CATNIP: Comprehensive Analysis Toolkit for Near-field Imaging and Phase-retrieval

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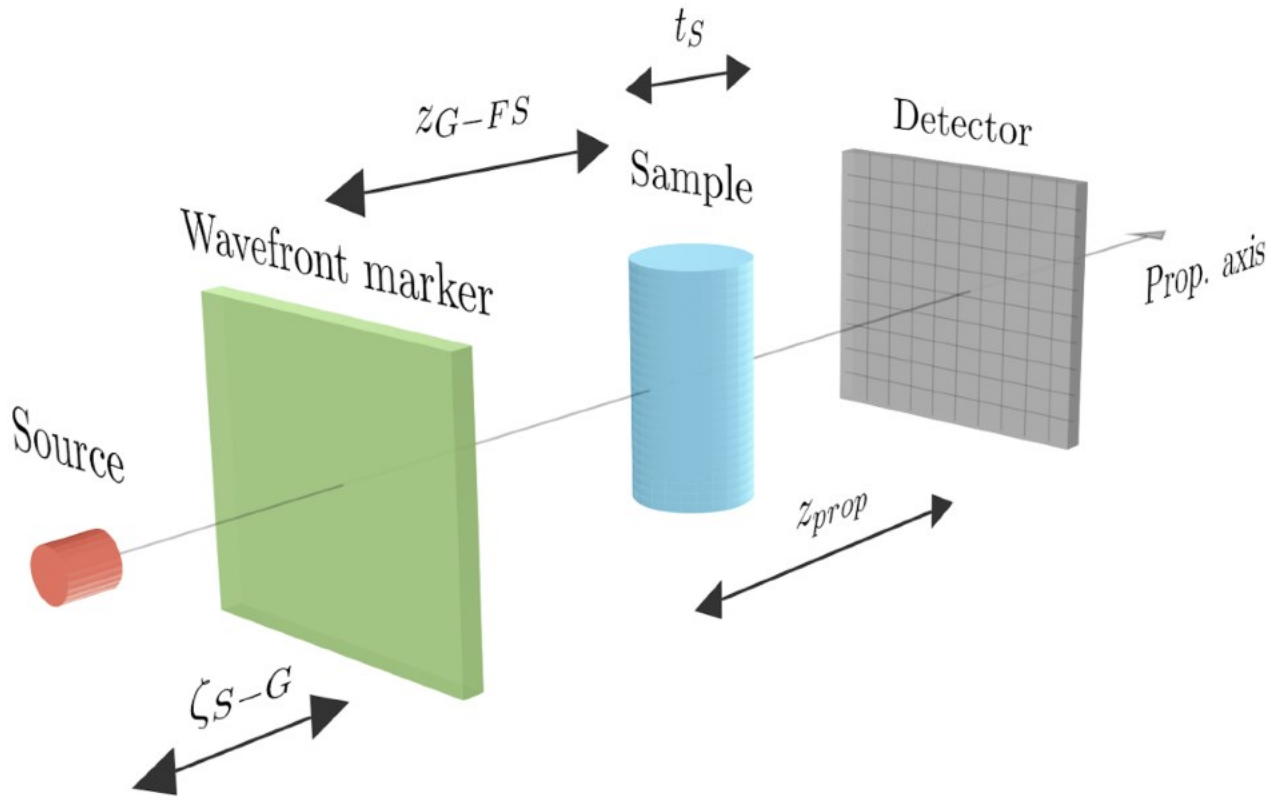
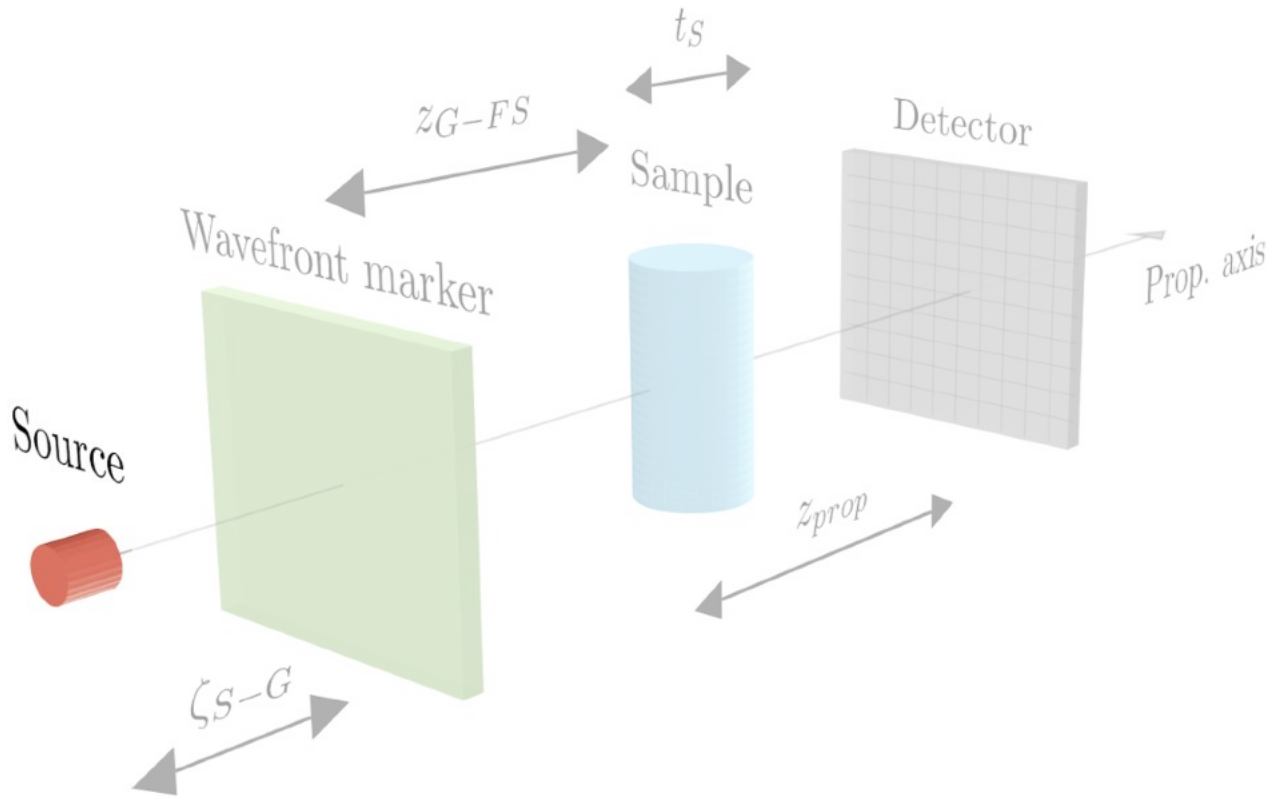
Università degli Studi di Trieste

X-ray Imaging Setup

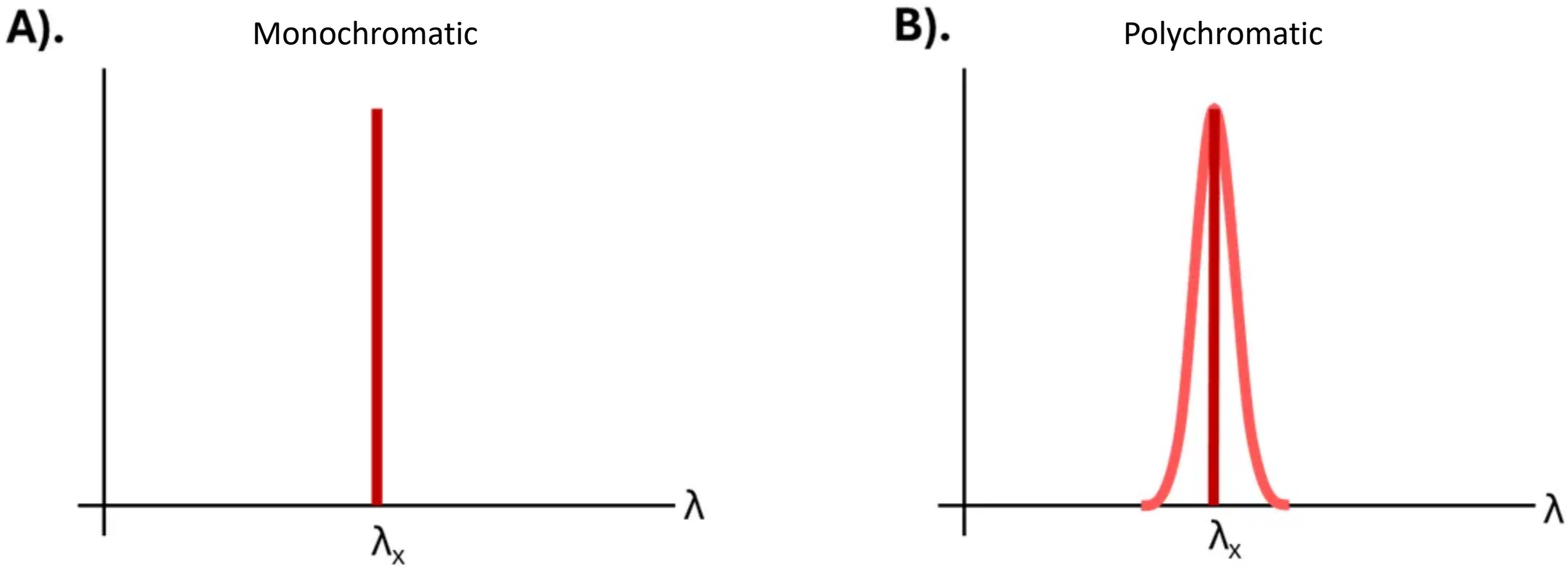
X-ray Imaging Setup



Source


t_S
z_{G-FS}
Detector
Sample
Wavefront marker
Prop. axis
Source
z_{prop}
ζ_{S-G}

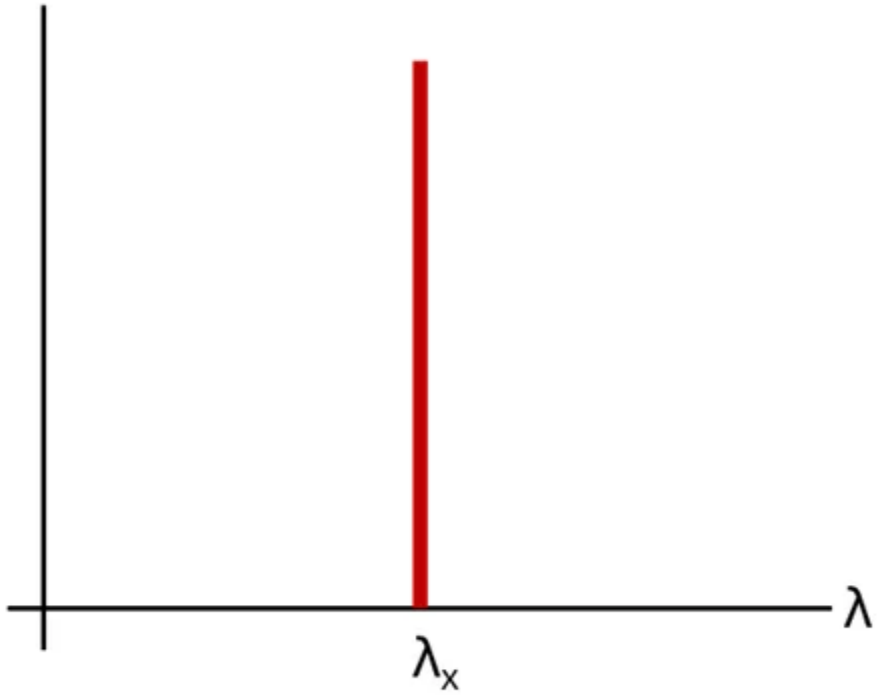
Source



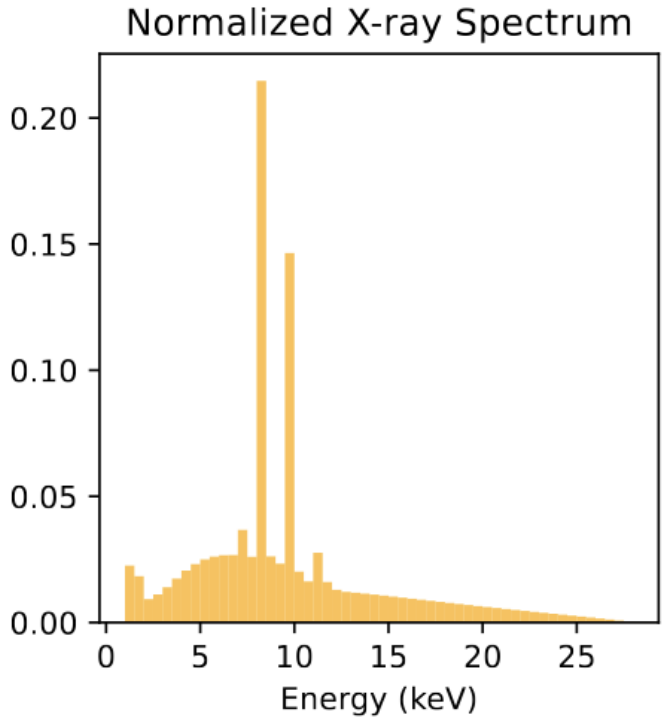
Taken from: https://www.edinst.com/resource/understanding-bandpass-and-resolution-in-photoluminescence-spectroscopy/

Source

A). Monochromatic

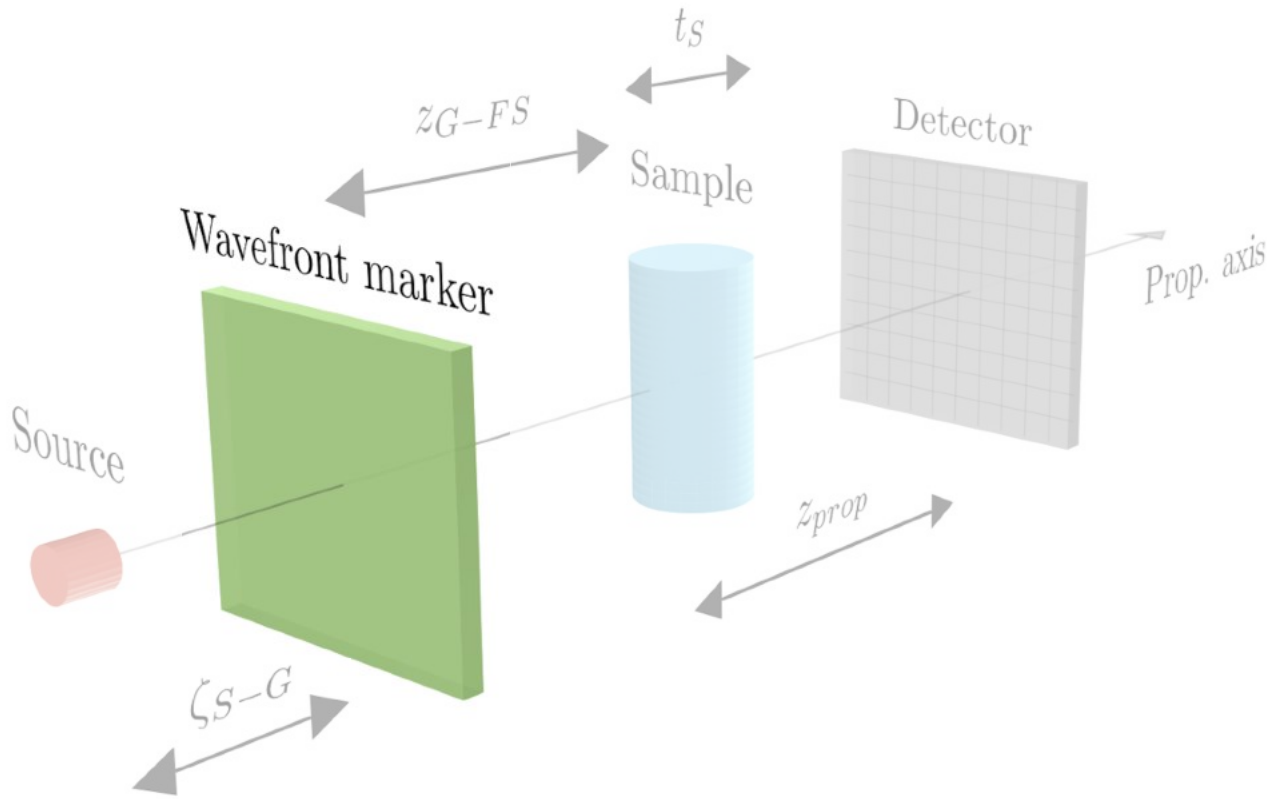


B). Polychromatic

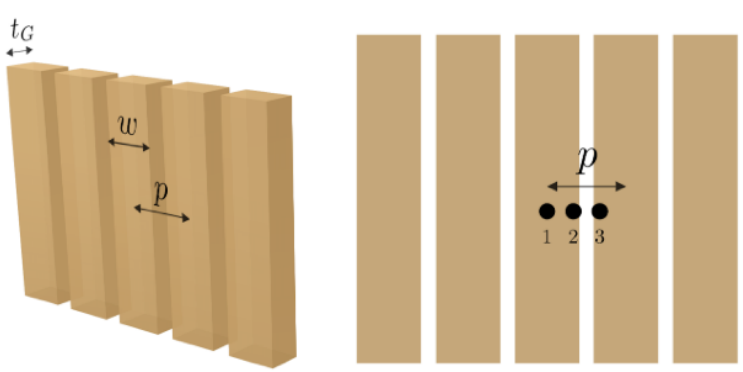


Taken from: https://www.edinst.com/resource/understanding-bandpass-and-resolution-in-photoluminescence-spectroscopy/

Wavefront Marker

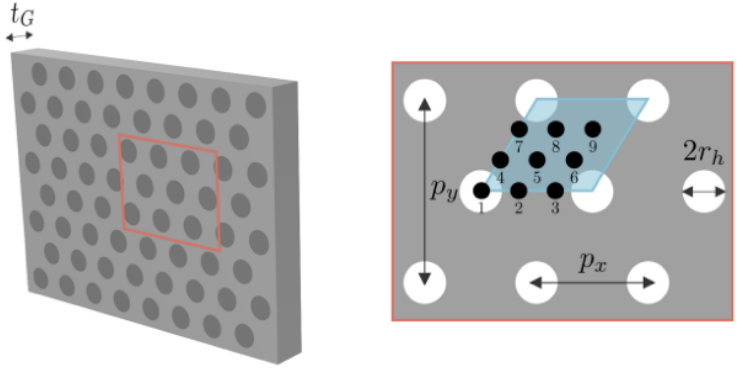


Wavefront Marker



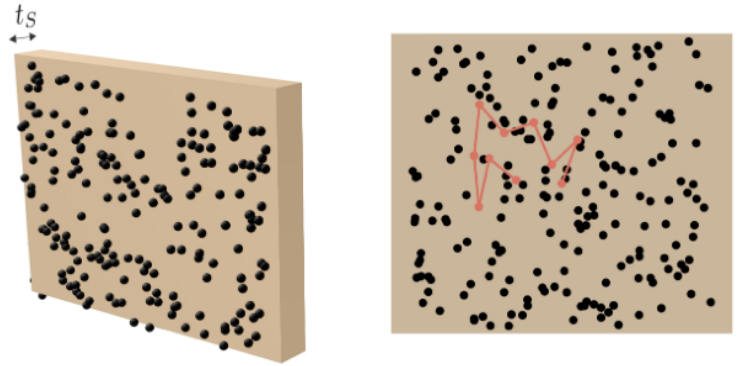
(a)

Edge-Illumination (EI)



(b)

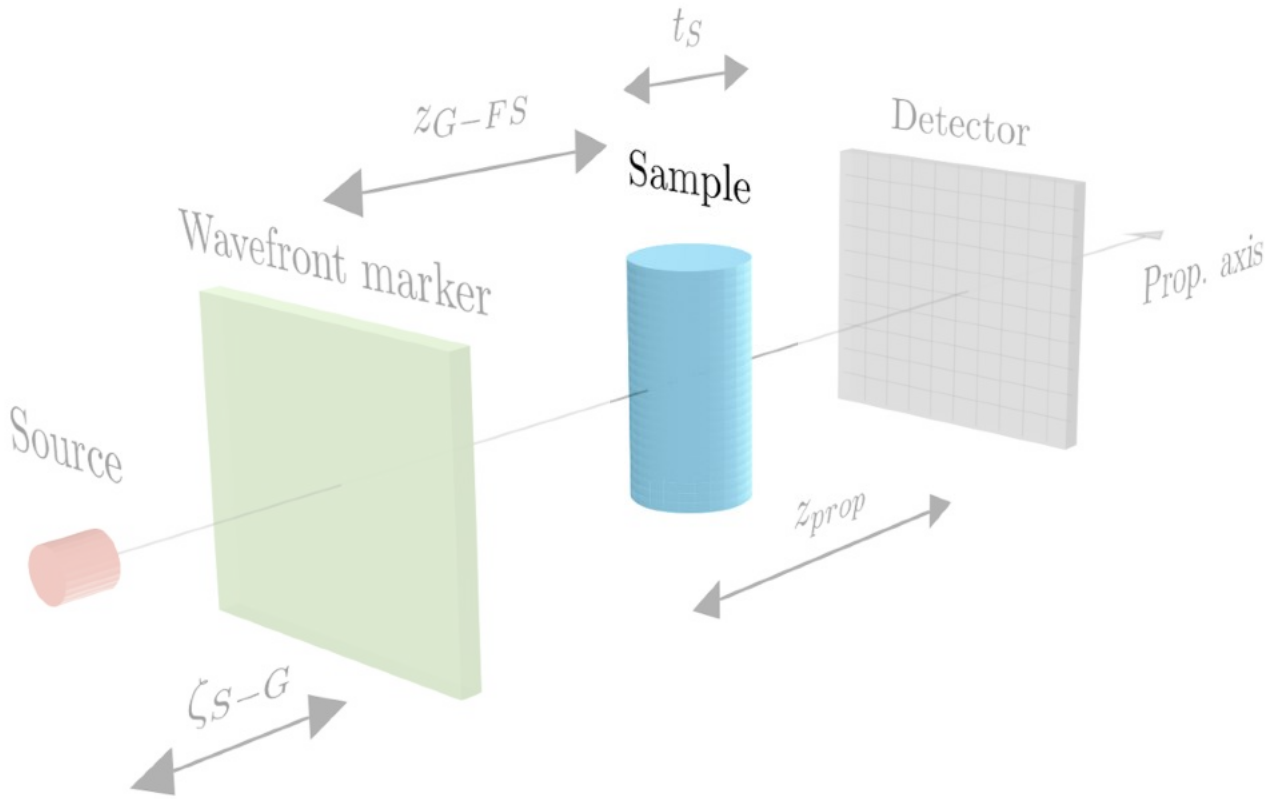
Single-Grating Based Imaging (SGBI)



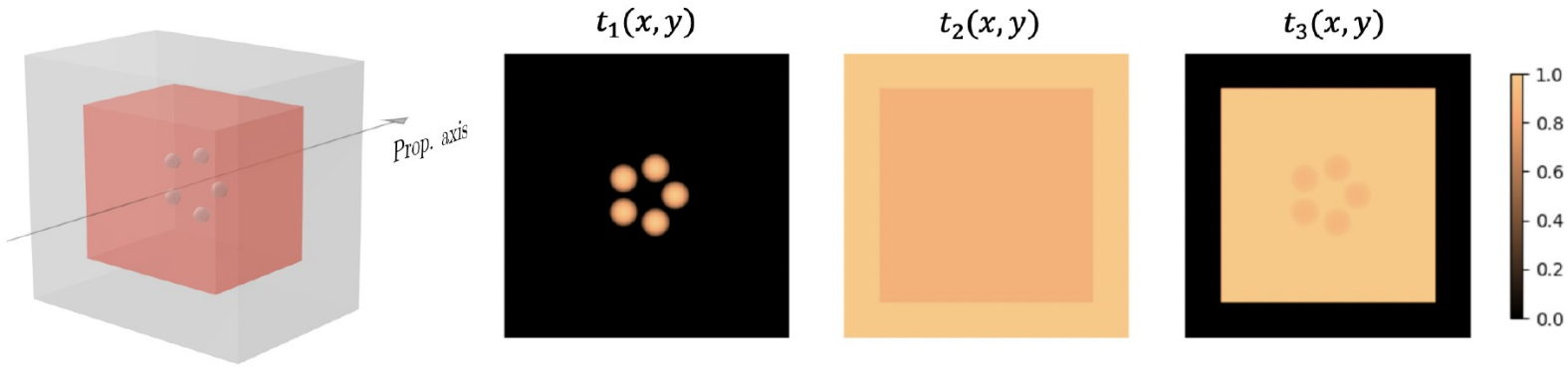
(c)

Speckle Based Imaging (SBI)

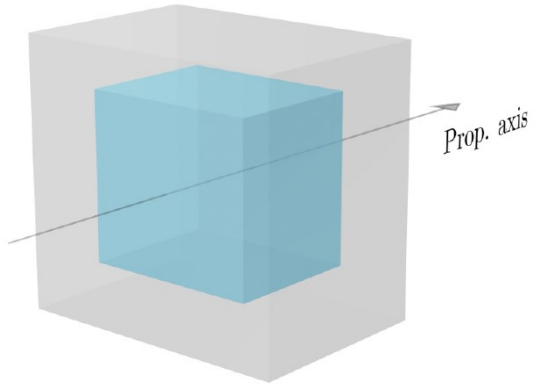
Sample


t_S
z_{G-FS}
Sample
Detector
Wavefront marker
Prop. axis
Source
z_{prop}
ζ_{S-G}

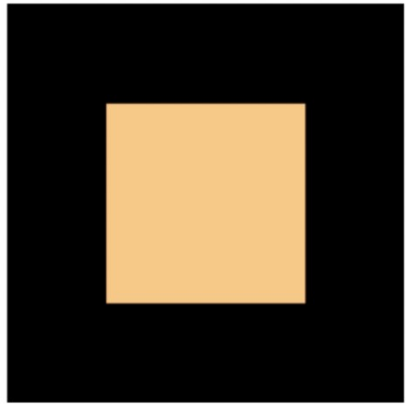
Sample: Mammo Phantom



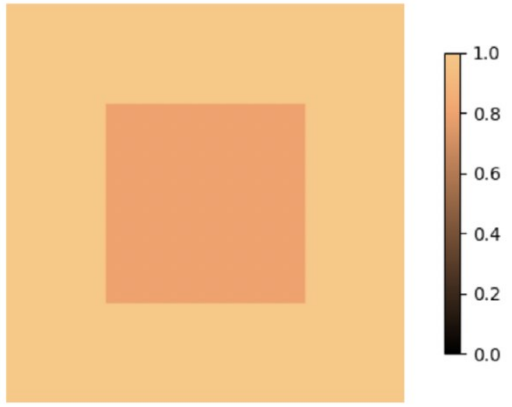
Sample: Block



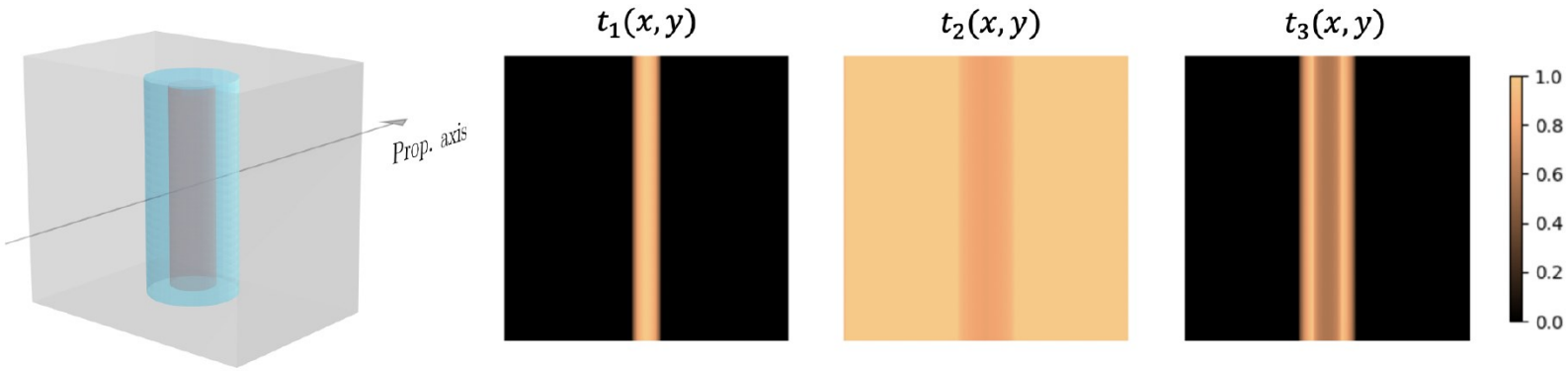
$t_1(x, y)$



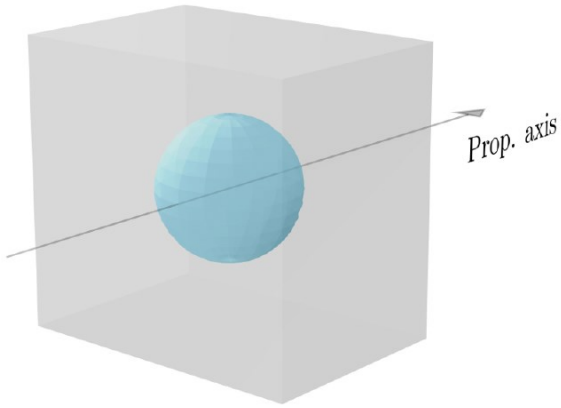
$t_2(x, y)$



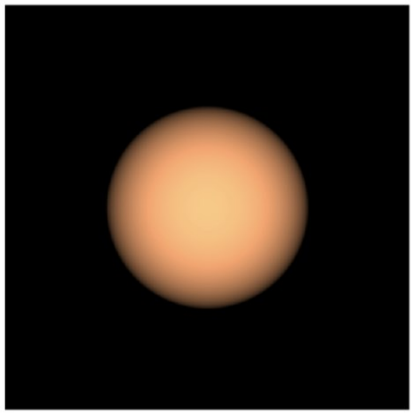
Sample: Angio tube



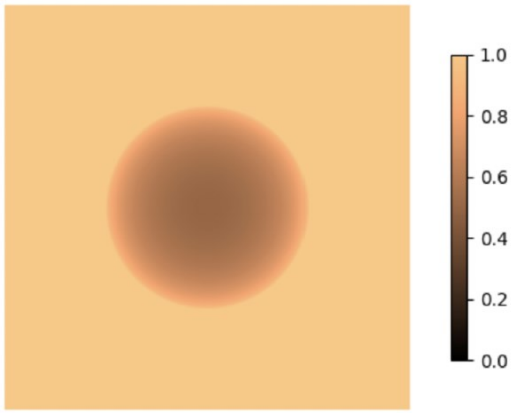
Sample: Sphere



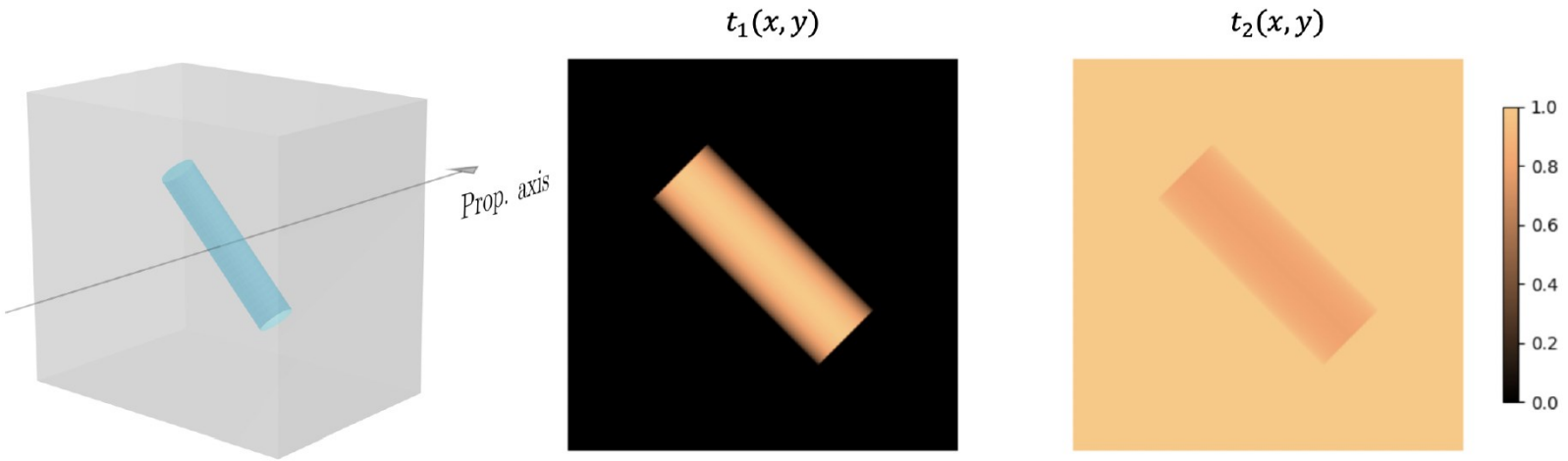
$t_1(x, y)$



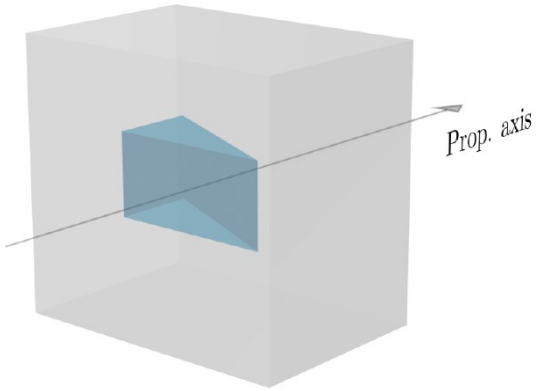
$t_2(x, y)$



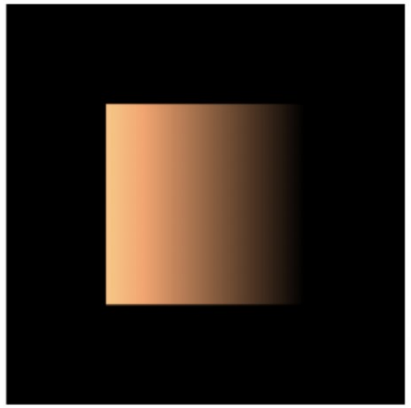
Sample: Fibre



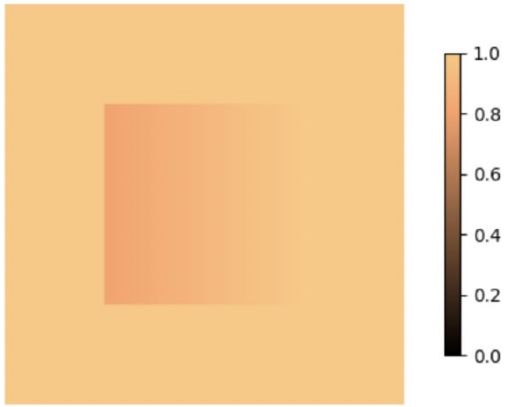
Sample: Wedge



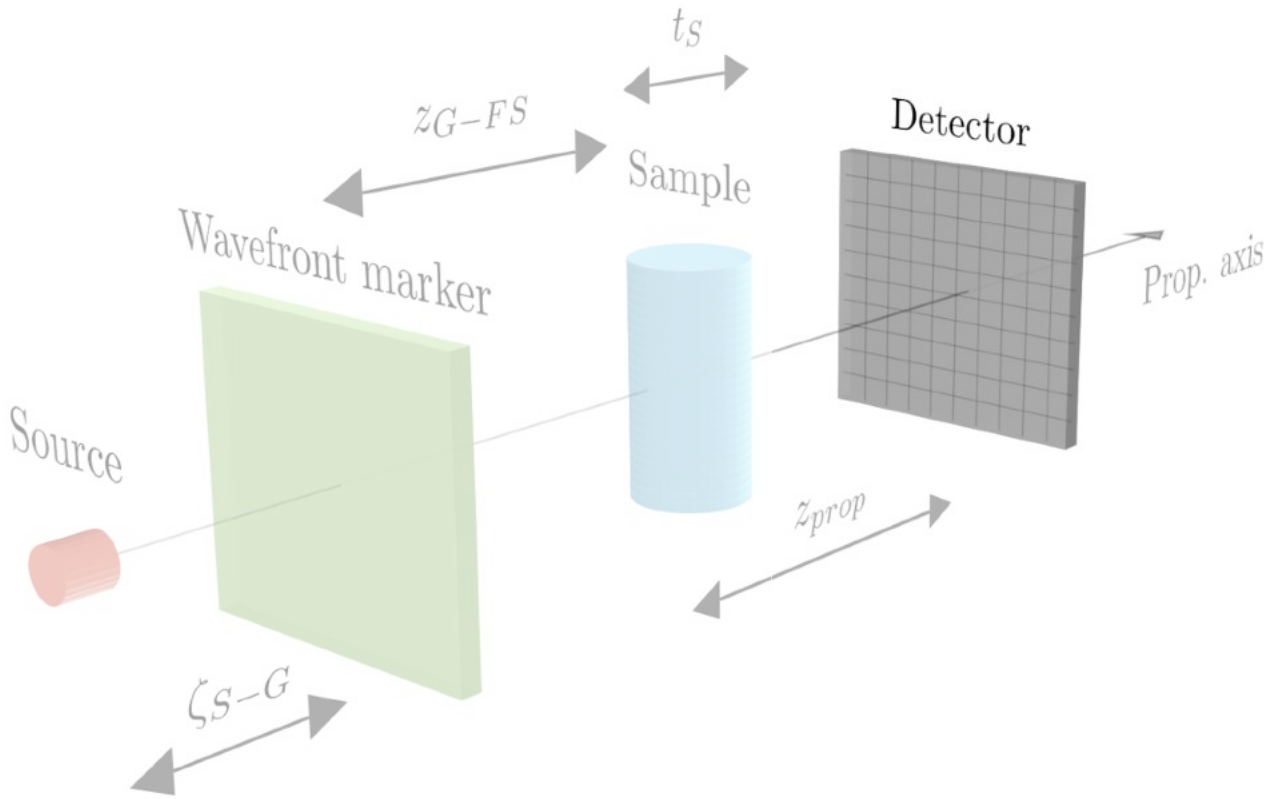
$t_1(x, y)$



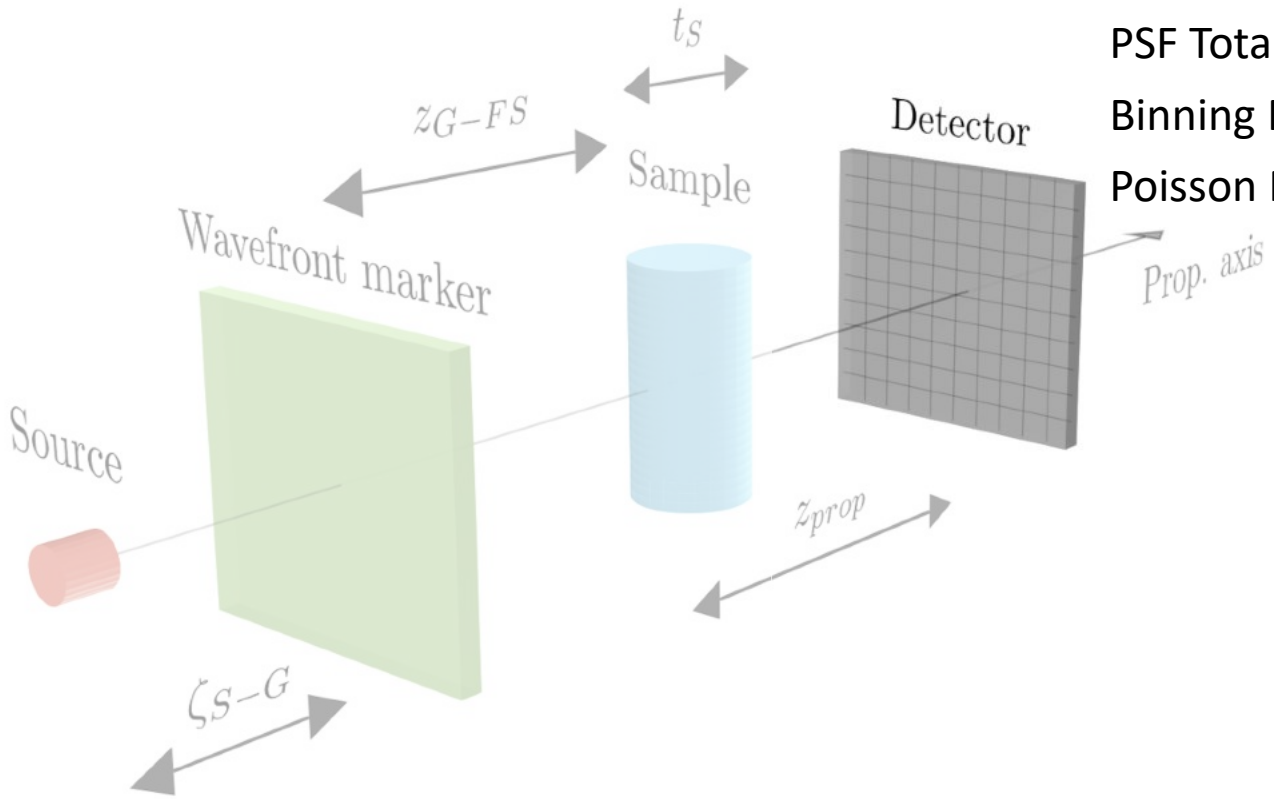
$t_2(x, y)$



Detector


t_S
z_{G-FS}
Detector
Sample
Wavefront marker
Prop. axis
Source
z_{prop}
ζ_{S-G}

Detector



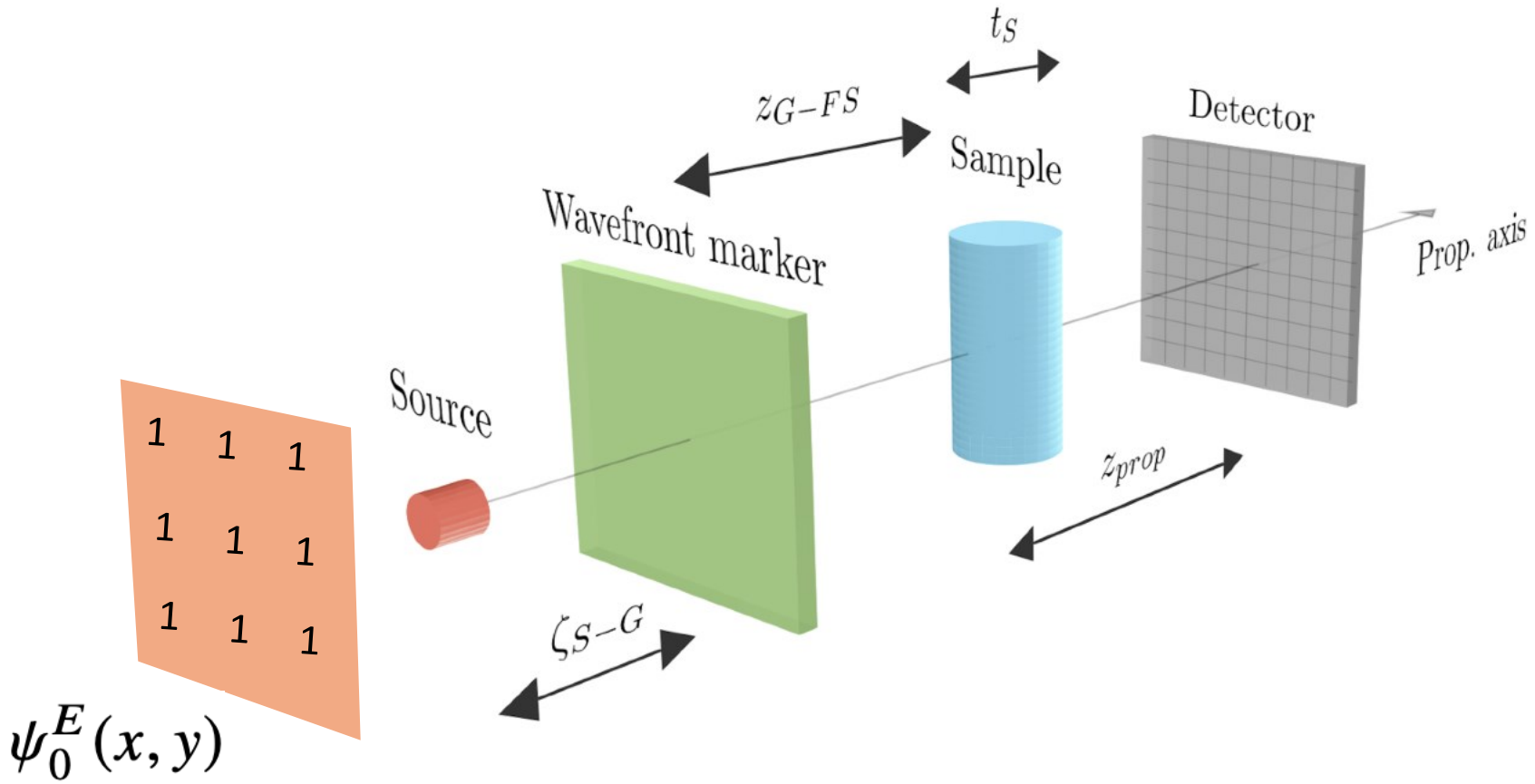
PSF Total: Detector + Source

Binning Factor

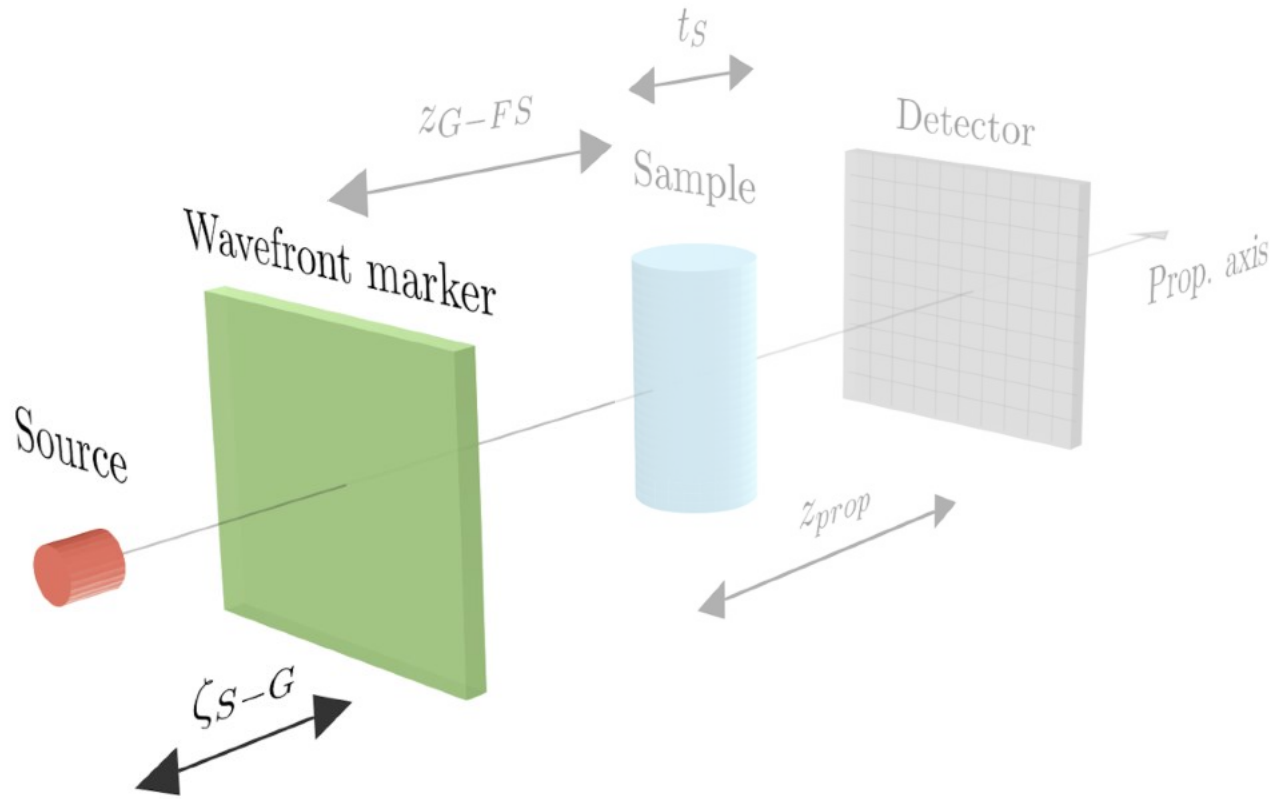
Poisson Noise

Simulation Algorithm

Simulations: Propagation + Interaction



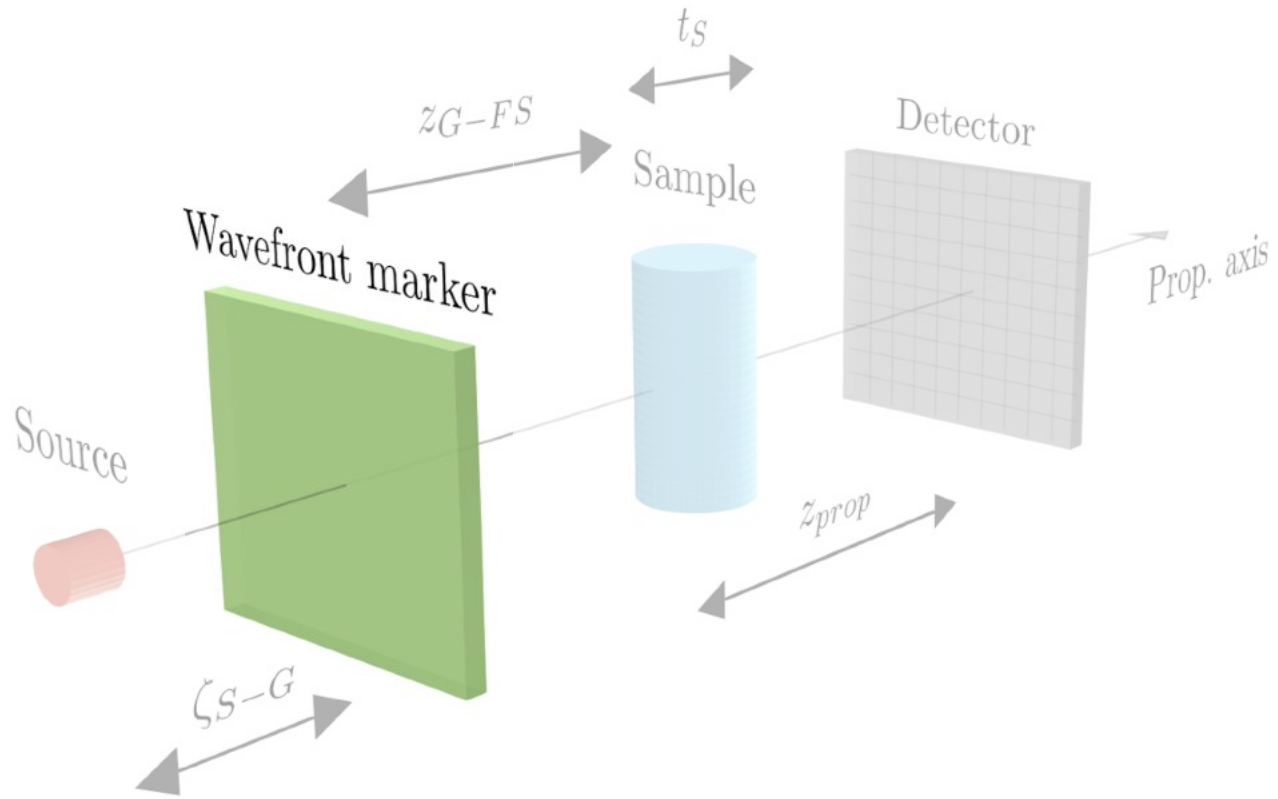
Simulations: Propagation + Interaction



$$\psi^E_{z_p}(x,y) = P_\zeta\{\psi^E_0(x,y)\}$$

$$P_\zeta\{\psi(x,y)\} = \mathcal{F}^{-1}\{\mathcal{F}[\psi(x,y)]H(k_x,k_y,\zeta)\}, \quad H(k_x,k_y,\zeta) = \exp\left(i\zeta\sqrt{k^2-k_x^2-k_y^2}\right)$$

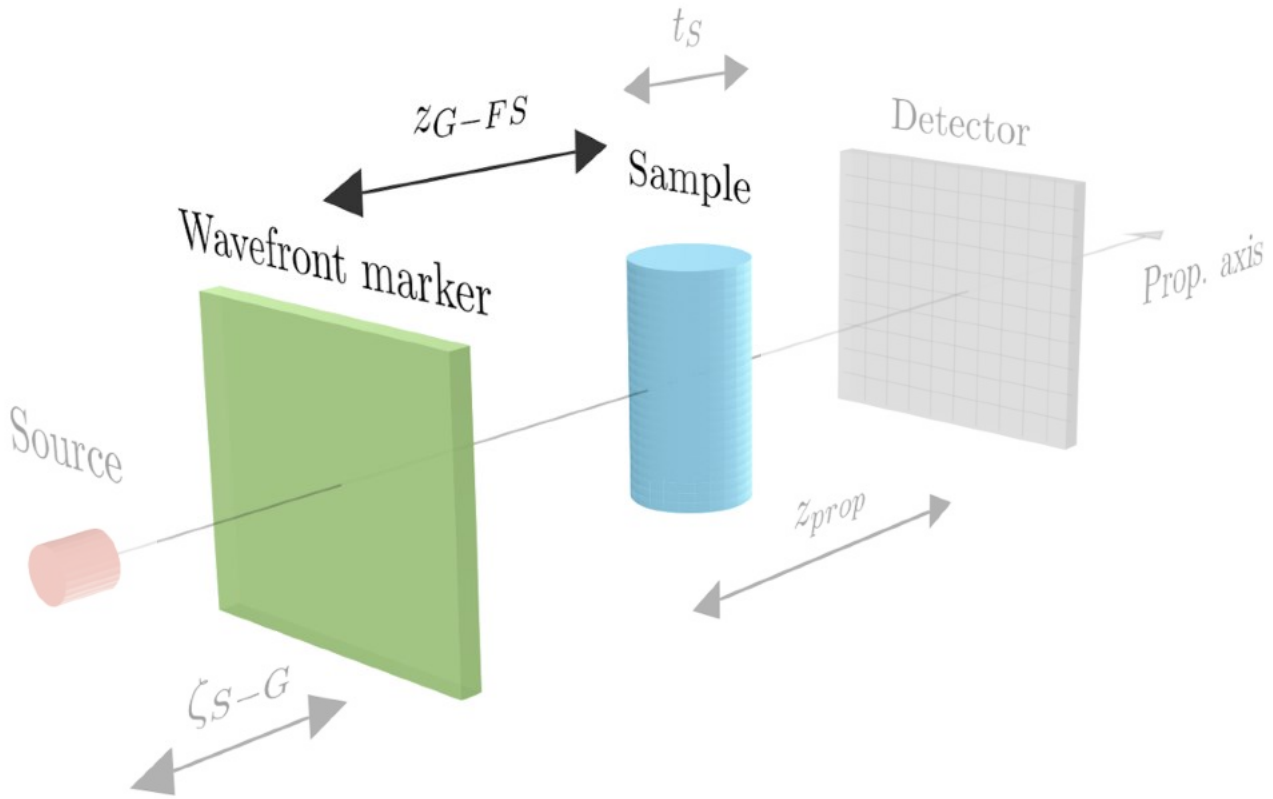
Simulations: Propagation + Interaction



$$\psi^E_{IG}(x,y) = T_G(x,y)\,\psi^E_{BG}(x,y)$$

$$T_G(x,y) = \exp\left(-ik\sum_{n=S,P}\delta_n(E)t_n(x,y)\right)\exp\left(-\frac{1}{2}\sum_{n=S,P}\mu_n(E)t_n(x,y)\right)$$

Simulations: Propagation + Interaction

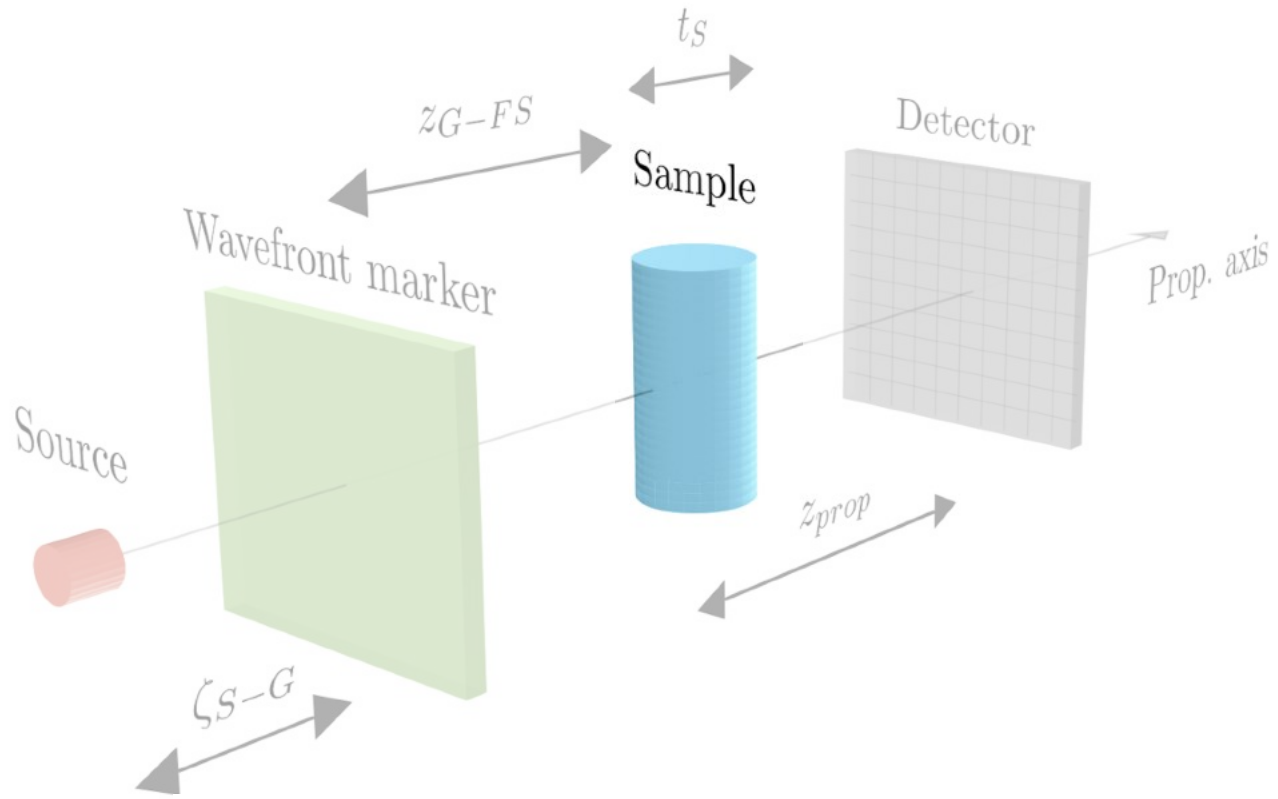


$$\psi_{BS}^{E}(x,y) = S_{1\to M_S}\left\{P_{\zeta_{G\text{-}FS}}\{\psi_{IG}^{E}(x,y)\}\right\}$$

$$M_S = \begin{cases} z_{S\text{-}FS}/\zeta_{S-G}, & \text{cone-beam,} \\ 1, & \text{parallel-beam,} \end{cases}$$

$$S_{M_1\to M_2}\left\{\psi\left(\frac{x}{M_1},\frac{y}{M_1}\right)\right\} = \psi\left(\frac{x}{M_2},\frac{y}{M_2}\right)$$

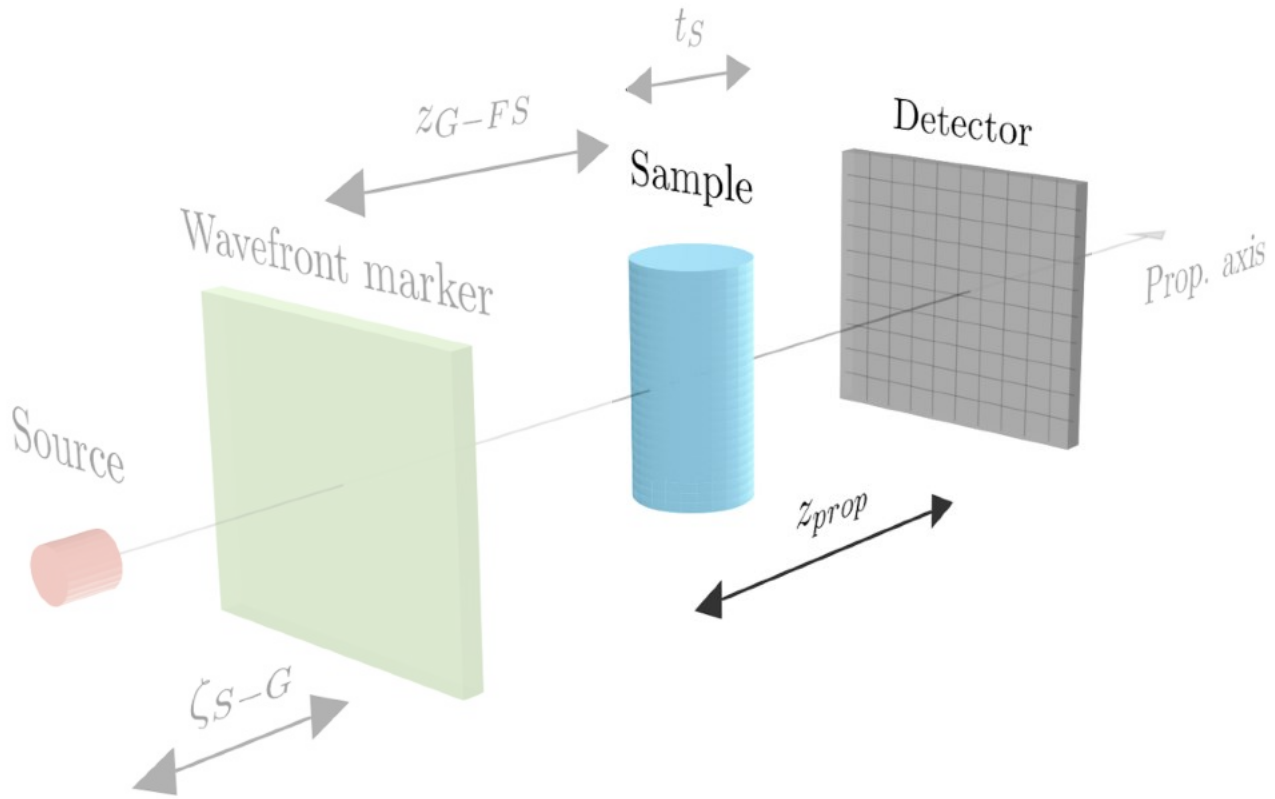
Simulations: Propagation + Interaction



$$\psi^E_{IS}(x,y) = T_S(x,y)\psi^E_{BS}(x,y)$$

$$T_S(x,y) = \exp\left(-ik\sum_{n=1}^{N_m}\delta_n(E)t_n(x,y)\right)\exp\left(-\frac{1}{2}\sum_{n=1}^{N_m}\mu_n(E)t_n(x,y)\right)$$

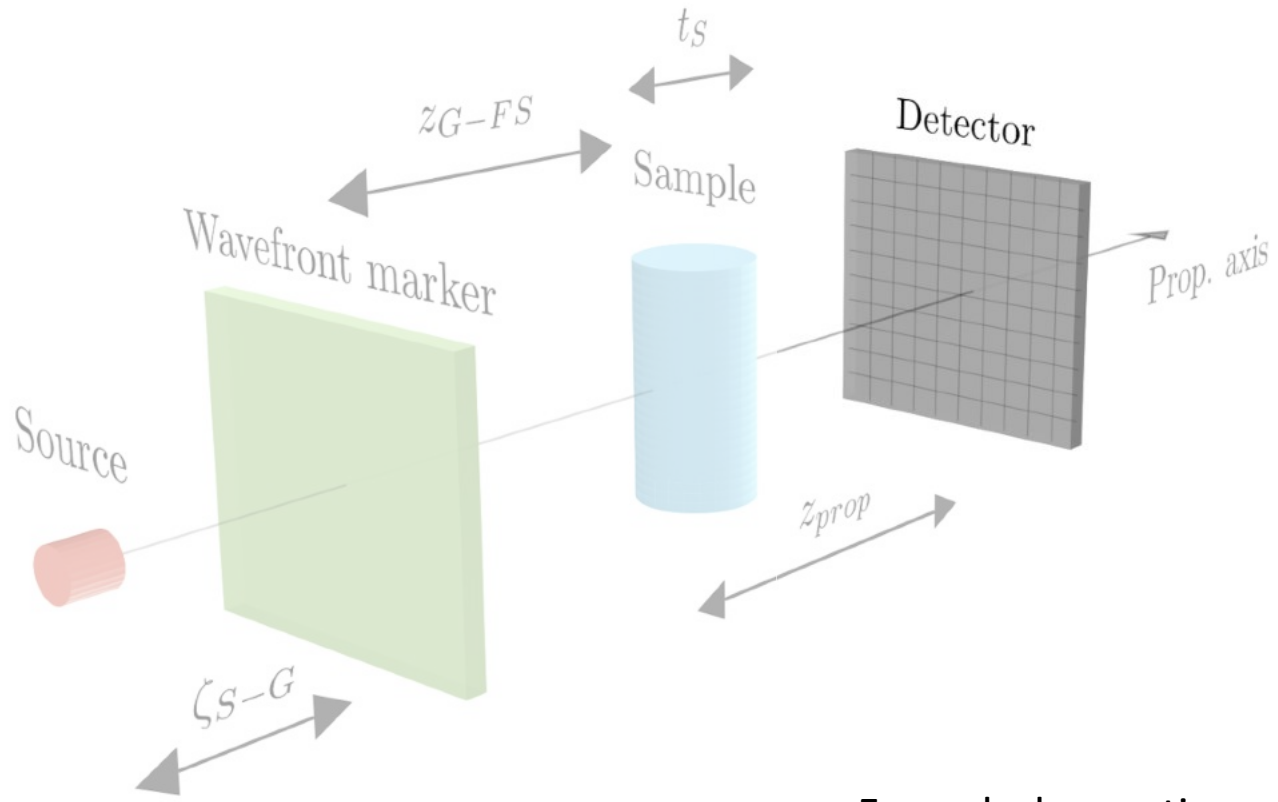
Simulations: Propagation + Interaction



$$\psi_D^E(x,y) = S_{M_S \to M_D}\{P_{\zeta_{BS\text{-}D}}\{\psi_{IS}^E(x,y)\}\}$$

$$M_D = \begin{cases} z_{S\text{-}D}/z_{S\text{-}BS}, & \text{cone-beam,} \\ 1, & \text{parallel-beam,} \end{cases}$$

Image Formation

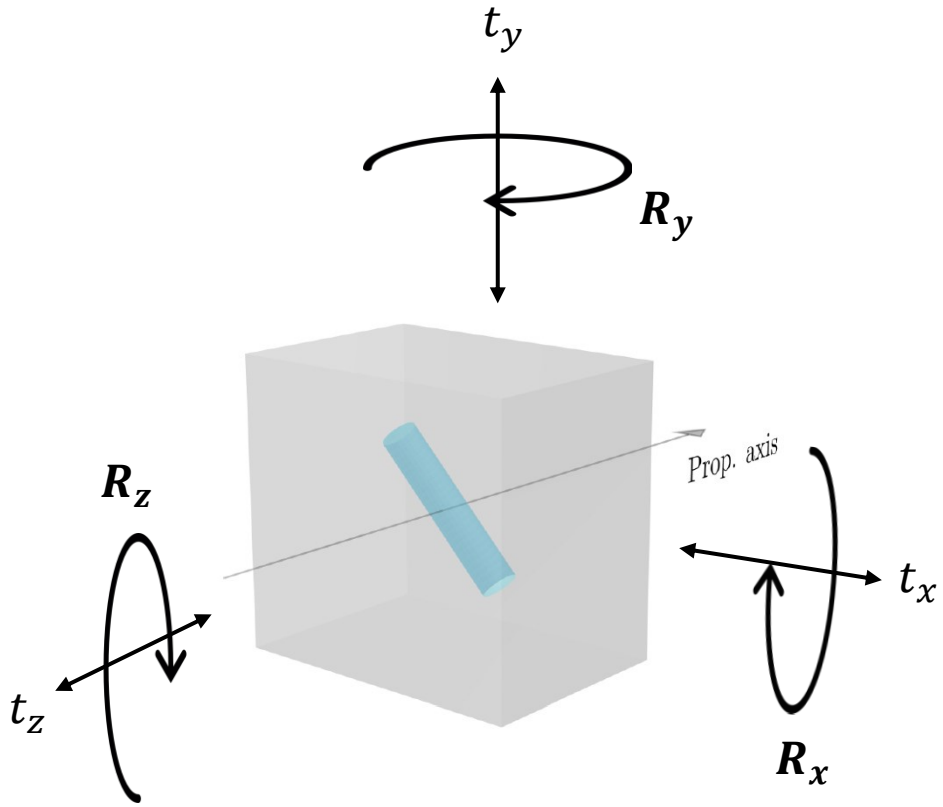


$$I_D^E(x,y) = \left|\psi_D^E(x,y)\right|^2$$ + Poisson Noise + PSF Blurring

For polychromatic sources:

$$I_{\text{Final}}(x,y) = \sum_E \tilde{S}(E) I_{\text{Final}}^E(x,y)$$

Computed Tomography



$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \begin{pmatrix} \boldsymbol{R_{3x3}} & \vec{t} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} \boldsymbol{R_{3x3}} & \vec{t} \\ 0 & 1 \end{pmatrix} \in SE(3), \quad \boldsymbol{R_{3x3}} \in SO(3), \quad \vec{t} = (t_x, t_y, t_z) \in \mathbb{R}^3$$

$SE(n)$: Special Euclidean Group
$SO(n)$: Special Orthonormal Group

References

- Pre-Print in Optica: https://preprints.opticaopen.org/articles/preprint/CATNIP_An_Open-Source_Wave-Optics_Simulation_Framework_for_Multimodal_X-ray_Imaging/30269386?file=58468411
- CATNIP Manual: https://github.com/Spoksonat/CATNIP/blob/main/CATNIP_Manual.pdf