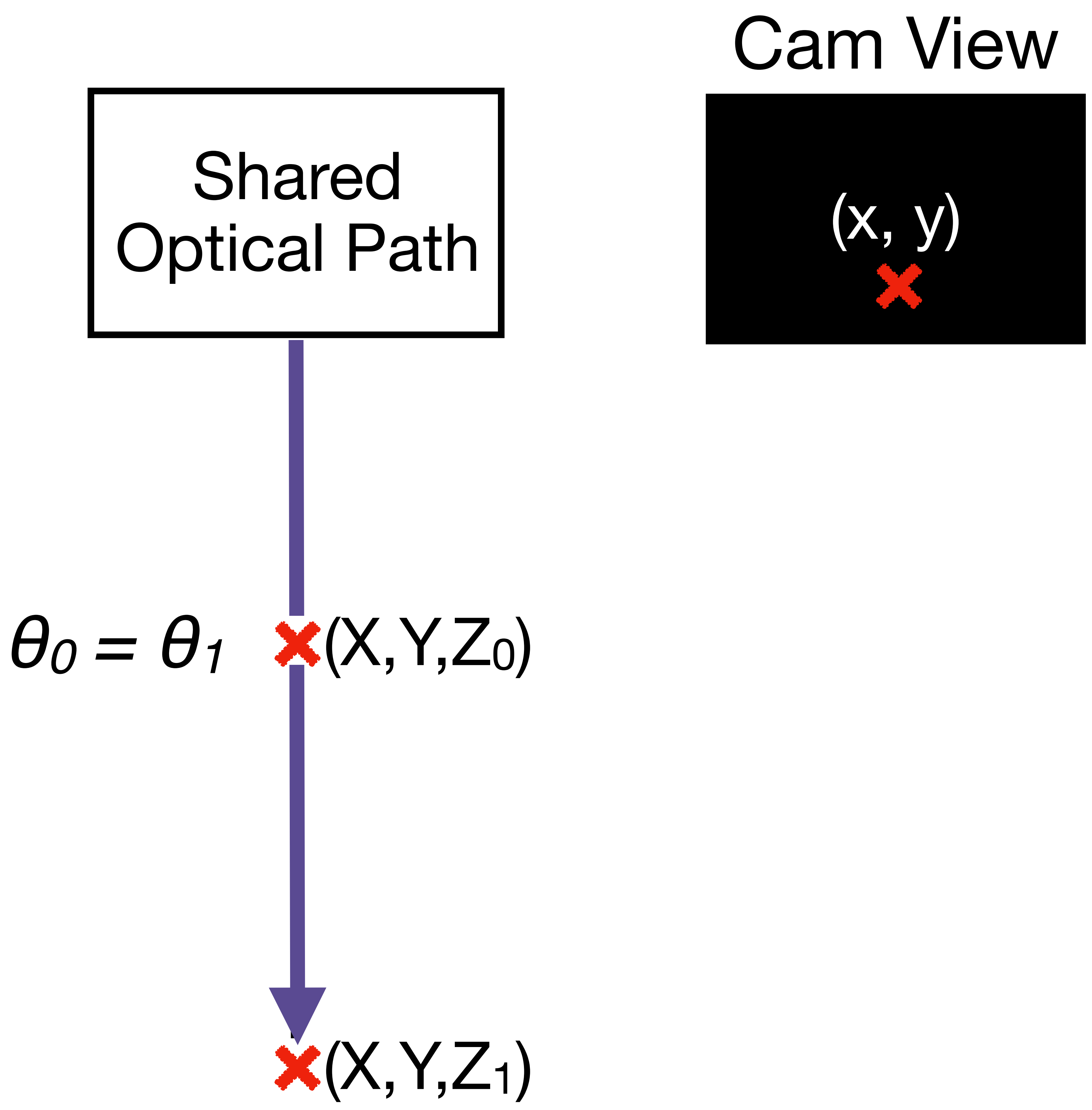
Camera-Based Tracking

✔ Accurate (constrained by image sensor resolution)

✔ Ease of co-location with steering

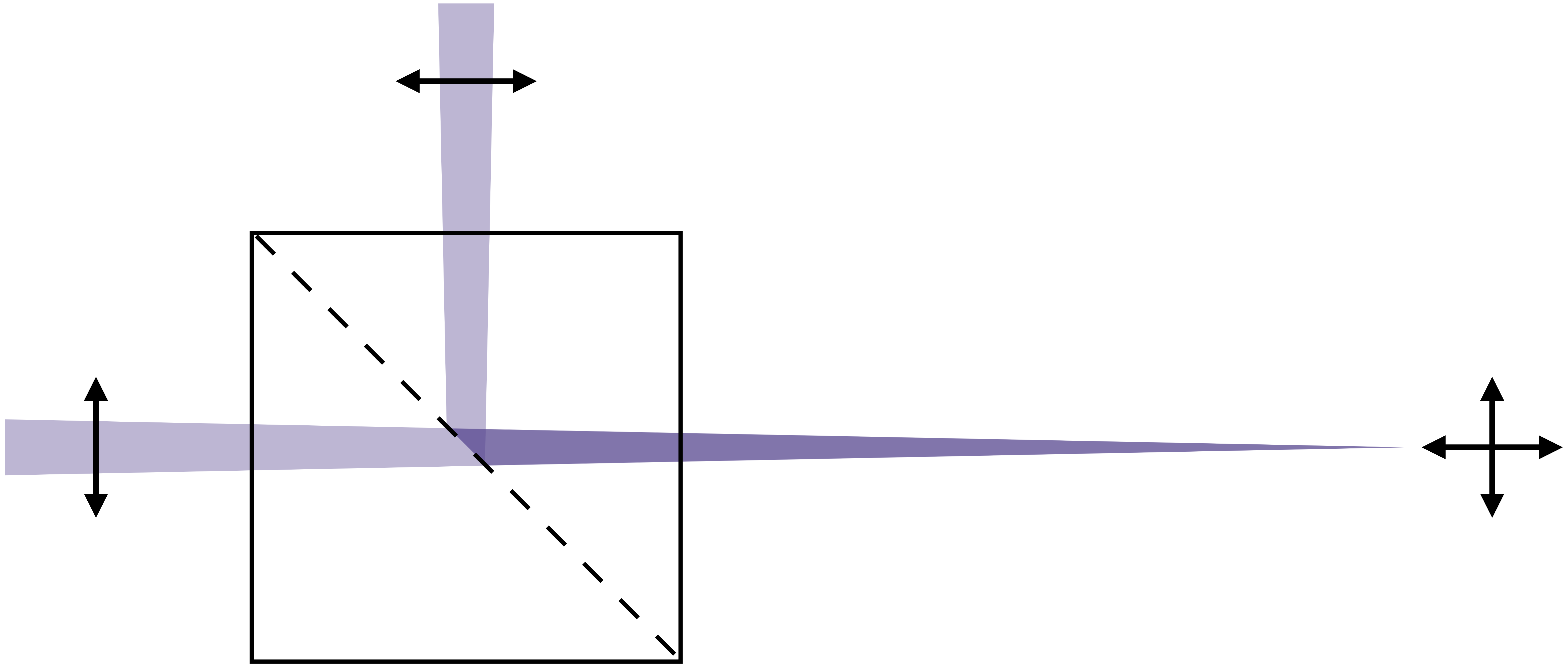
✗ Offset introduces **depth ambiguity** when translating position to angle

✔ Our design: eliminating offset with a shared optical path



Optical Design

#1 Efficient Optical Path Sharing

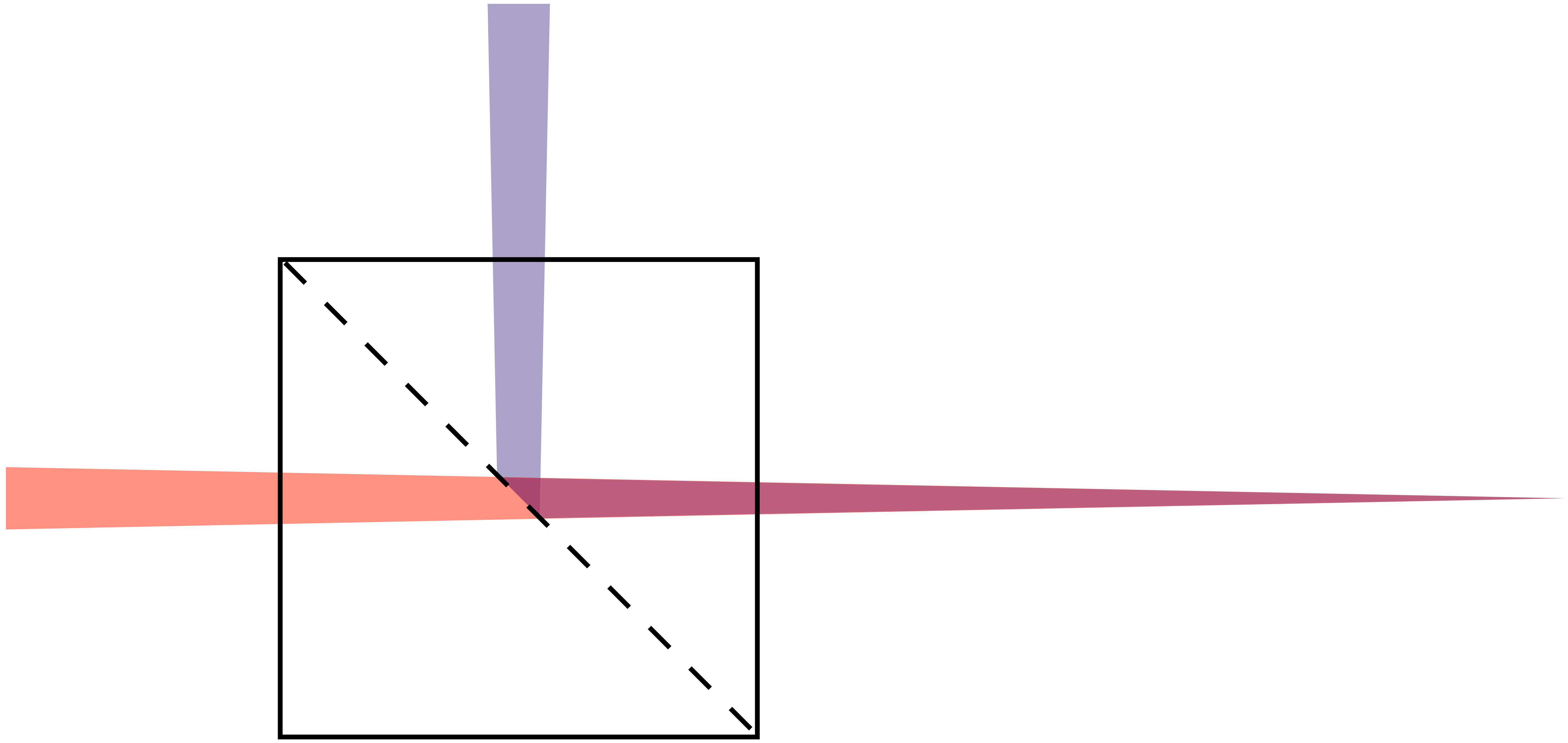


Beamsplitter

Polarization-dependent

Optical Design

#1 Efficient Optical Path Sharing

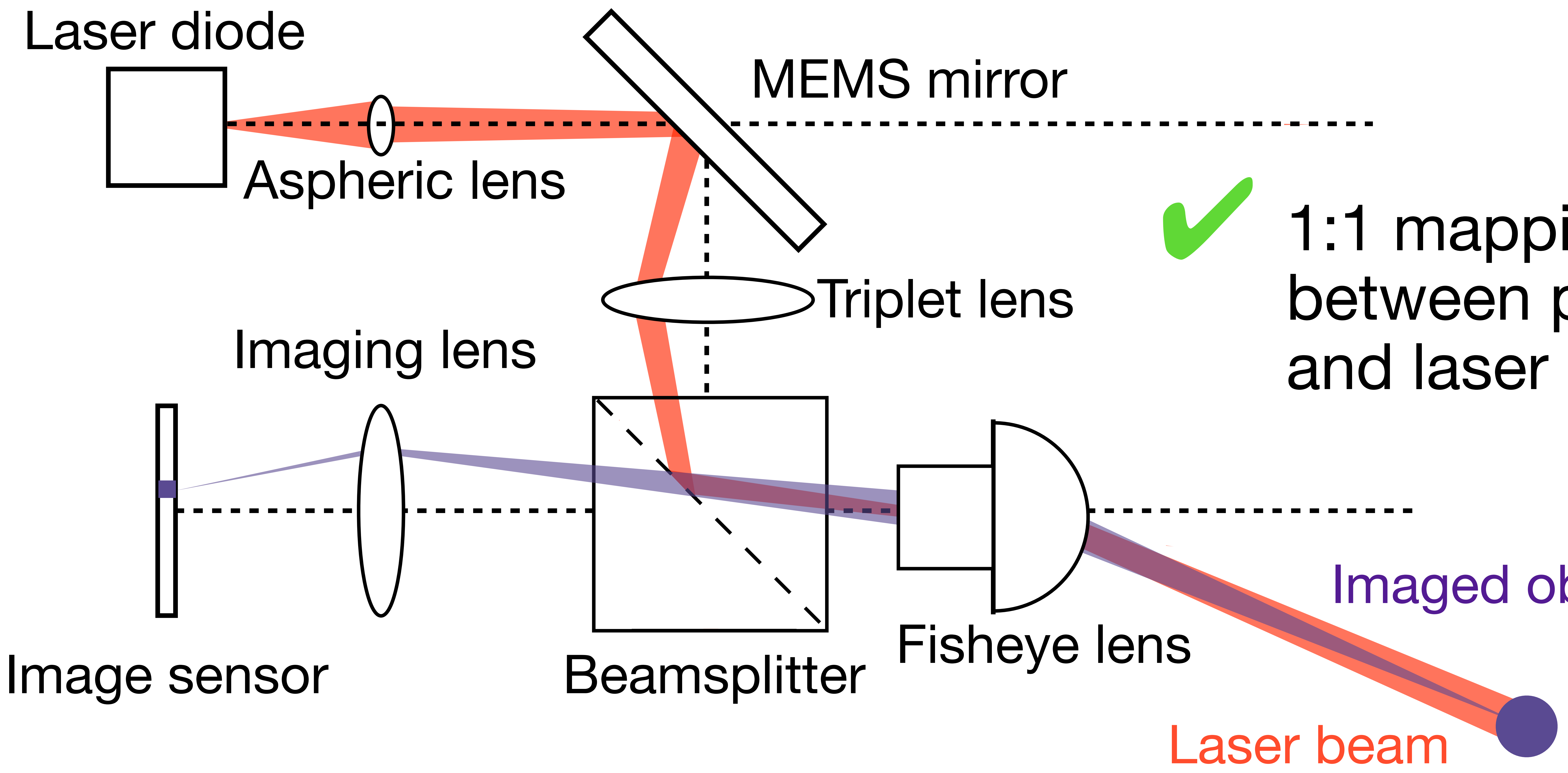


Beamsplitter

Wavelength-dependent

Optical Design

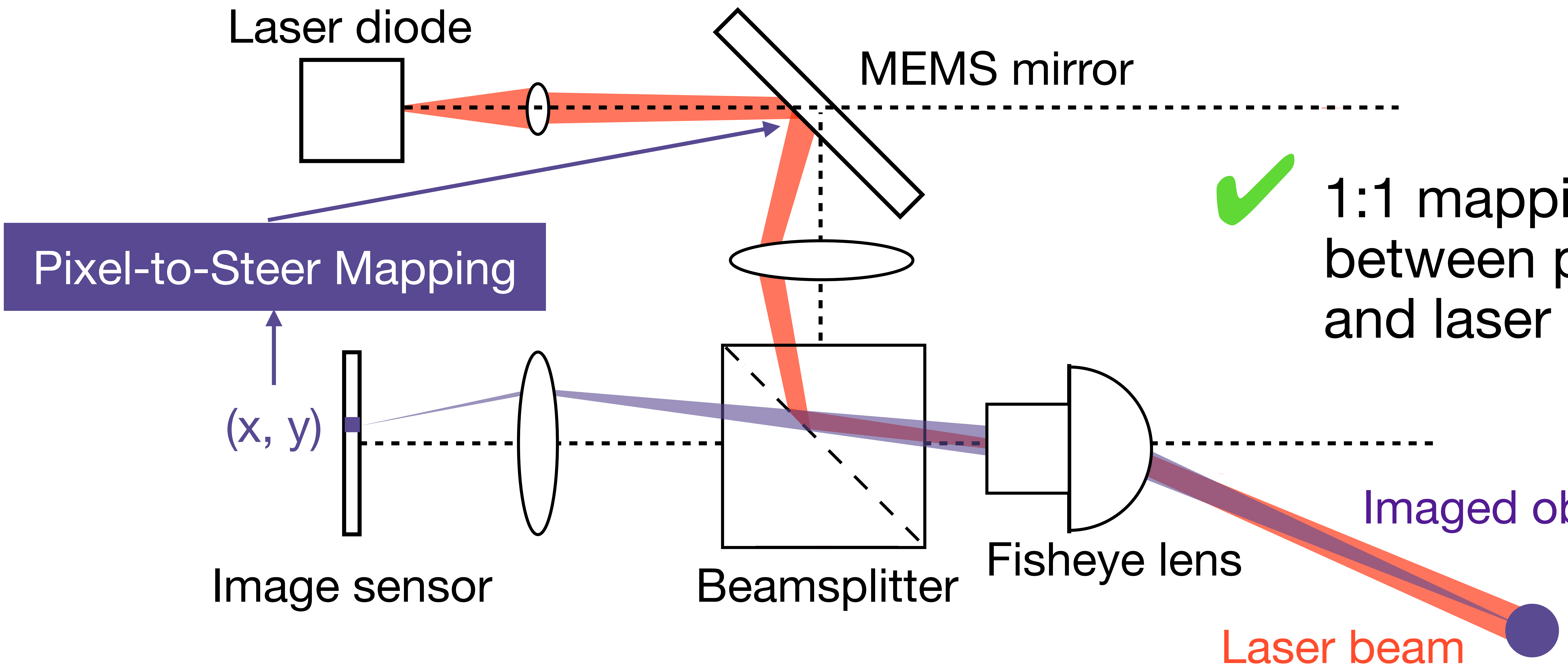
#1 Efficient Optical Path Sharing



✔ 1:1 mapping between pixel and laser angles

Optical Design

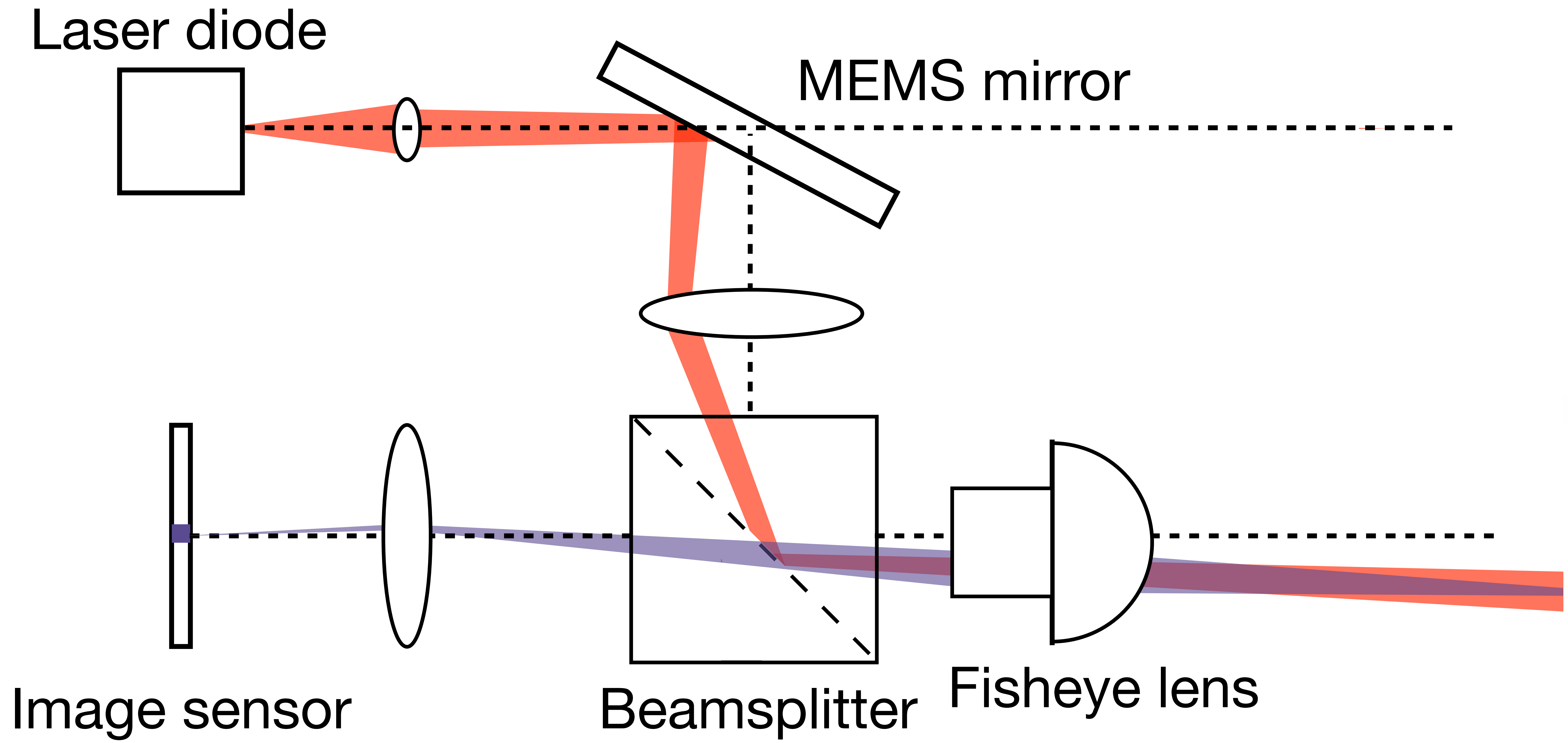
#1 Efficient Optical Path Sharing



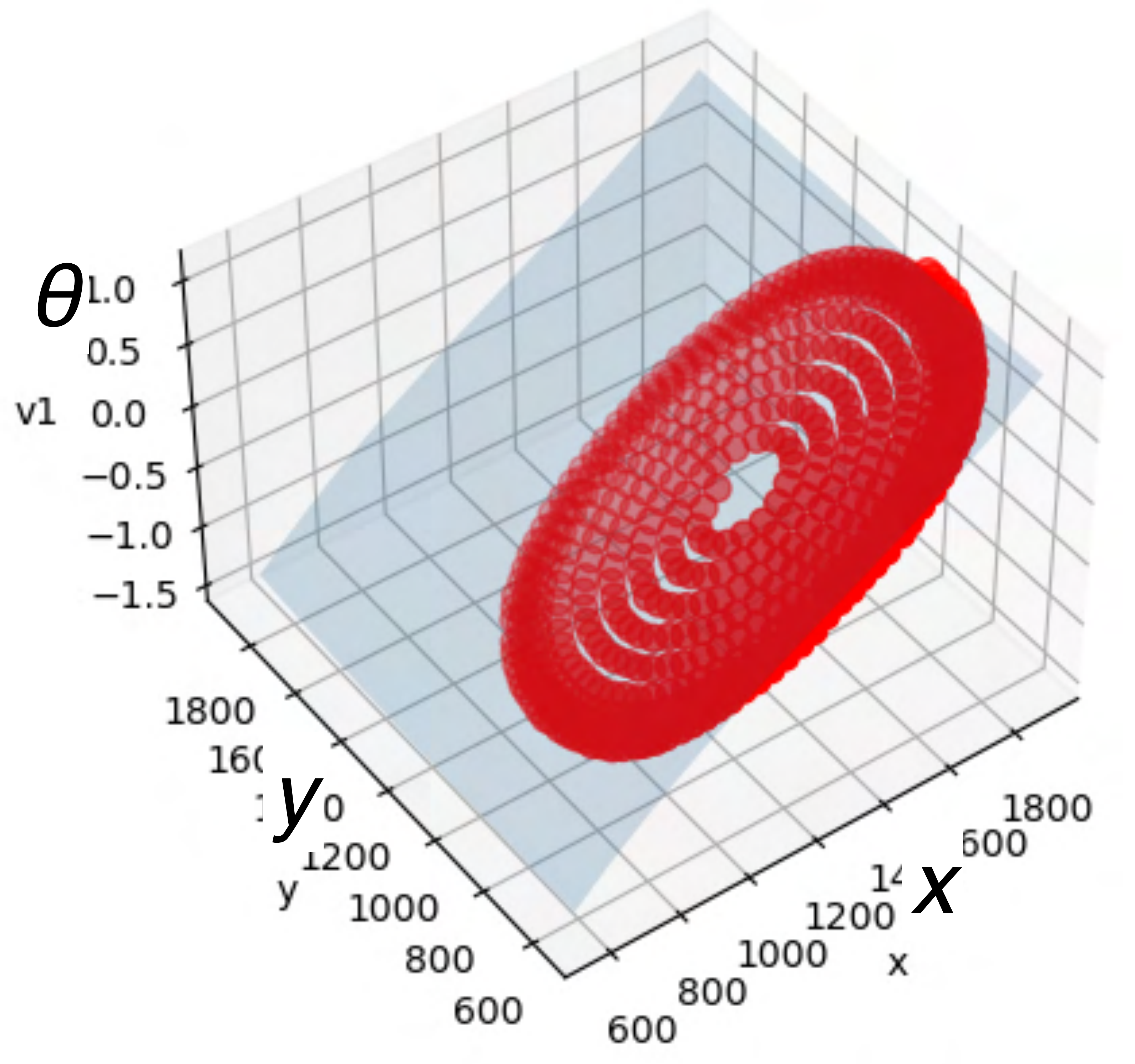
✔ 1:1 mapping between pixel and laser angles

Optical Design

#2 Automated, Short, One-Time Calibration



Pixel-to-Steer Mapping



Optical Design

#3 Fast Tracking with Retroreflective Imaging

Retroreflective
Marker

Cutout + Photodiode

Optical Design

#3 Fast Tracking with Retroreflective Imaging

- ✔ Simple and computationally efficient
- ✔ Generic and application-agnostic
- ✔ Compatible with any computer vision-based tracking technique

Lasertag Design Components

1. Low tolerance for localization error
2. Integration of tracking and laser steering

→ Optical design for streamlined tracking and laser steering

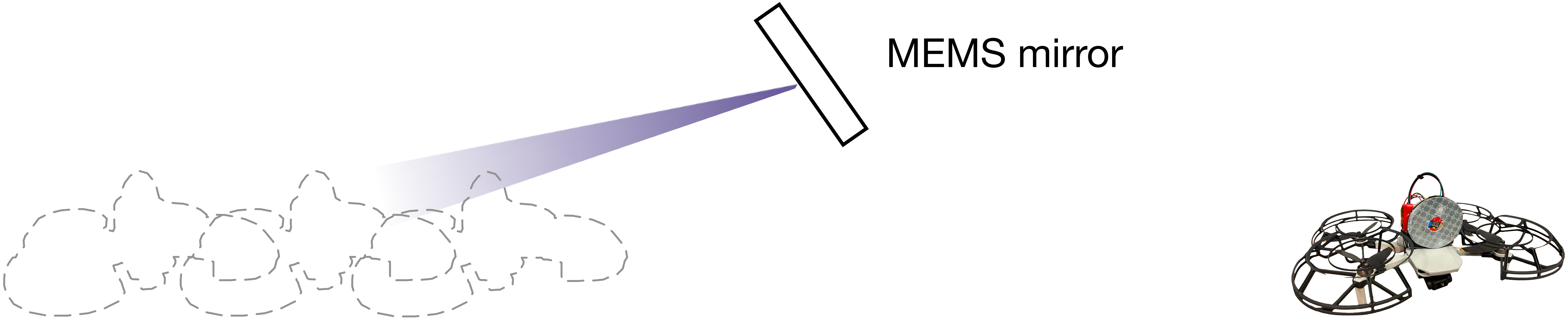
3. Demanding angular tracking rates (e.g., 47°/s for a 6.5 m/s target 6 m away)

→ Predictive steering for high mobility

Sources of Tracking and Steering Delays

- ✗ Image capture (e.g., 28 ms for a 35 FPS camera)
- ✗ Image processing (e.g., 8 ms for our retroreflective imaging)
- ✗ Steering (e.g., 2 ms for our MEMS mirror)

Predictive Steering for High Mobility



✗ Significant tether downtime during tracking and steering delays.

Predictive Steering for High Mobility

Predictive Steering for High Mobility

Predictive Steering for High Mobility

✔ Quadrupled steering rate

Predictive Steering for High Mobility

✔ Quadrupled steering rate

Lasertag Prototype

Lasertag Prototype

Lasertag Prototype

Evaluation
Setup

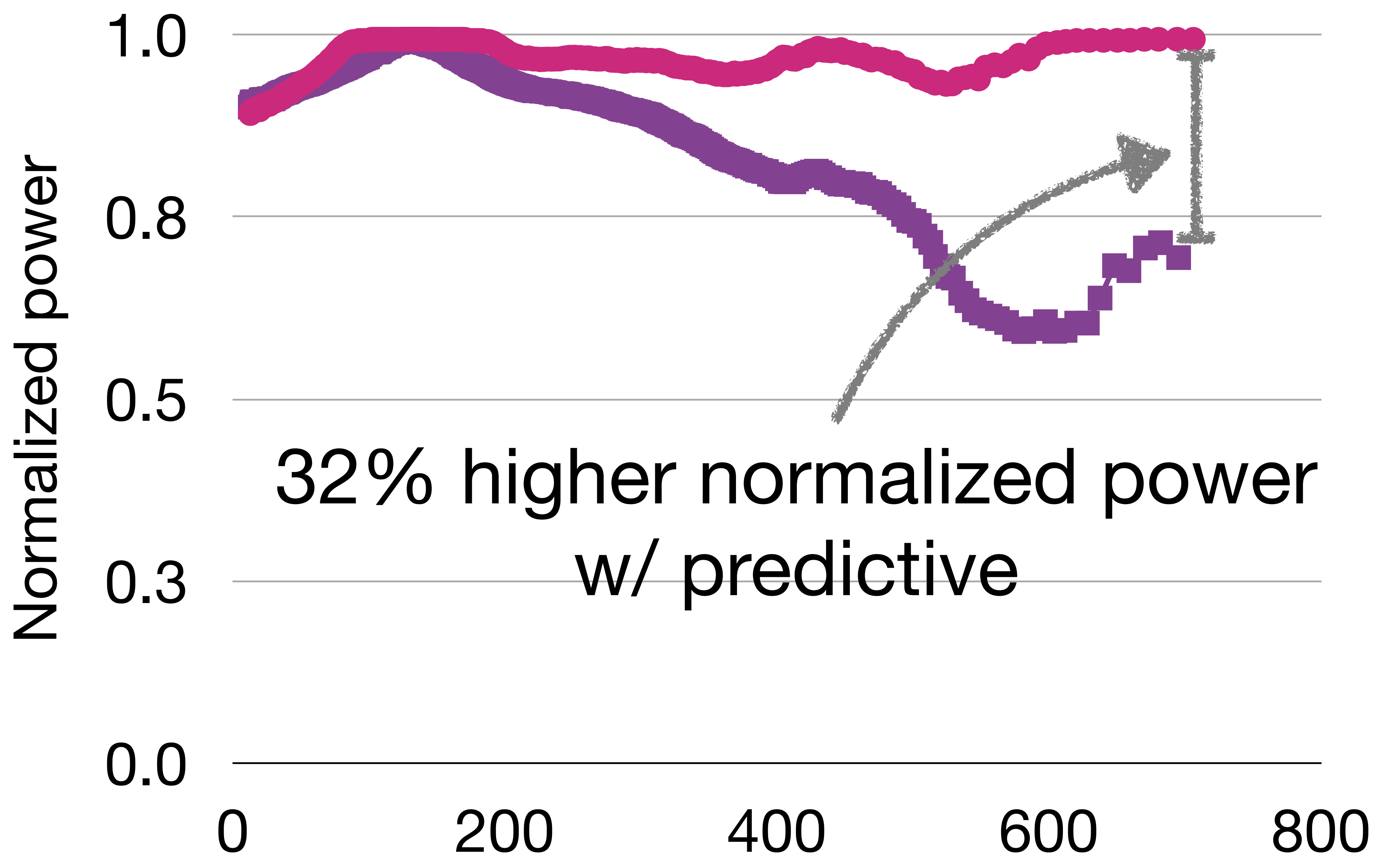

Evaluation
Setup
Lasertag Prototype
Drone Communication
Laser VR
Retroreflective
Marker
Wireless Power Delivery

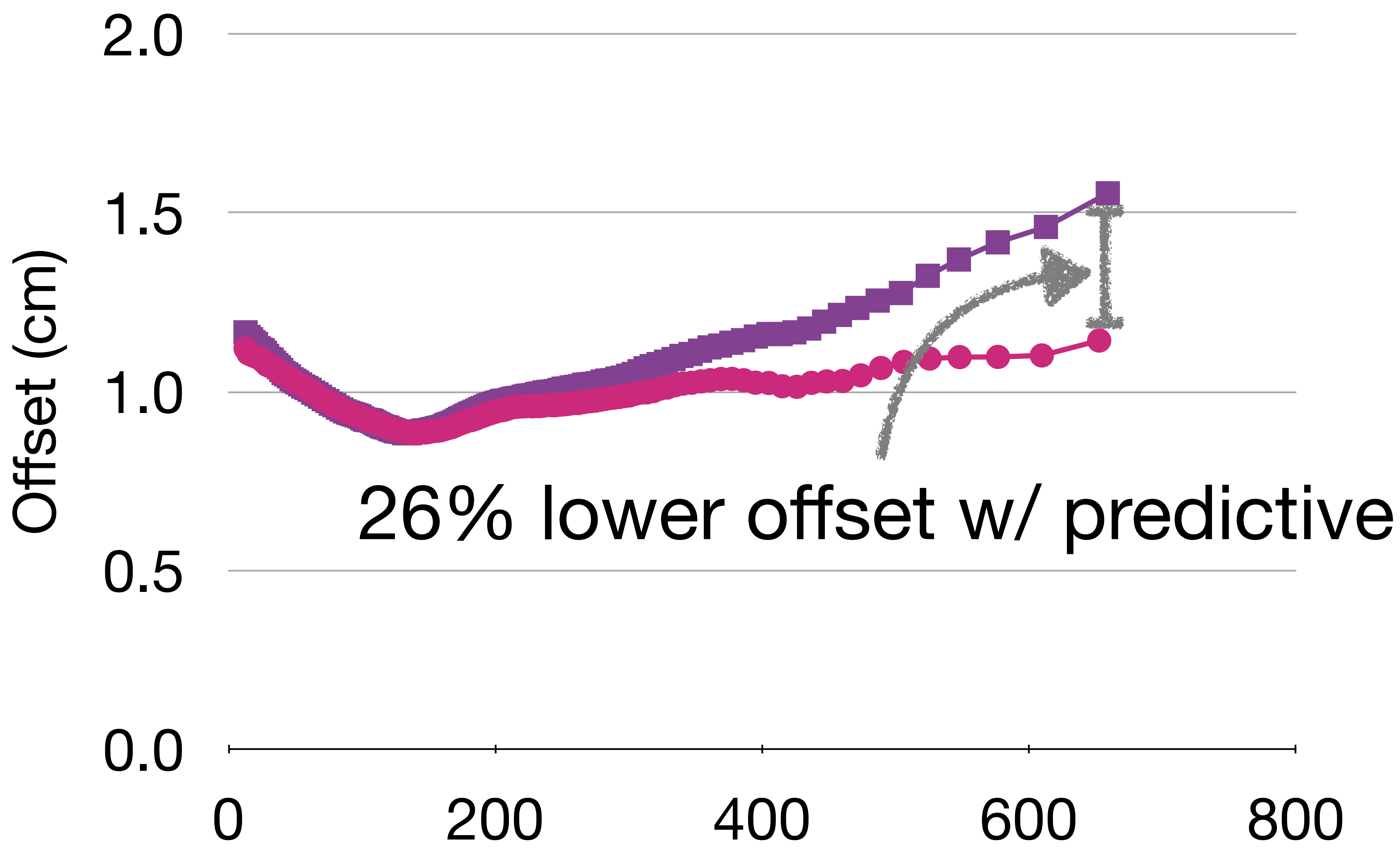
Evaluation
Metrics

1. Normalized power
2. Offset between beam and marker

Evaluation

Aggregated Results



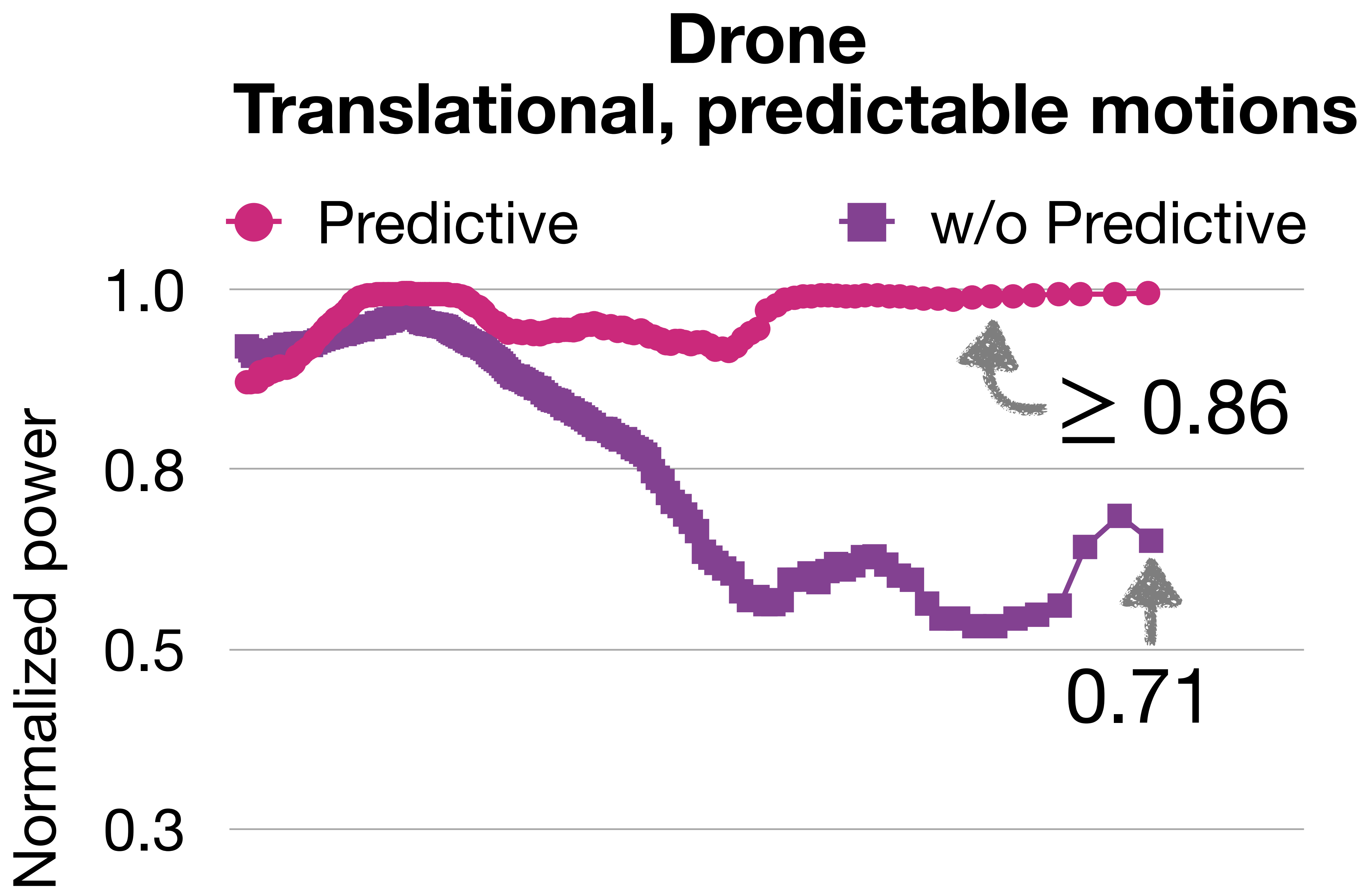


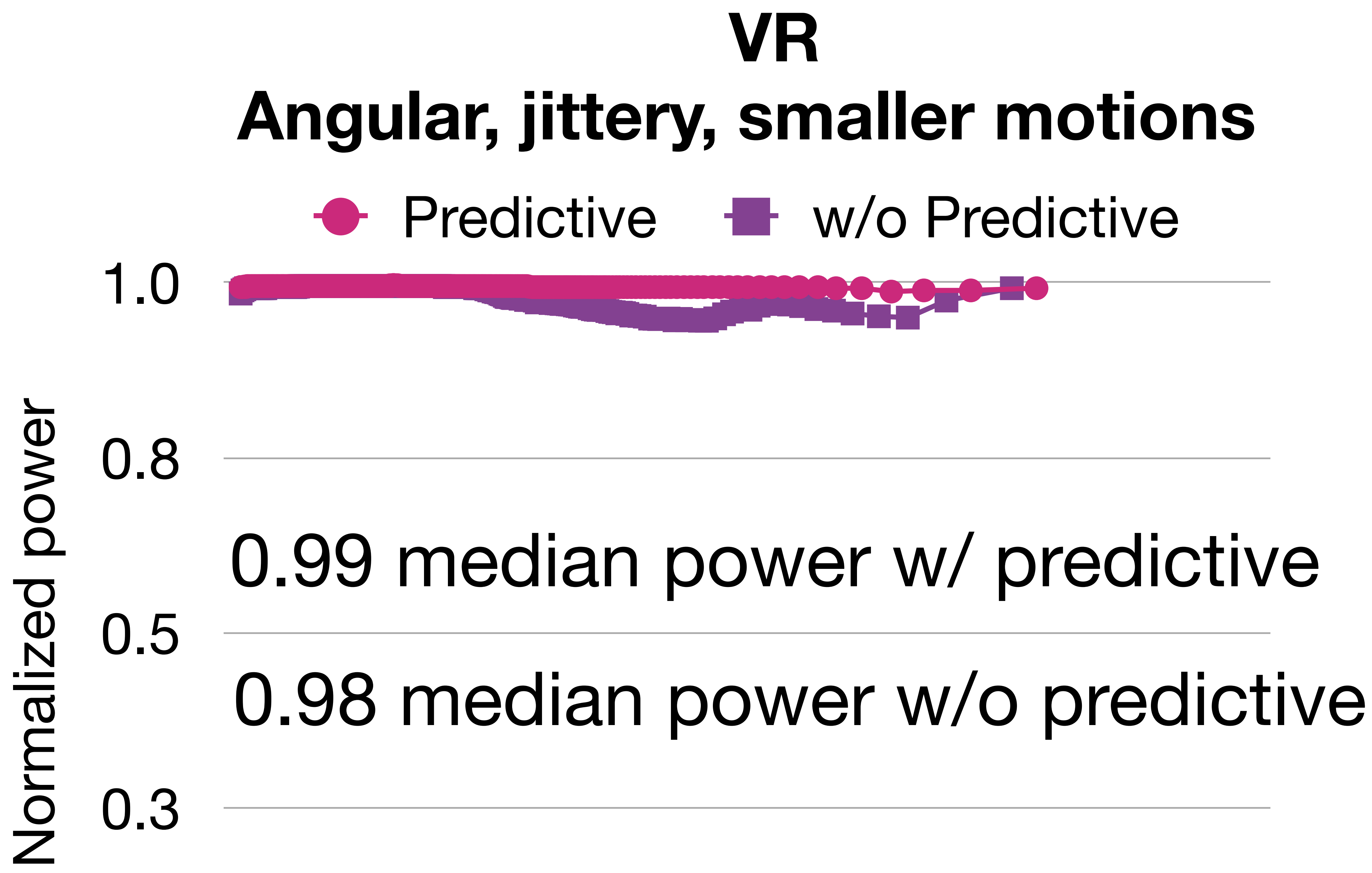
✔ 0.97 median normalized power
→ 1 x 10^{-8} BER @ 1Gbps

✔ 1.03 cm median offset

Evaluation

Application-Specific Results

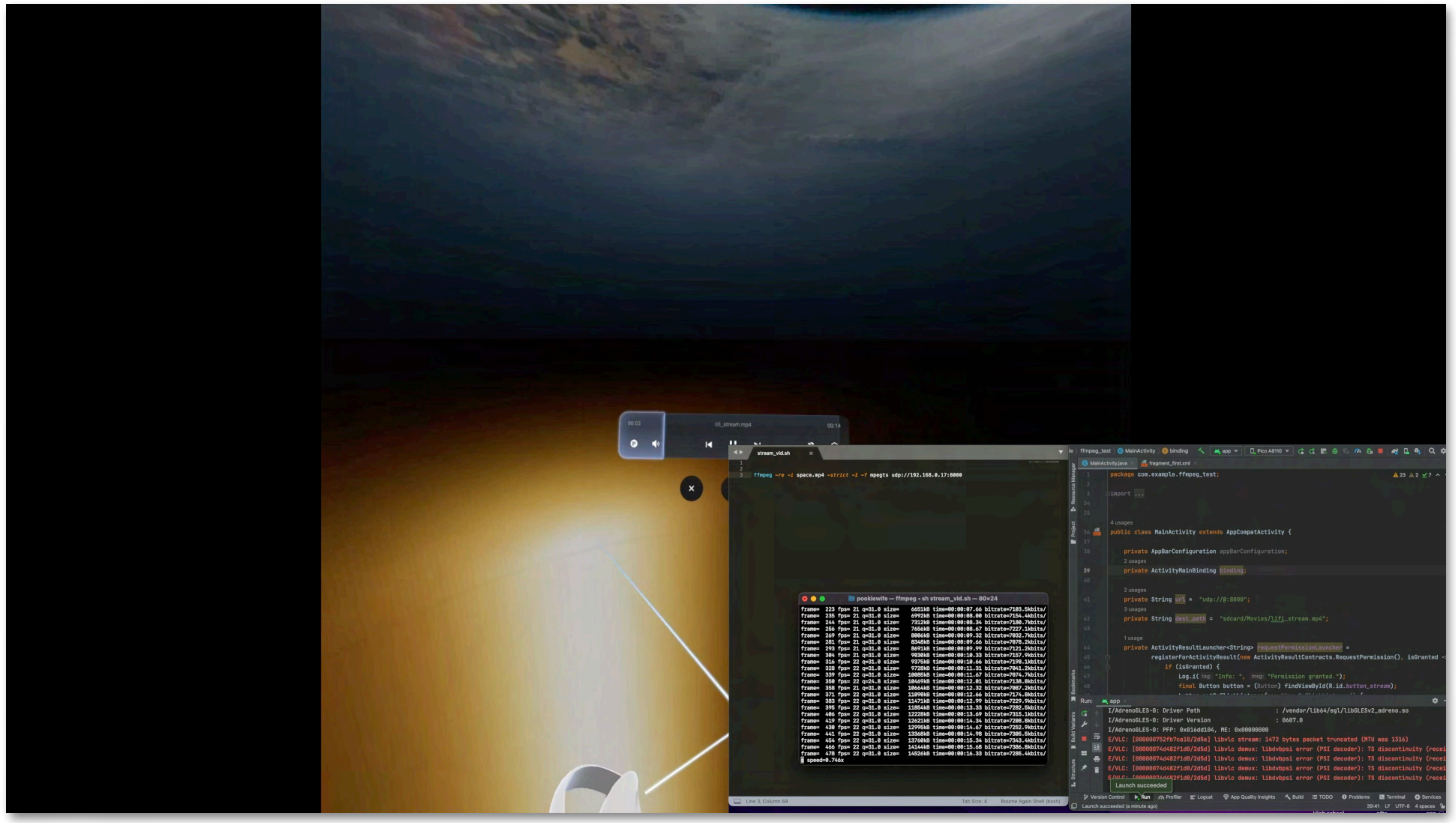




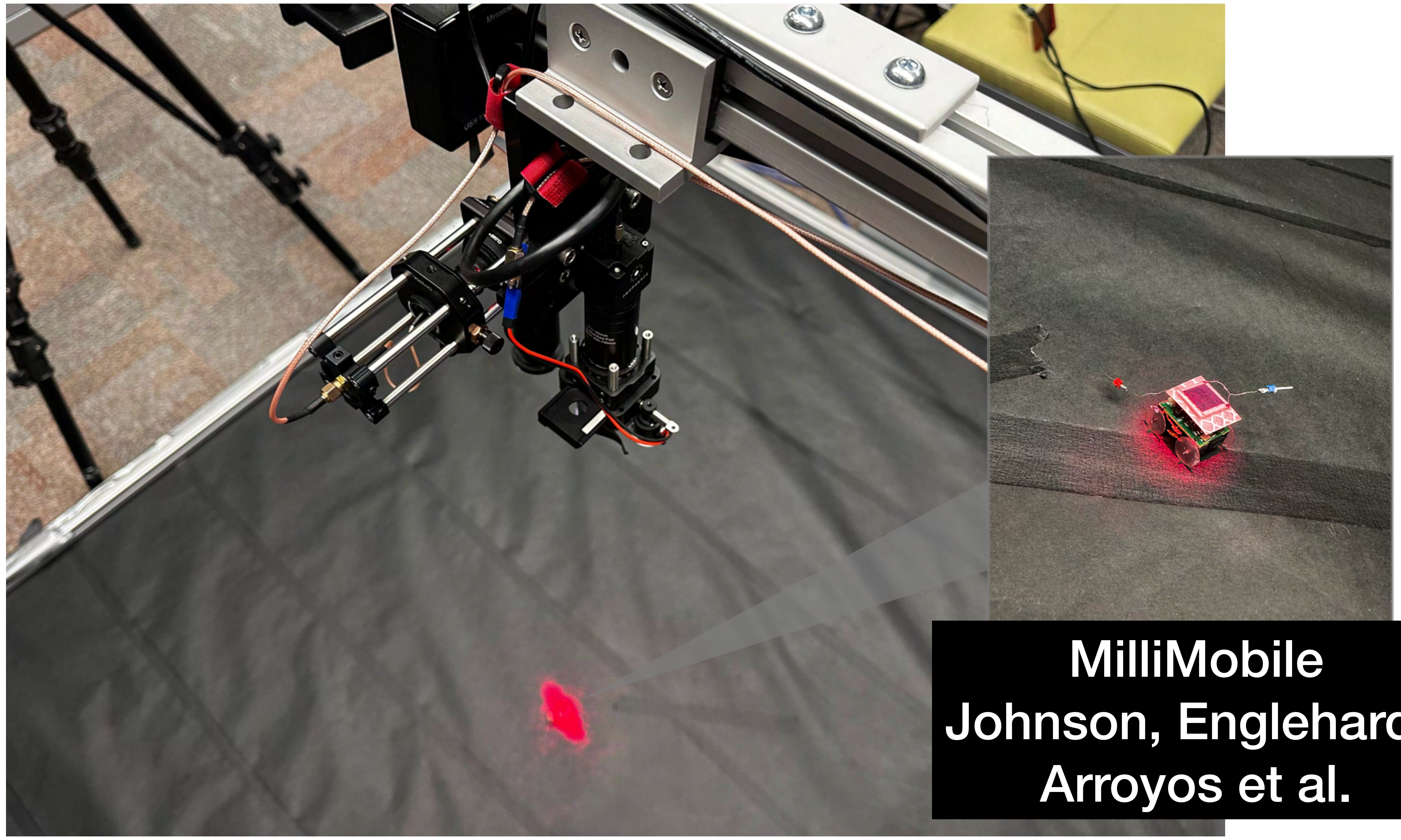
✔ Predictive gain proportional to translational velocity

Future Work

Gbps VR streaming



Wireless power delivery



MilliMobile
Johnson, Englehardt,
Arroyos et al.

Thank you!