Geometric system analysis of an imaging LID measuring system using Monte Carlo simulation

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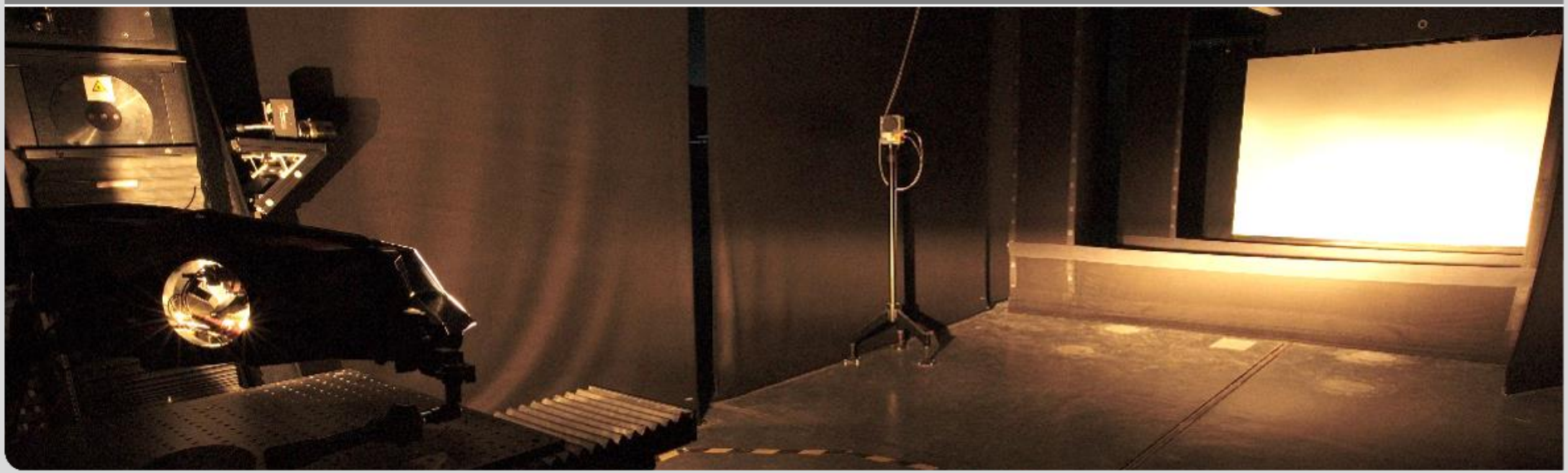


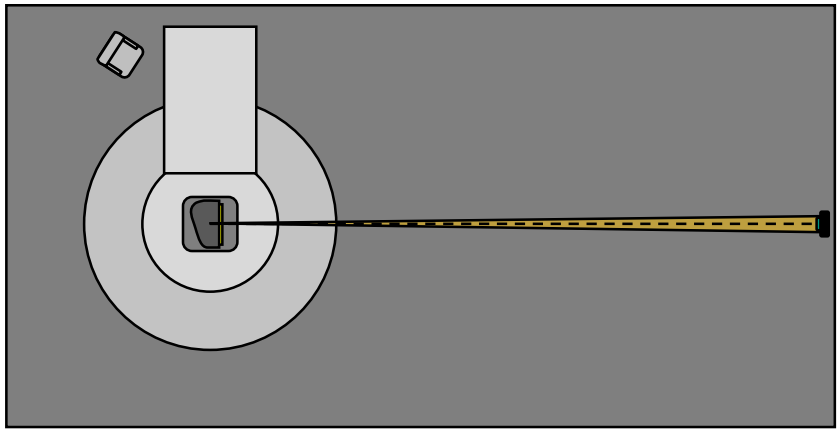
LID measurement system

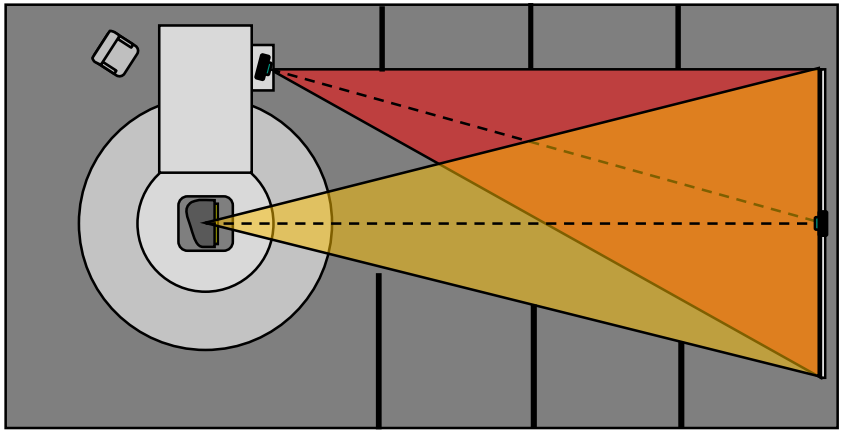
Photometer based measurement

- (-) Long measurement time, depending on resolution
- (+) High dynamics

Camera based measurement

- (+) Short measurement and high resolution
- (-) Limited dynamics





system analysis

Sensitivity analysis for LID measurement system

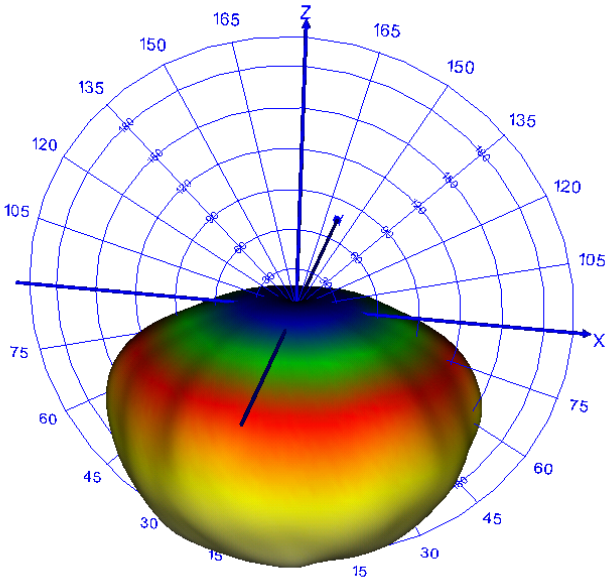
- $I(\varphi, \vartheta) = \frac{d\Phi}{d\Omega} \quad [cd]$

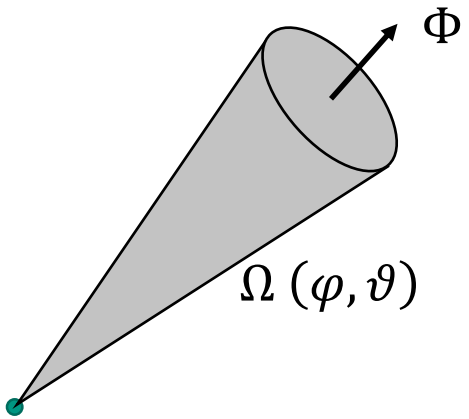
Geometric component

- System model
  - DUT
  - DUT mounting
  - Goniometer
  - Camera, screen and goniometer pose

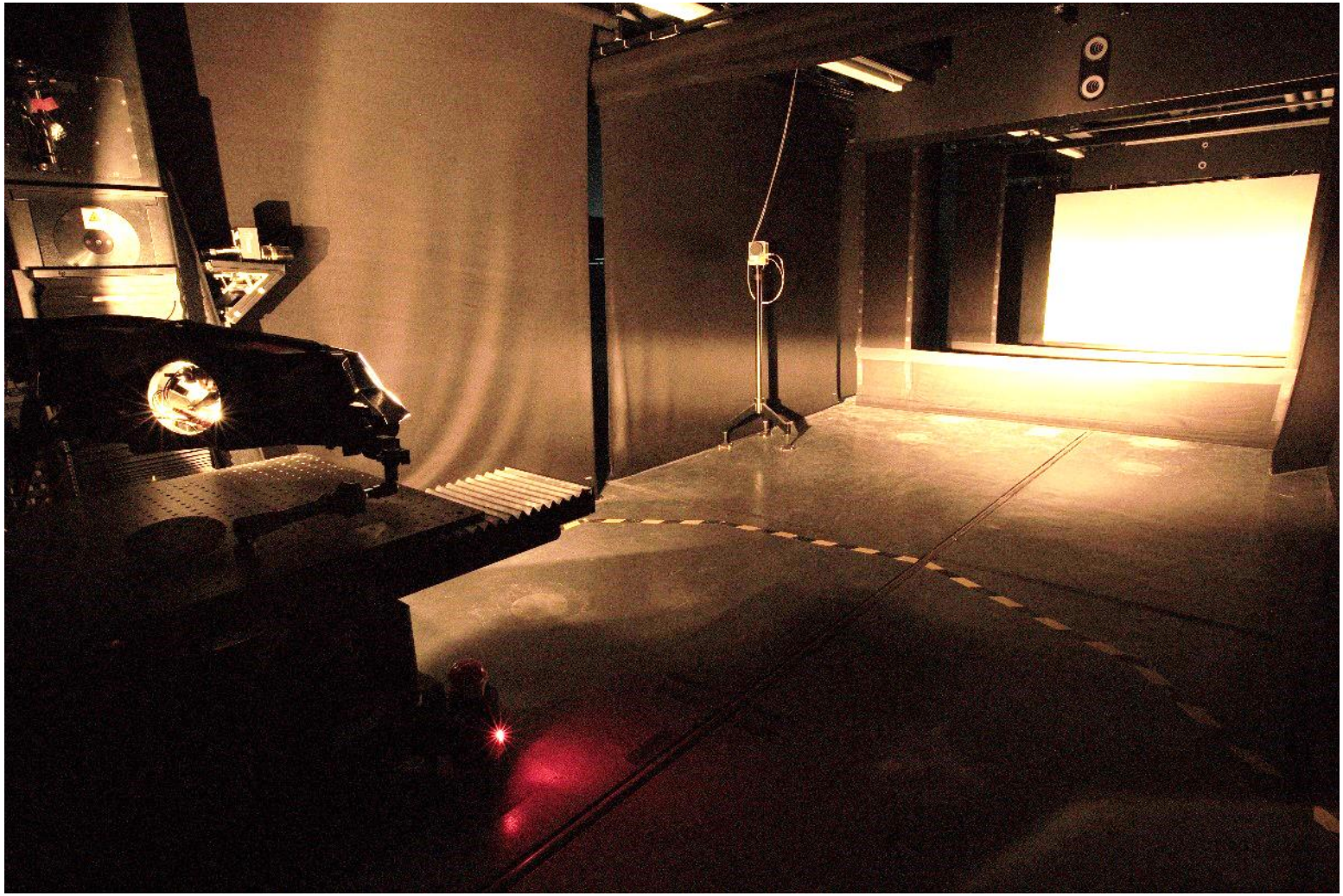
- Standard deviation of input parameter

- Monte Carlo simulation

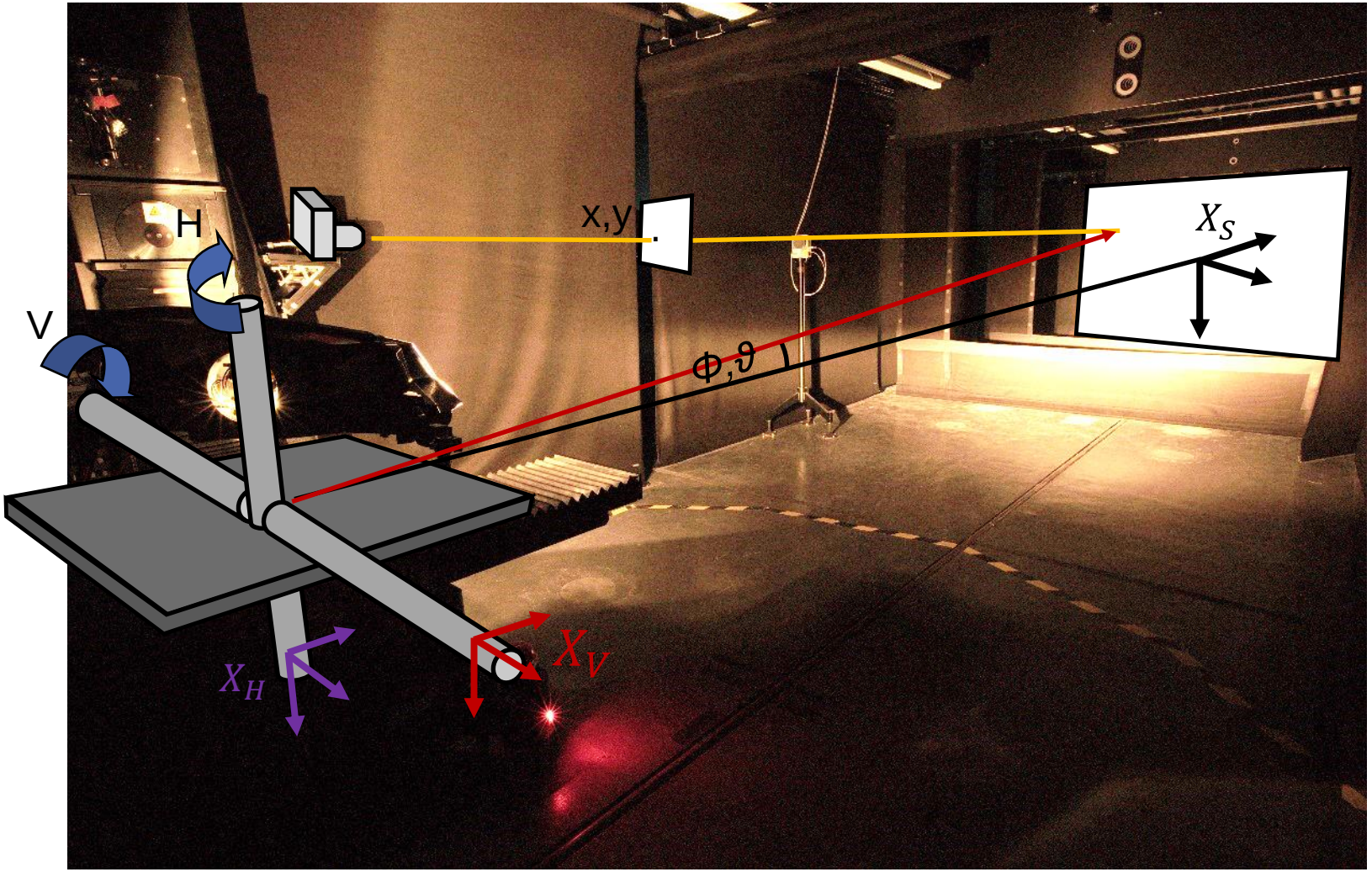




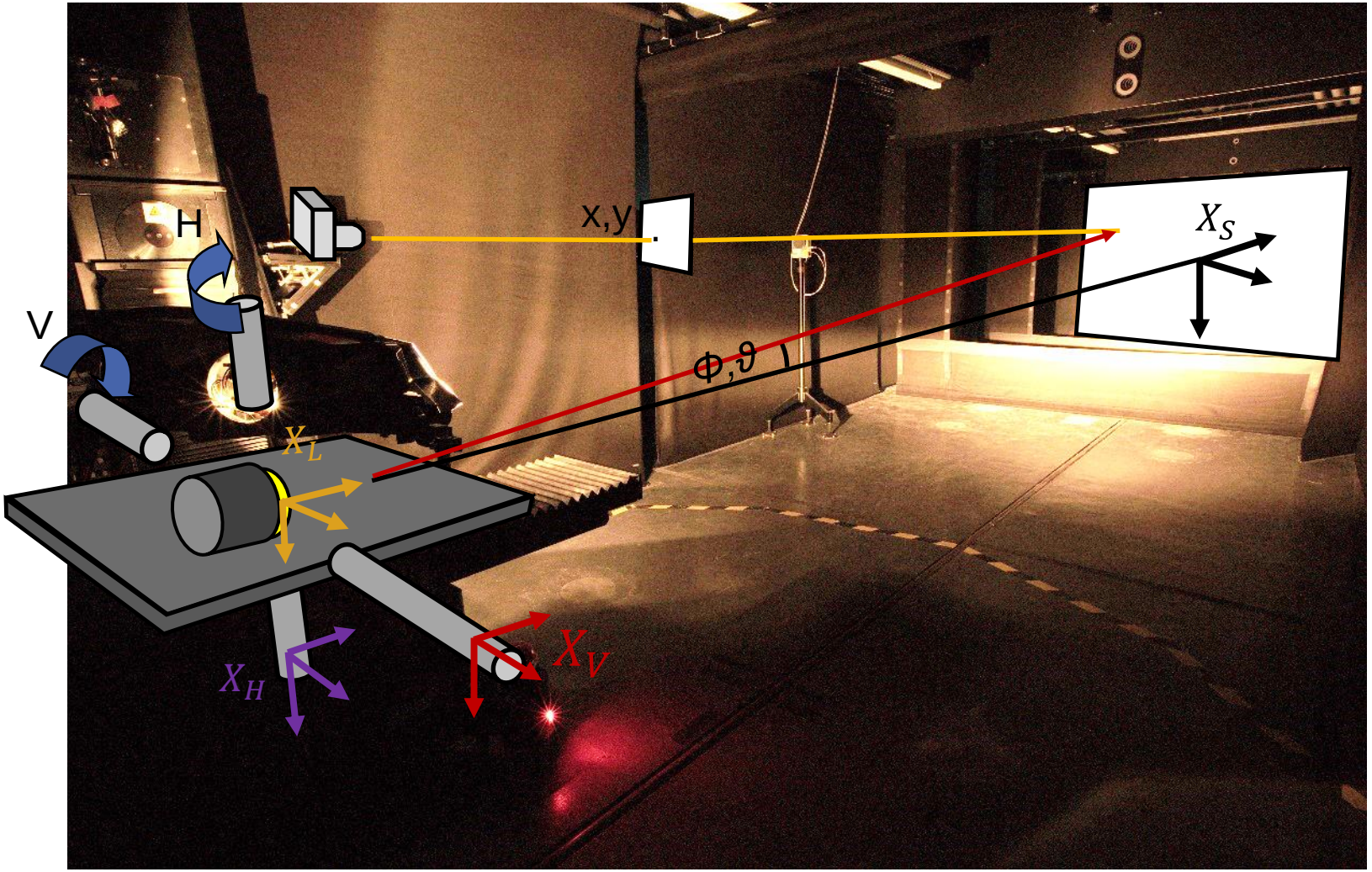
LTI measurement system



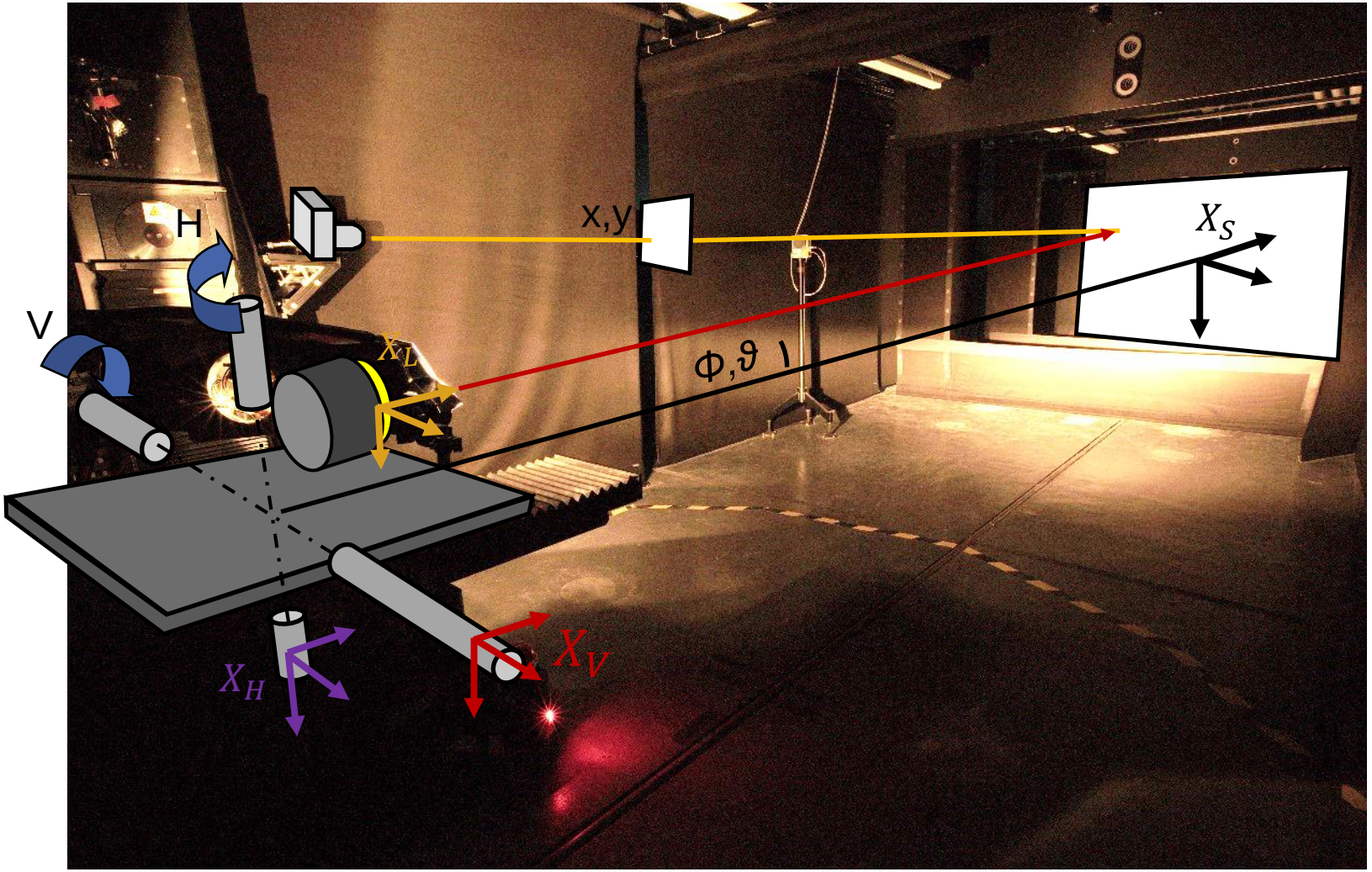
System model setup



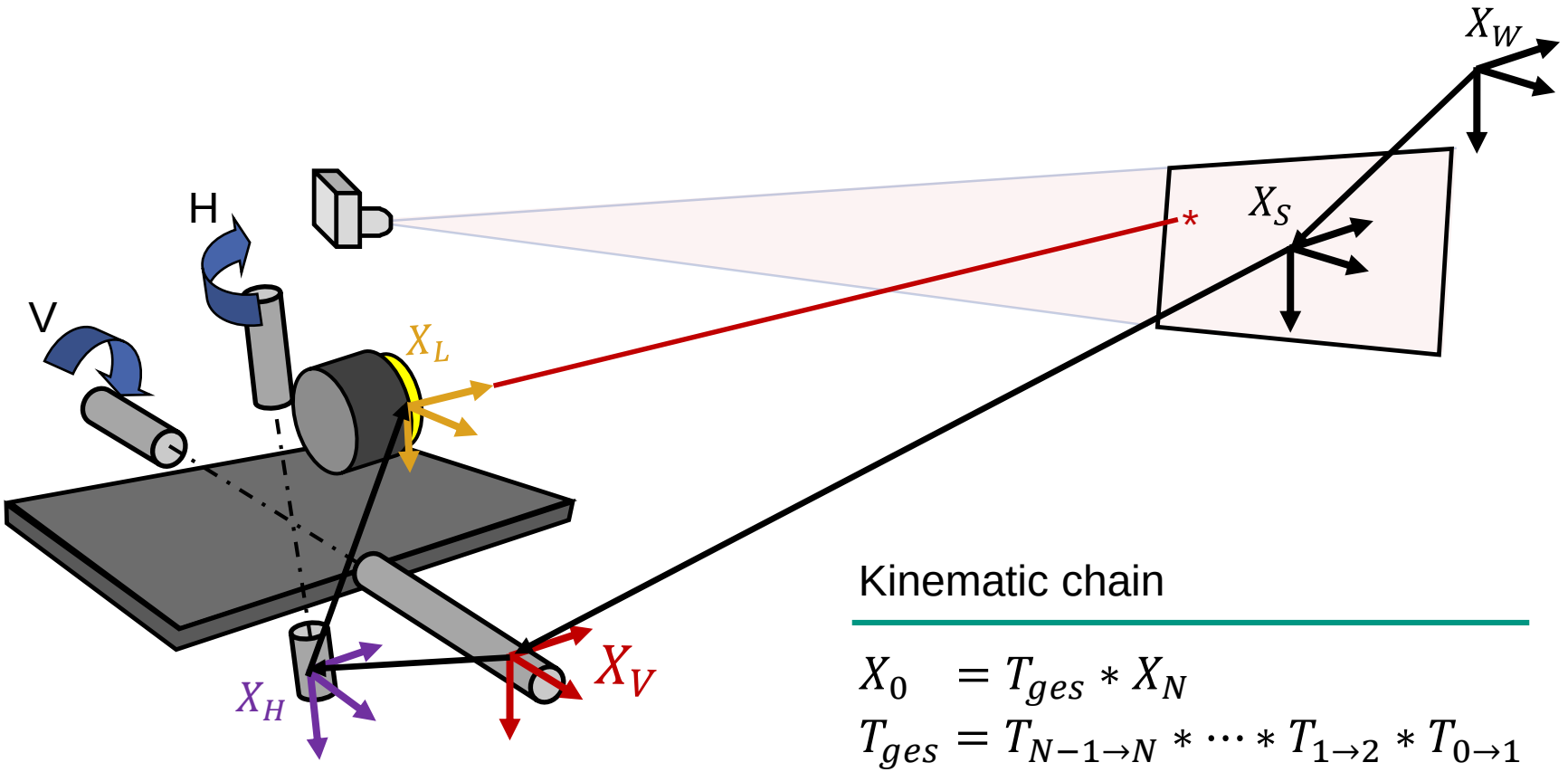
System model setup



System model setup



Kinematic chain



Kinematic chain

$$X_0 = T_{ges} * X_N$$

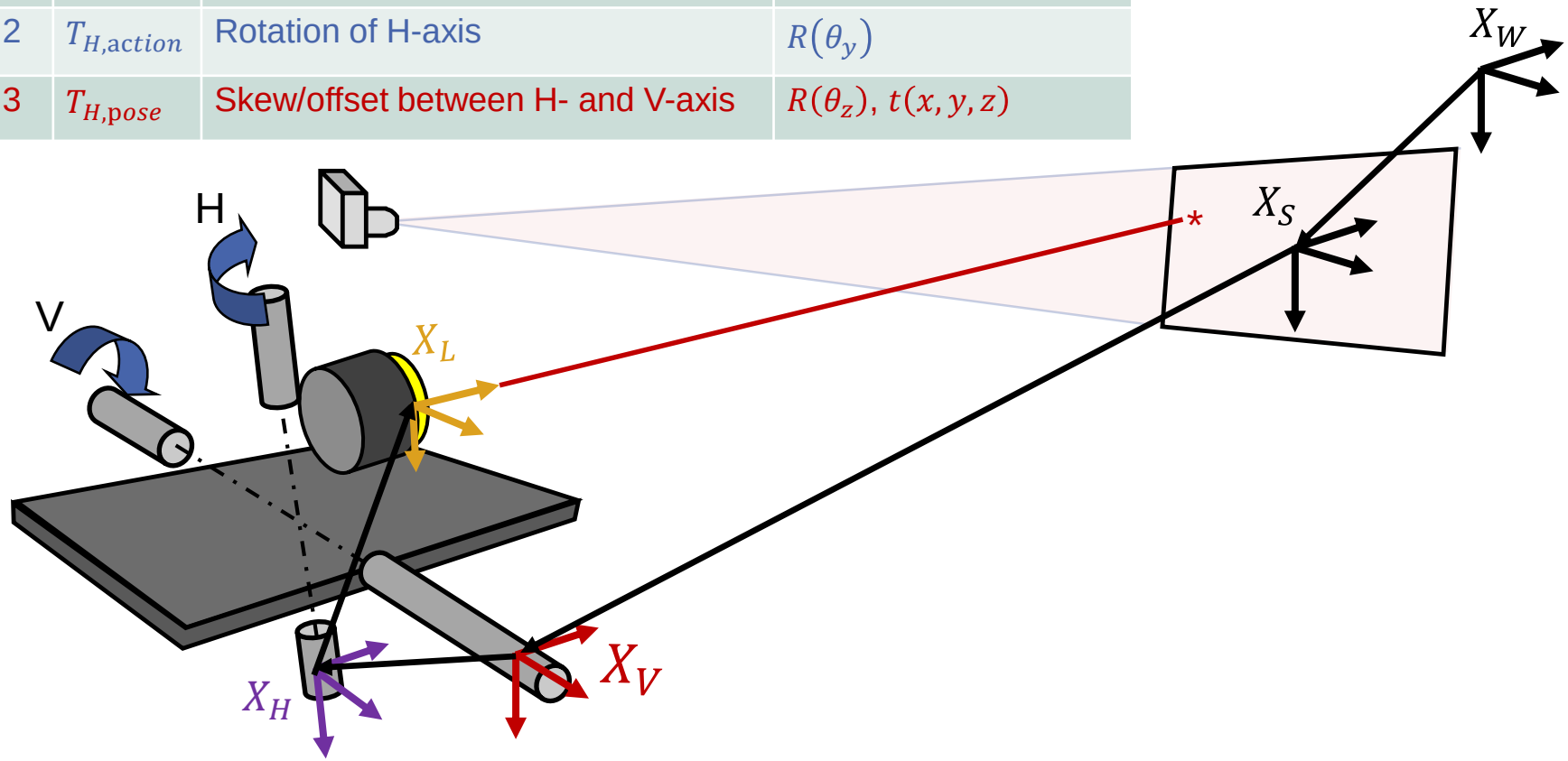
$$T_{ges} = T_{N-1\rightarrow N} * \cdots * T_{1\rightarrow 2} * T_{0\rightarrow 1}$$

$$T_i = \begin{pmatrix} R(\theta_x, \theta_y, \theta_z) & t(x,y,z) \\ 0\ 0\ 0 & 1 \end{pmatrix}$$

Kinematic chain

- $T_{ges} = T_{screen} * T_{V,pose} * T_{V,action} * T_{H,pose} * T_{H,action} * T_{laser}$

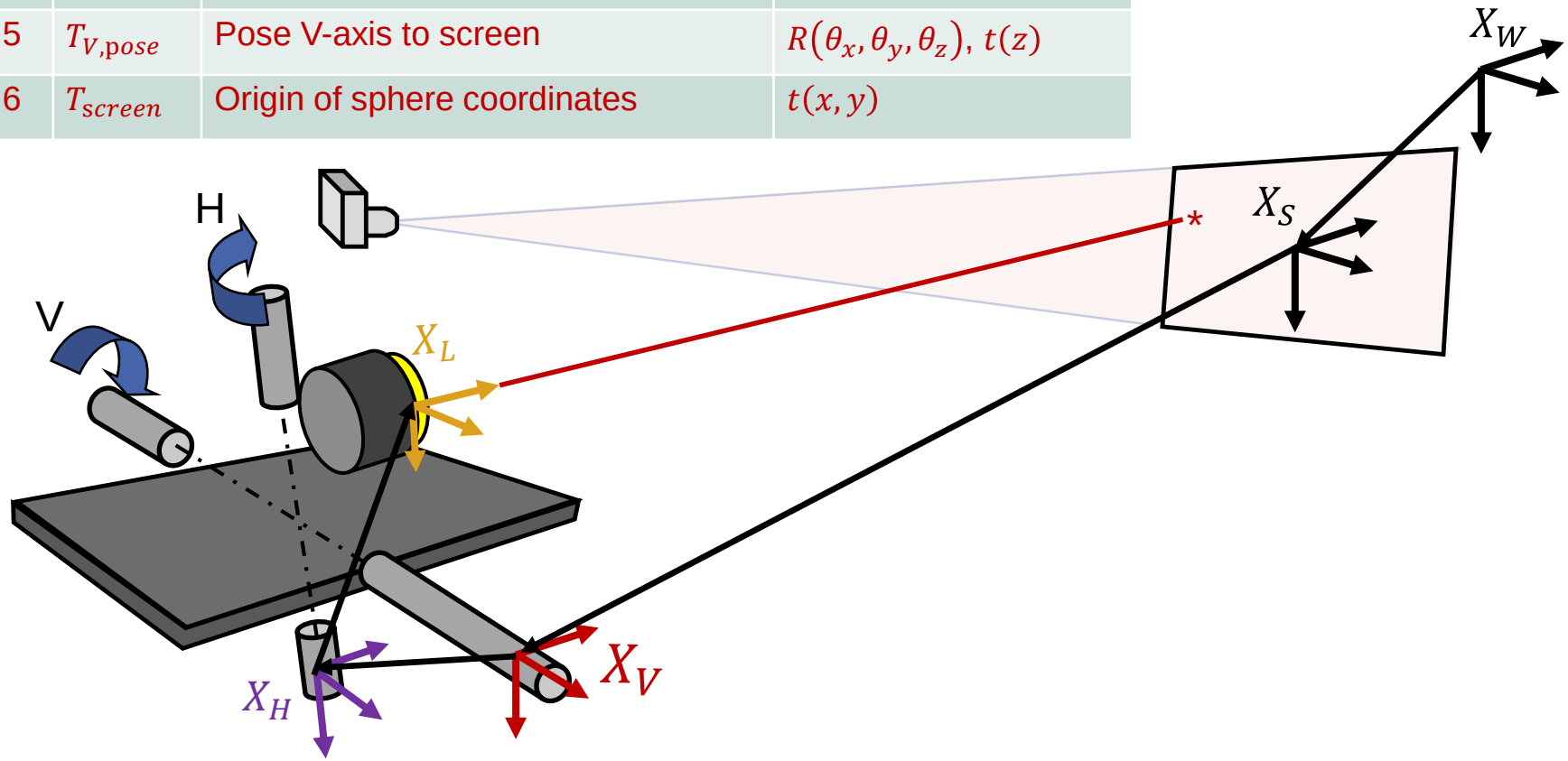
#		Transformation	Degrees of freedom
1	T_{laser}	Laser alignment	$R(\theta_x, \theta_y, \theta_z),\ t(x,y,z)$
2	$T_{H,action}$	Rotation of H-axis	$R(\theta_y)$
3	$T_{H,pose}$	Skew/offset between H- and V-axis	$R(\theta_z),\ t(x,y,z)$



Kinematic chain

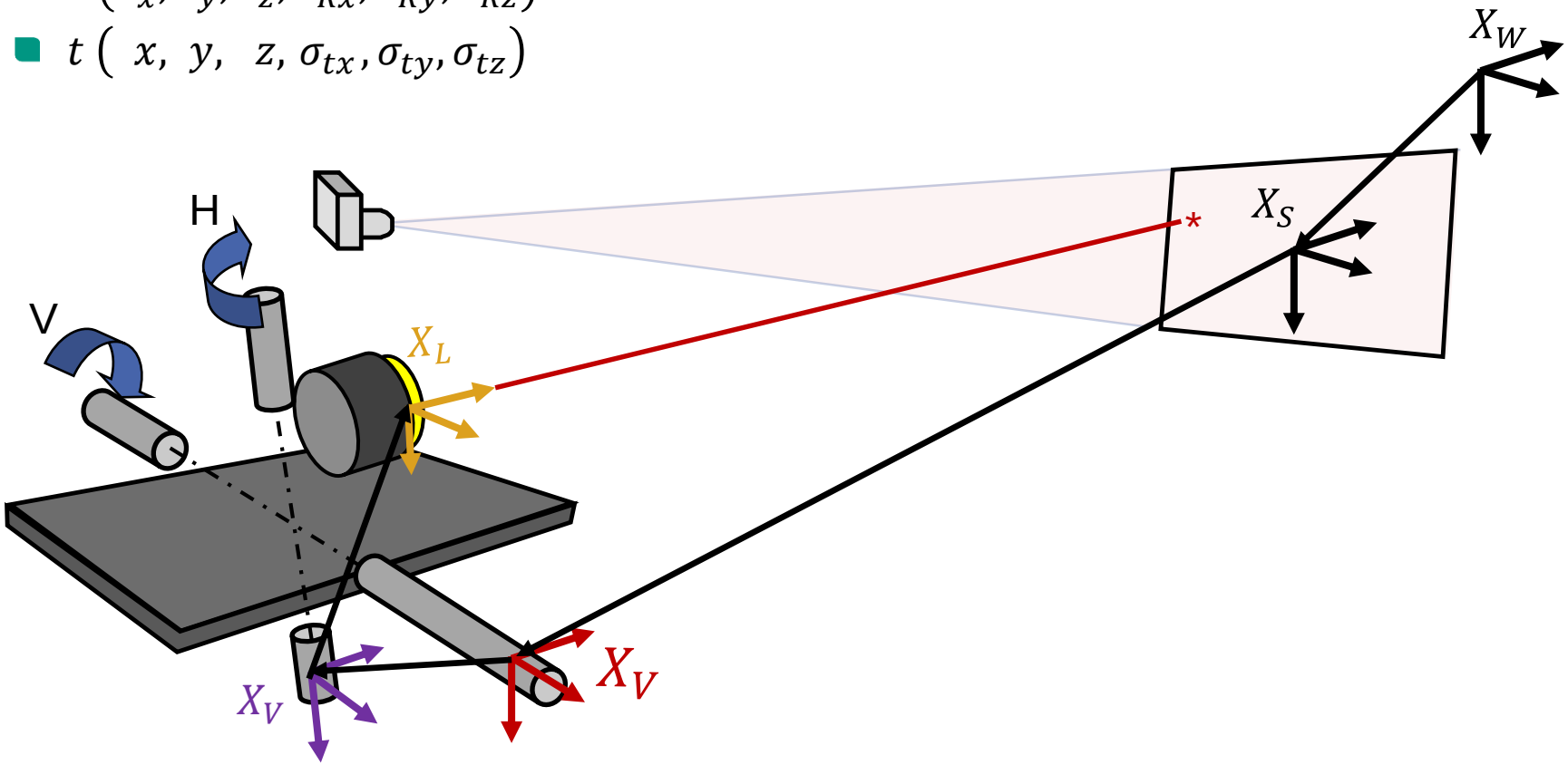
- $T_{ges} = T_{screen} * T_{V,pose} * T_{V,action} * T_{H,pose} * T_{H,action} * T_{laser}$

#		Transformation	Degrees of freedom
4	$T_{V,action}$	Rotation of V-axis	$R(\theta_x)$
5	$T_{V,pose}$	Pose V-axis to screen	$R(\theta_x, \theta_y, \theta_z)$, $t(z)$
6	T_{screen}	Origin of sphere coordinates	$t(x, y)$



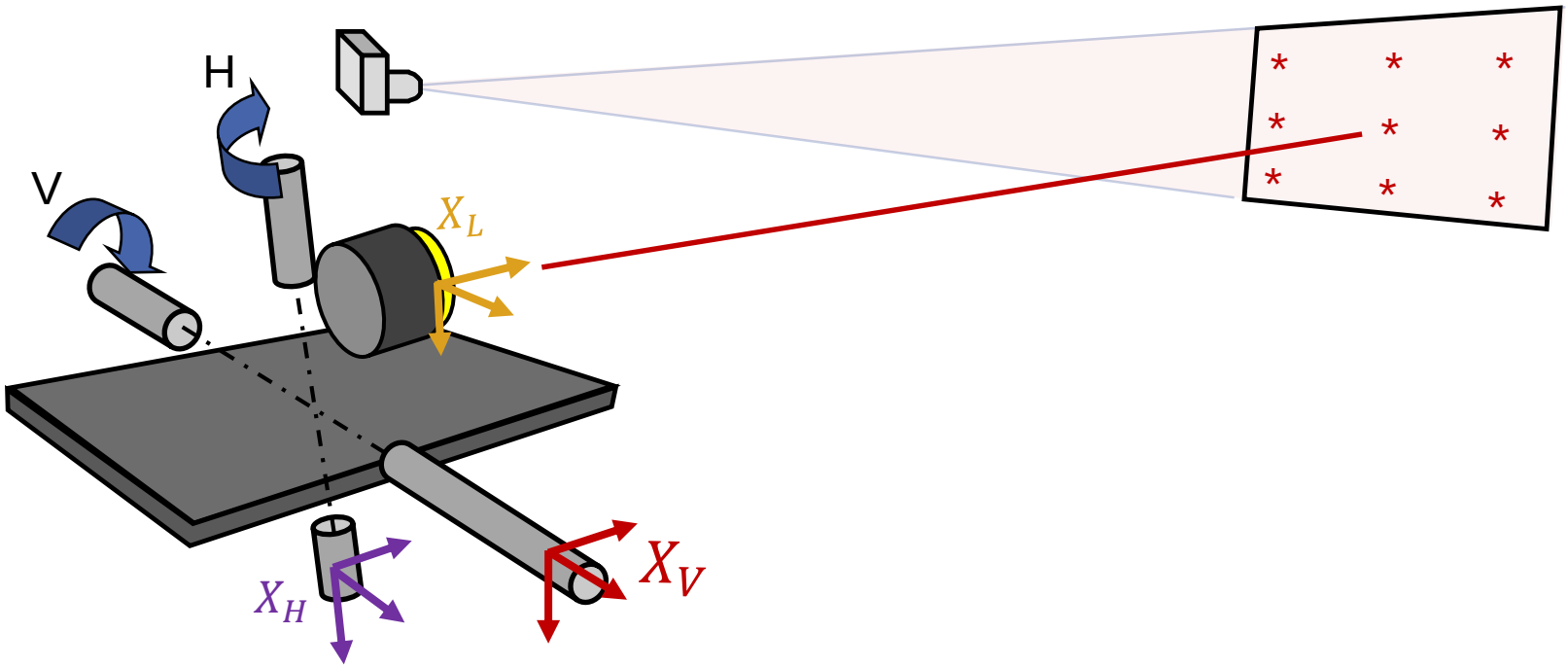
Kinematic chain

- Uncertainty of input parameters
  - $T_i = \begin{pmatrix} R & t \\ 0\,0\,0 & 1 \end{pmatrix}$
  - $R(\theta_x, \theta_y, \theta_z, \sigma_{Rx}, \sigma_{Ry}, \sigma_{Rz})$
  - $t\,(\ x,\ y,\ \ z, \sigma_{tx}, \sigma_{ty}, \sigma_{tz})$



Evaluation

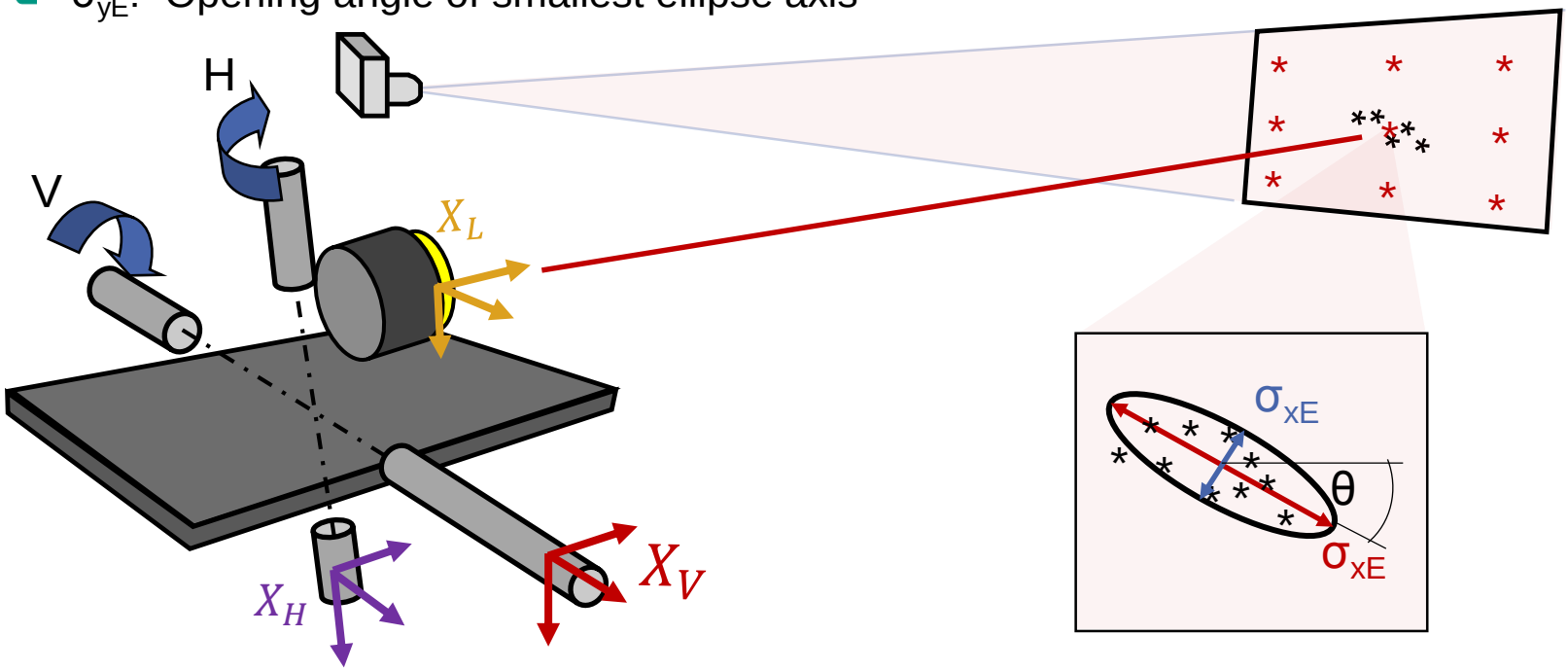
- DUT simulation
  - 3x3 laser matrix
- Monte Carlo simulation
  - N=10 000



Evaluation

- Evaluation of point cloud

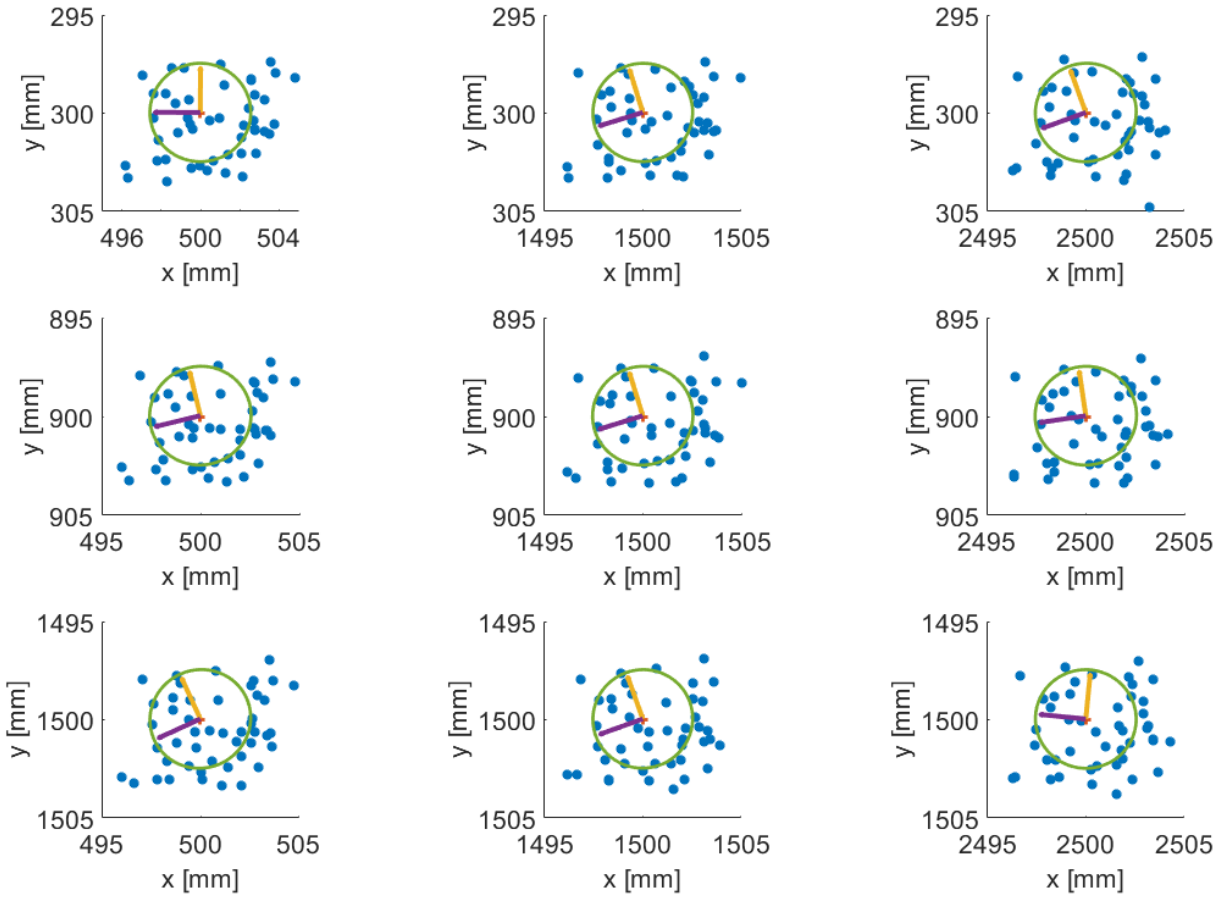
- Parameter given as standard deviation
  - σ_{dist}: Distantance ratio $\left(\mathbf{1} - \frac{\boldsymbol{d}}{\boldsymbol{d_0}}\right)$
  - σ_{xE}: Opening angle of largest ellipse axis
  - σ_{yE}: Opening angle of smallest ellipse axis



Evaluation

#	t/R		x,y,z [mm] $\theta_x,\theta_y,\theta_z$ [°]			Standard deviation [mm] or [°]			Distance ratio σ_{dist}	Large ellipse axis σ_{xE}	Smallest ellipse axis σ_{yE}
			x	y	z	σ_x	σ_y	σ_z			
1	T_{laser}	t				1	1	1	0.00010	0.00576	0.00571
		R				0.01	0.01	0.01	0.00002	0.01004	0.01000
2	$T_{H,action}$	R					0.0043		0.00001	0.00428	0.00000
3	$T_{H,pose}$	t				0.1	0.1	0.1	0.00001	0.00058	0.00057
		R						0.05	0.00000	0.00044	0.00000
4	$T_{V,action}$	R				0.0036			0.00000	0.00360	0.00000
5	$T_{V,pose}$	t			10000			2	0.00020	0.00100	0.00000
		R				0.005	0.005		0.00001	0.00505	0.00497
6	T_{screen}	t	1500	800		1	1		0.00000	0.00580	0.00573
7	T_{DUT}	φ,ϑ							0.00000	0.00051	0.00050
	$\boldsymbol{T_{ges}}$								**0.00023**	**0.01441**	**0.01429**

Uncertainty of complete system



Rotation:
H,V = 0°,0°

Random number:
$N_{simulation}$ = 10000
$N_{displayed}$ = 50

Uncertainty input:

Para-meter	σ
t_{laser}	1 mm
R_{laser}	0.01°
$R_{H,action}$	0.0043°
$t_{H,pose}$	0.1 mm
$R_{H,pose}$	1/200°
$R_{V,action}$	0.0036°
$t_{V,pose}$	2 mm
$R_{V,pose}$	1/200°
T_{screen}	1 mm
$d\vartheta_{DUT}$	1.2000°

Evaluation

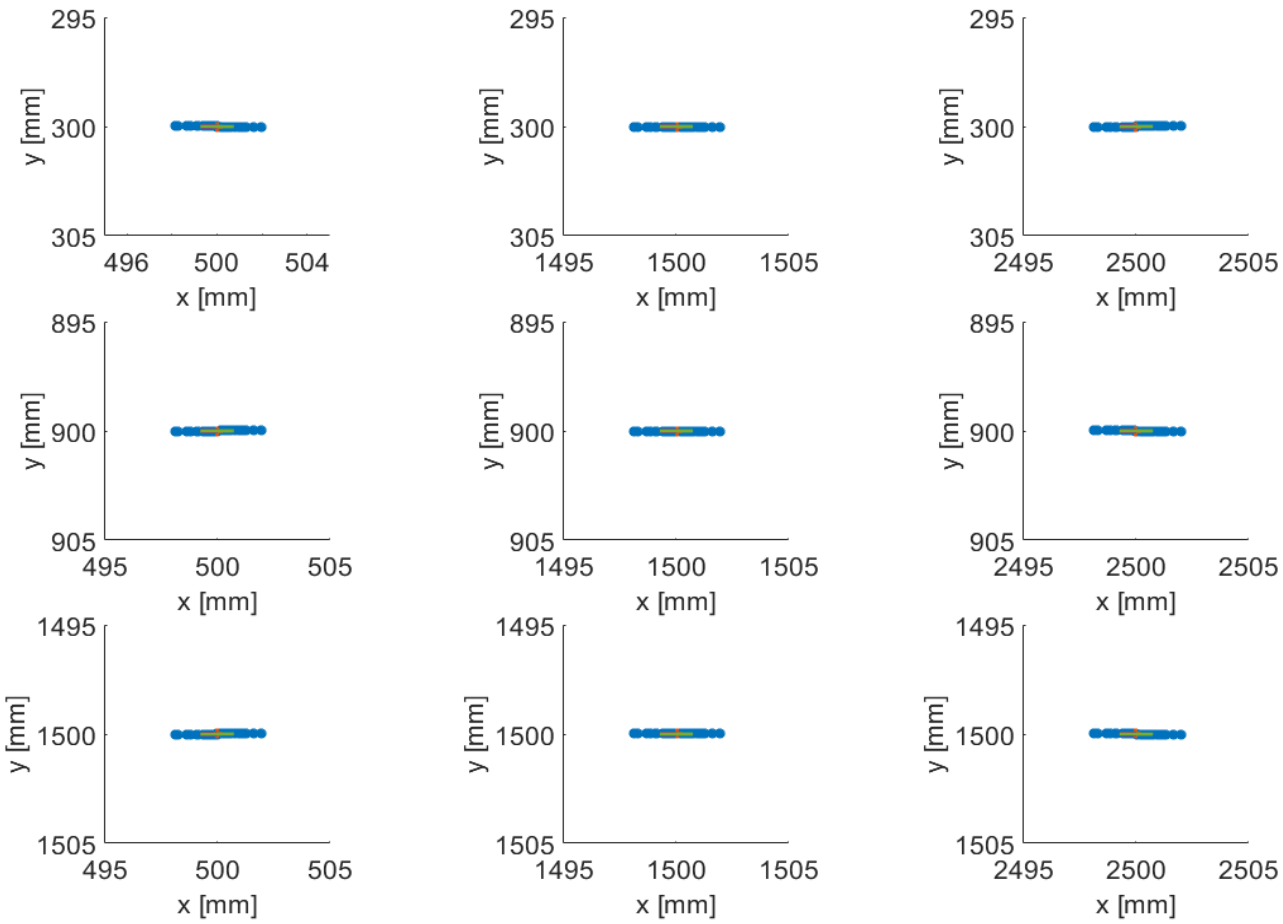
#	t/R		x,y,z [mm] $\theta_x,\theta_y,\theta_z$ [°]			Standard deviation [mm] or [°]			Distance ratio σ_{dist}	Large ellipse axis σ_{xE}	Smallest ellipse axis σ_{yE}
			x	y	z	σ_x	σ_y	σ_z			
1	T_{laser}	t				1	1	1	0.00010	0.00576	0.00571
		R				0.01	0.01	0.01	0.00002	0.01004	0.01000
2	$T_{H,action}$	R					0.0043		0.00001	0.00428	0.00000
3	$T_{H,pose}$	t				0.1	0.1	0.1	0.00001	0.00058	0.00057
		R						0.05	0.00000	0.00044	0.00000
4	$T_{V,action}$	R				0.0036			0.00000	0.00360	0.00000
5	$T_{V,pose}$	t			10000			2	0.00020	0.00100	0.00000
		R				0.005	0.005		0.00001	0.00505	0.00497
6	T_{screen}	t	1500	800		1	1		0.00000	0.00580	0.00573
7	T_{DUT}	φ,ϑ							0.00000	0.00051	0.00050
	$\boldsymbol{T_{ges}}$								**0.00023**	**0.01441**	**0.01429**

Validation

- Calculated
- Visually

#	t/R		x,y,z [mm] $\theta_x,\theta_y,\theta_z$ [°]			Standard deviation [mm] or [°]			Distance ratio σ_{dist}	Large ellipse axis σ_{xE}	Smallest ellipse axis σ_{yE}
			x	y	z	σ_x	σ_y	σ_z			
2	$T_{H,action}$	R					0.0043		0.00001	0.00428	0.00000
5	$T_{V,pose}$	t			10000			2	0.00020	0.00100	0.00000

Validation – Hysteresis H-axis



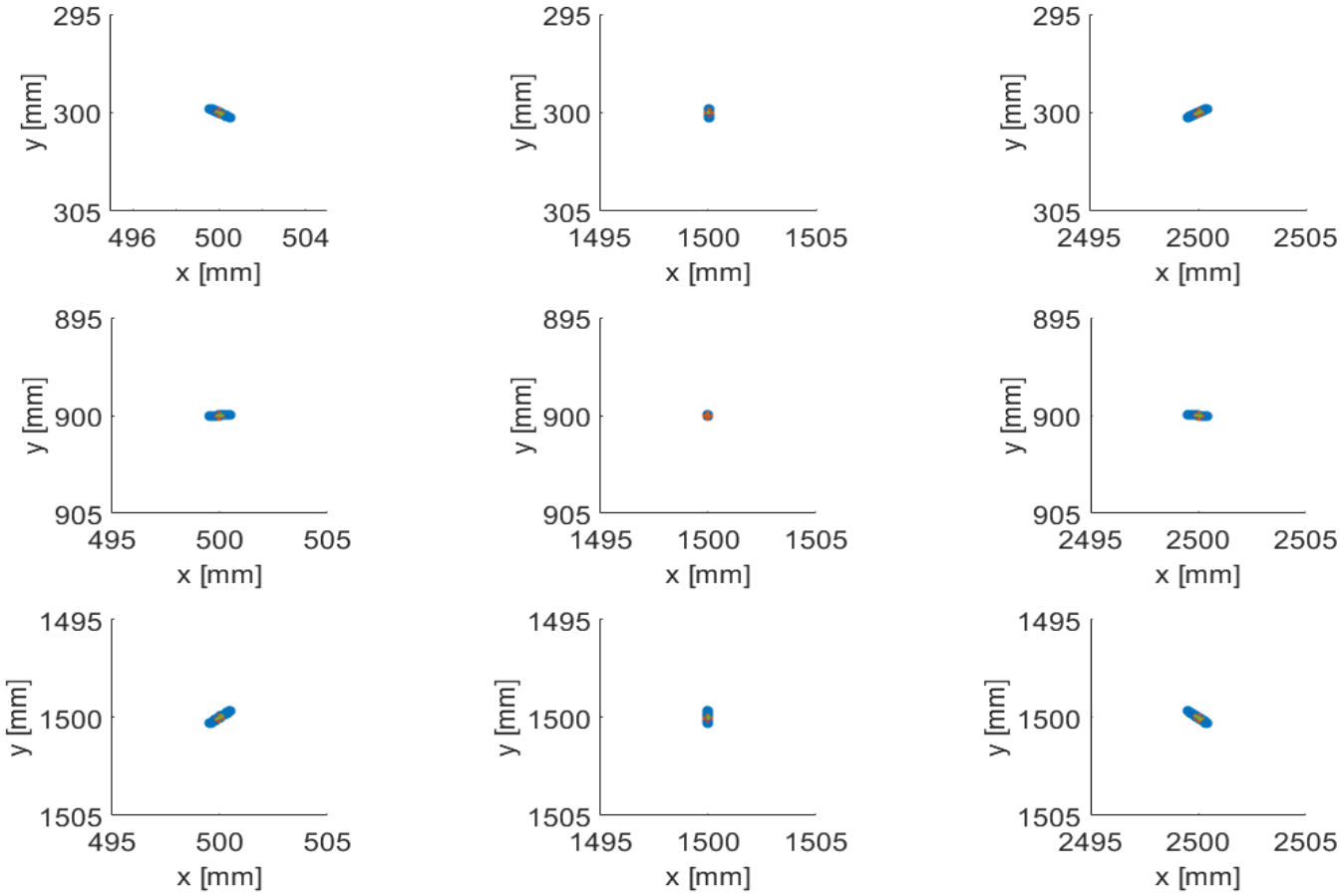
Rotation:
H,V = 0°,0°

Random number:
$N_{simulation}$ = 10000
$N_{displayed}$ = 50

Uncertainty input:

Para-meter	σ
$R_{H,action}$	0.0043°

Validation – Measurement distance



Rotation:
H,V = 0°,0°

Random number:
$N_{simulation}$ = 10000
$N_{displayed}$ = 50

Uncertainty input:

Para-meter	σ
$t_{V,pose}$	2 mm

Summary

- **Implementation** and **validation** of geometric system model

- Methods to determine input parameter
  - x, y, z and θ_x, θ_y, θ_z
  - σ_x, σ_y, σ_z and $\sigma_{\theta x}$, $\sigma_{\theta y}$, $\sigma_{\theta z}$

- System analysis
  - Calibration
  - Measurements

- Laser tracker reference measurement

- Photometric uncertainty
  - Camera stray light
  - Room stray light