# Odd order aberration cancellation with entangled two-photon states

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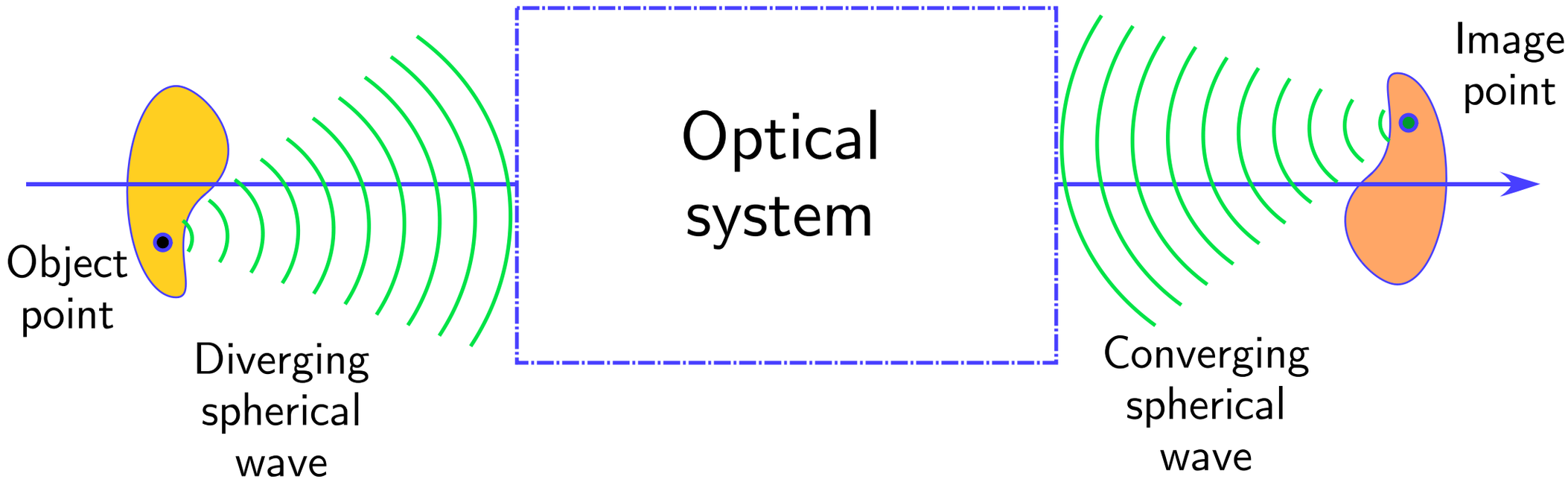
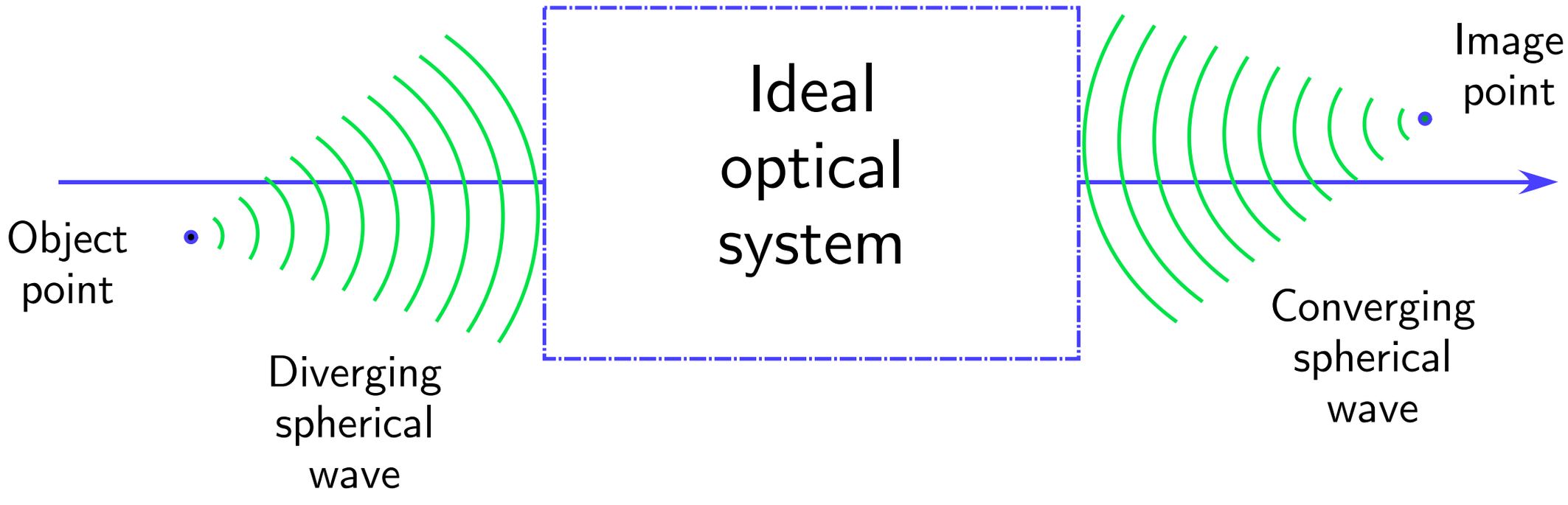
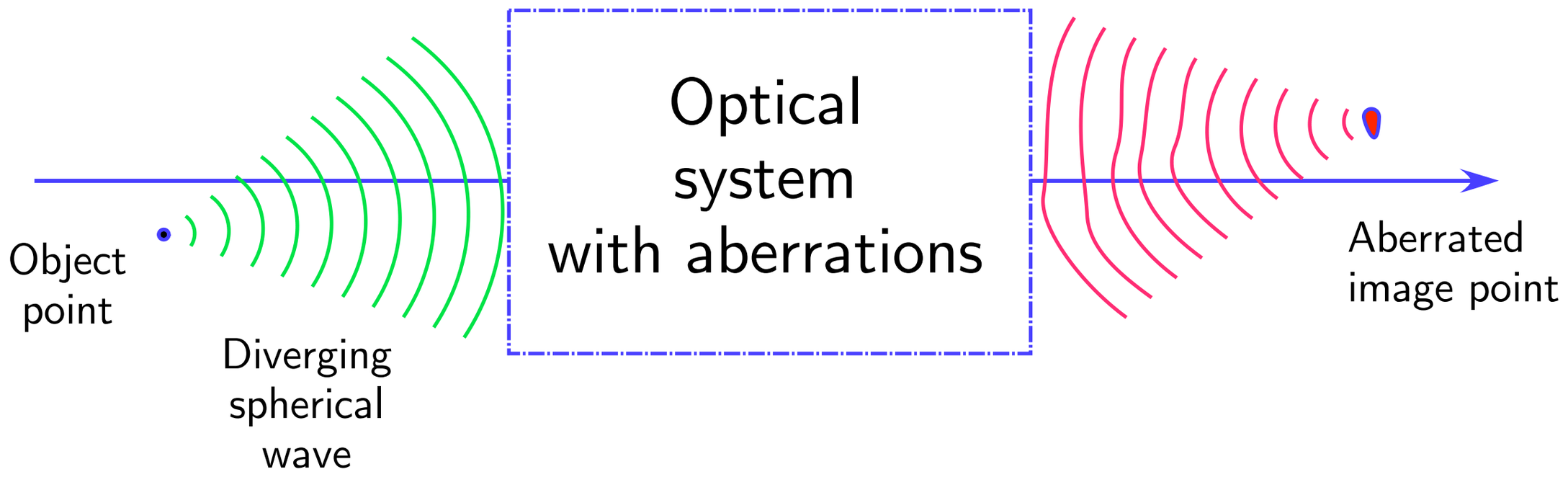
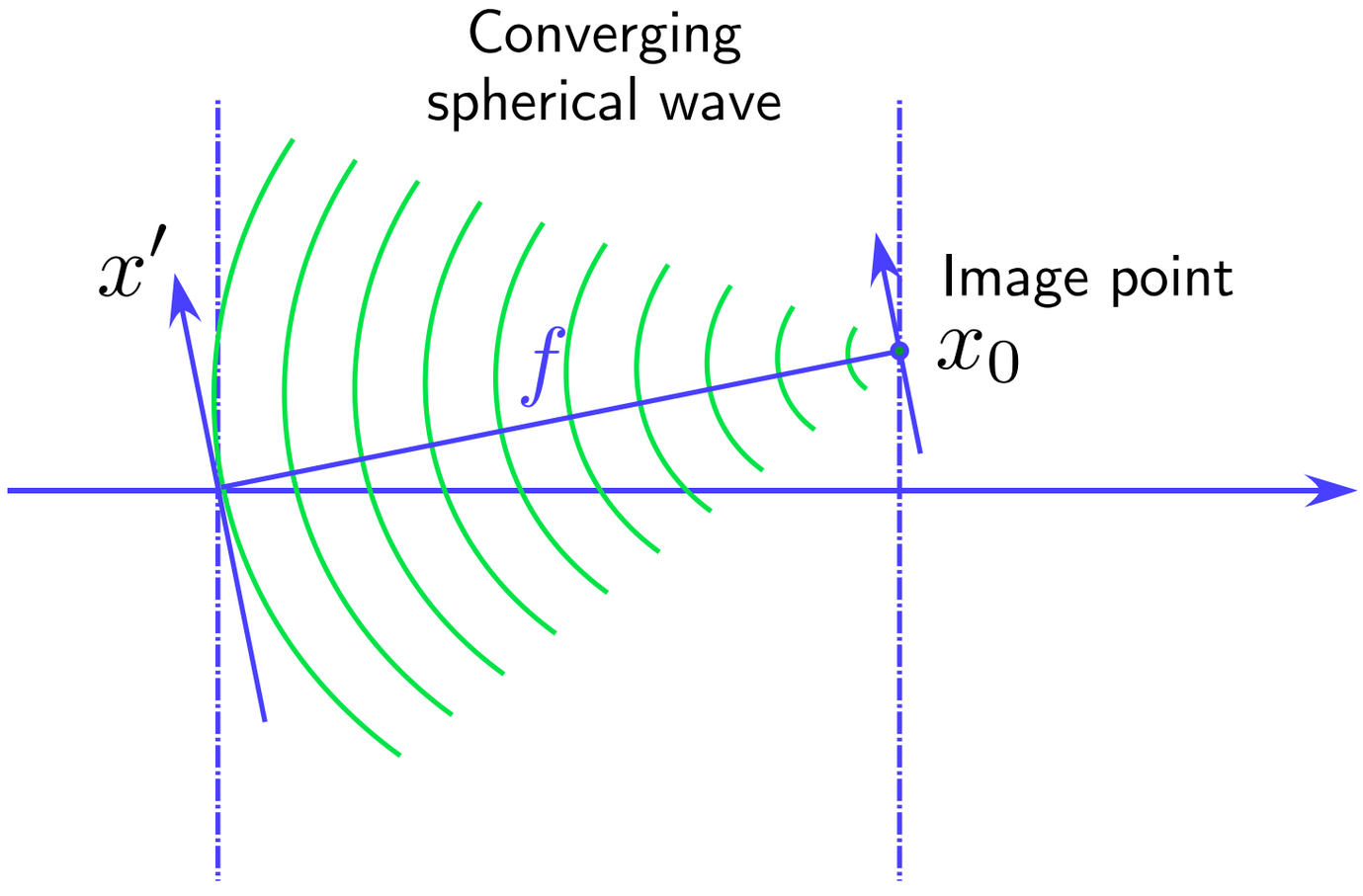
# Imaging Systems



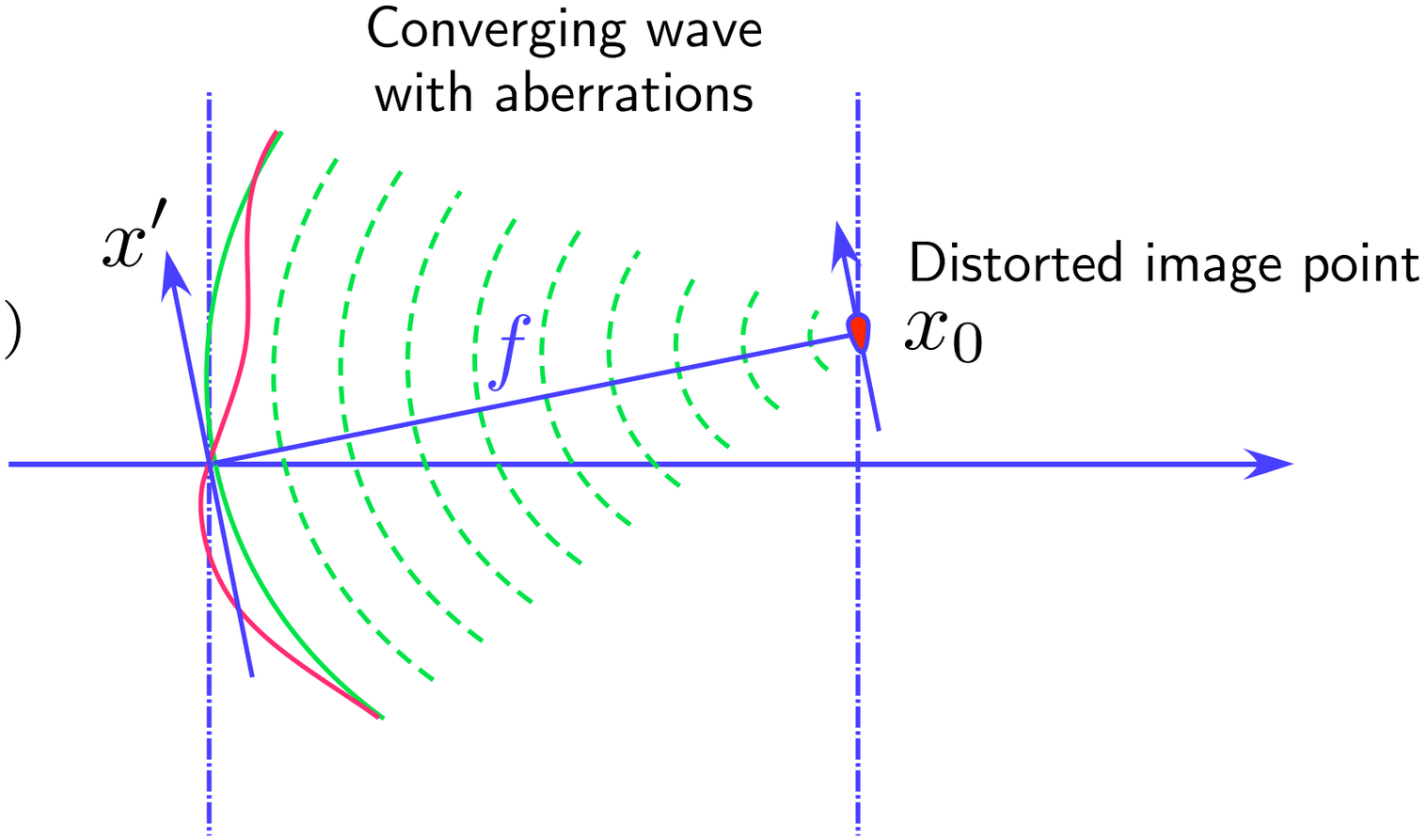

Ideal
optical
system
Object
point
Diverging
spherical
wave
Converging
spherical
wave
Image
point


Optical
system
with aberrations
Object
point
Diverging
spherical
wave
Aberrated
image point

$$\frac{1}{f}e^{-ikf}$$

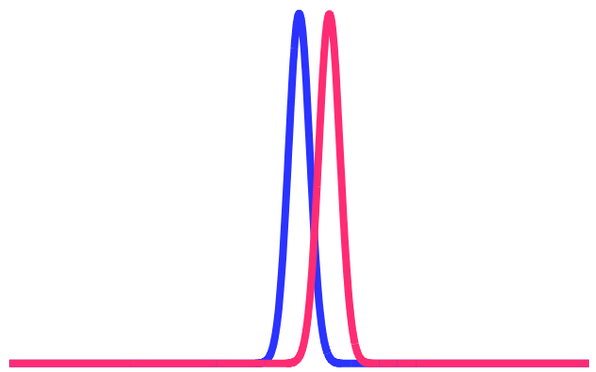



$$\frac{1}{f}e^{-ik(f+W)}$$

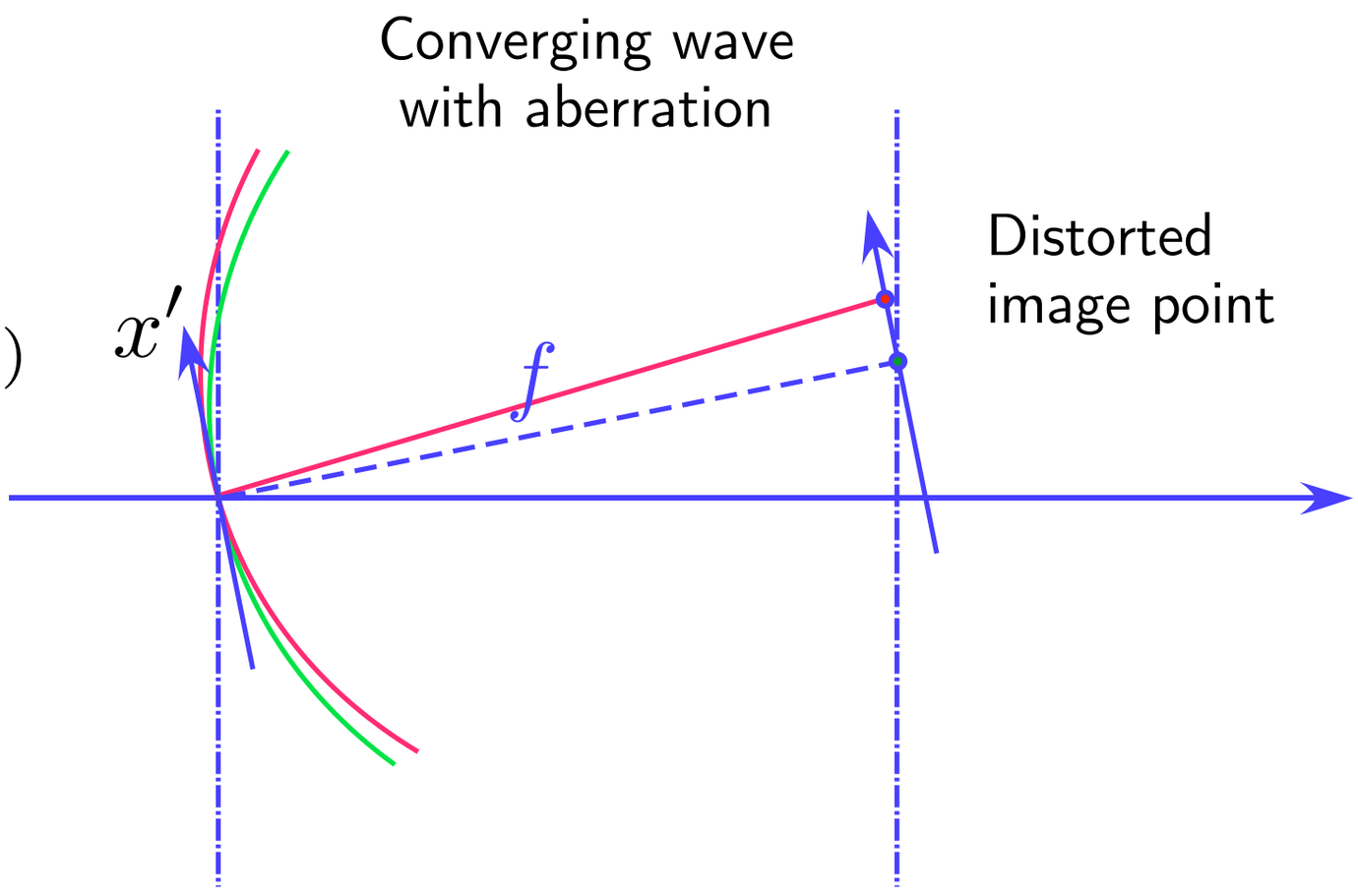


# Examples

Tilt $W(x') = \alpha x'$

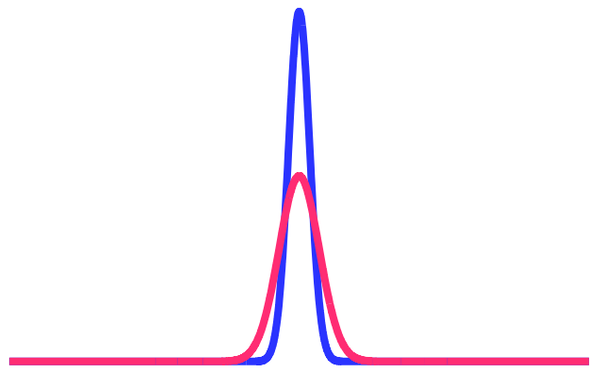


$$\frac{1}{f} e^{-ik(f+W)}$$

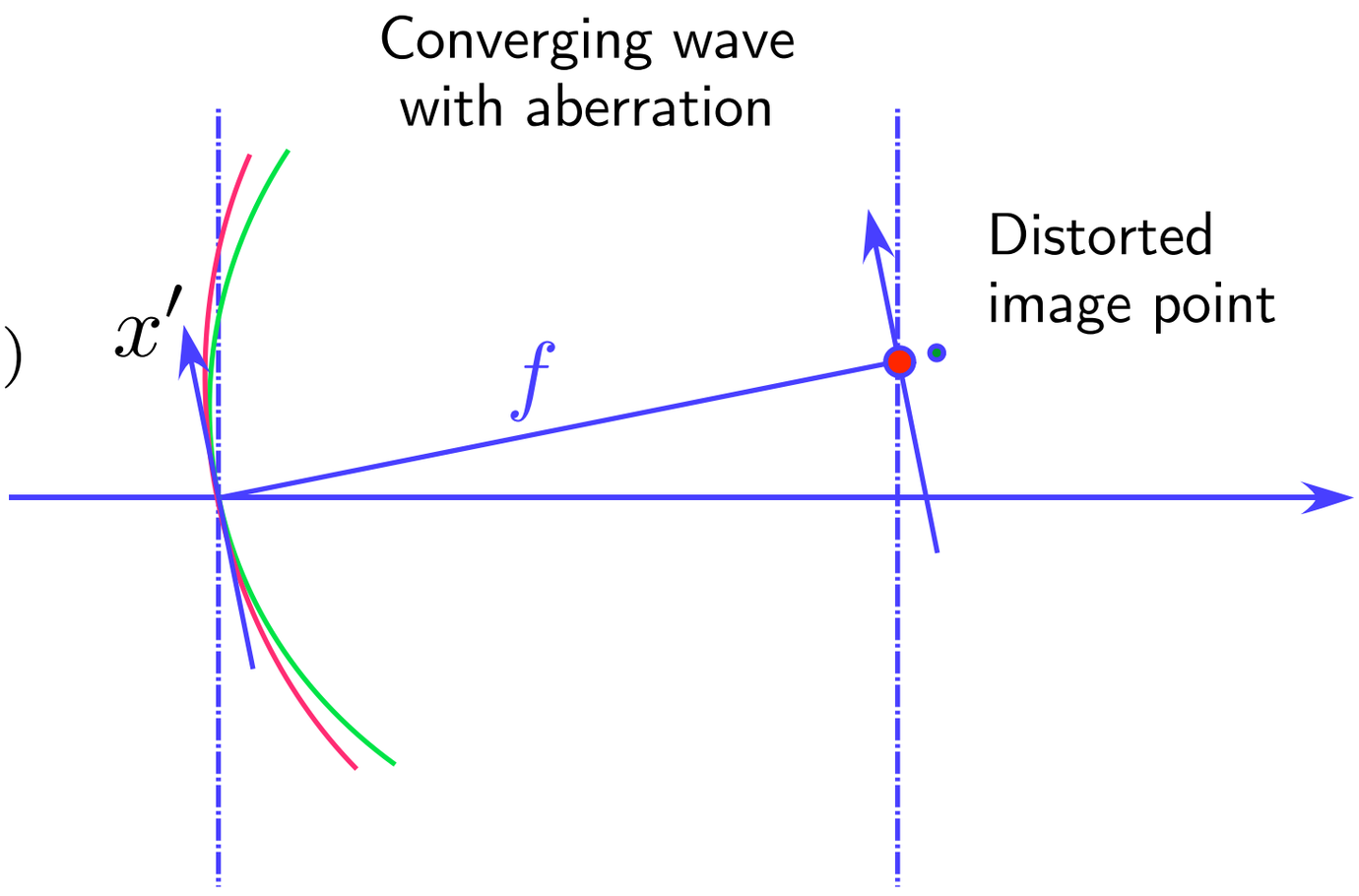


# Examples

Curvature $W(x') = \alpha x'^2$

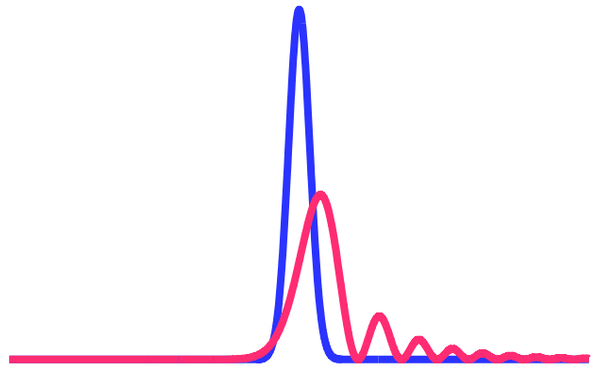


$$\frac{1}{f} e^{-ik(f+W)}$$

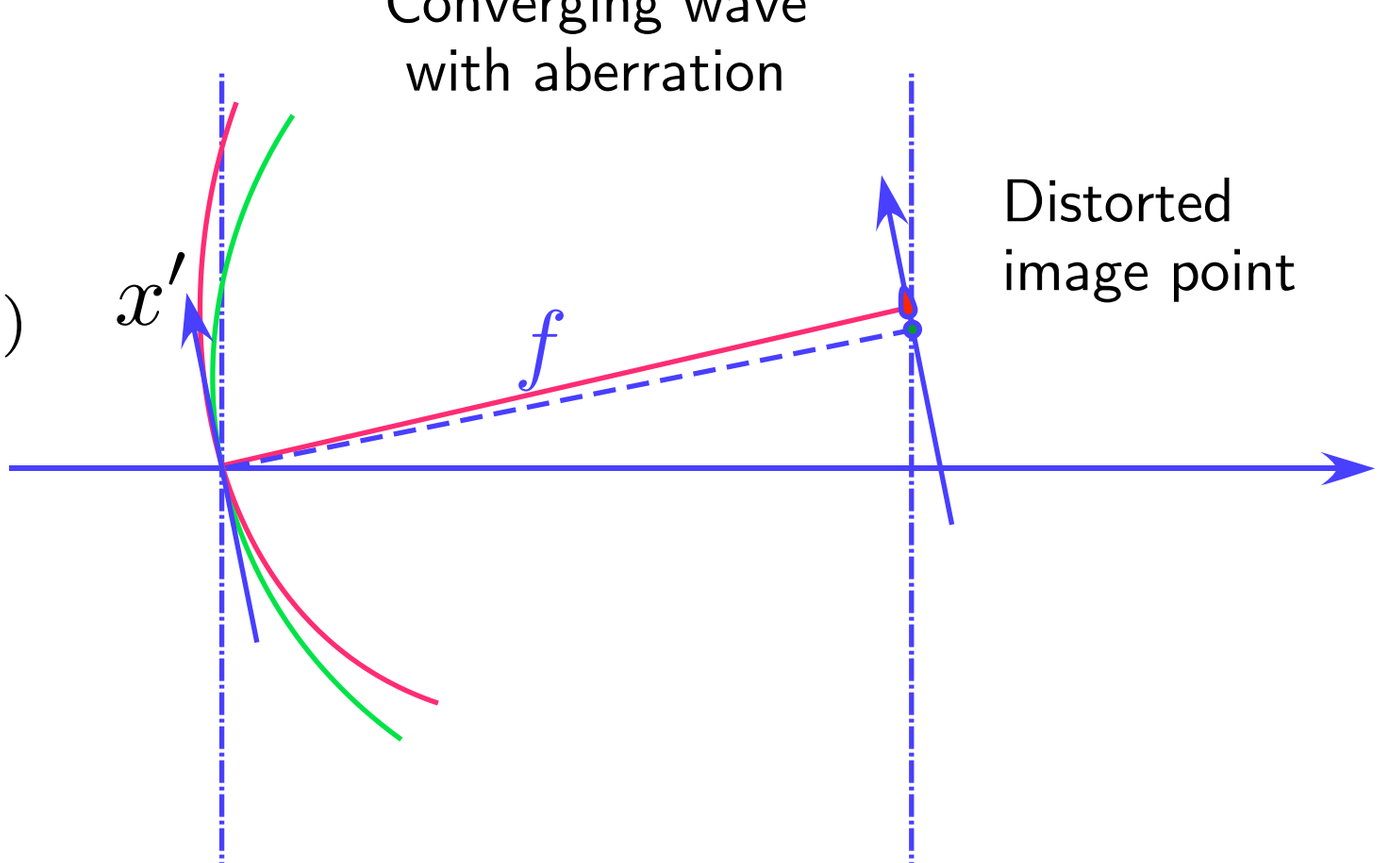


# Examples

Coma $W(x') = \alpha x'^3$

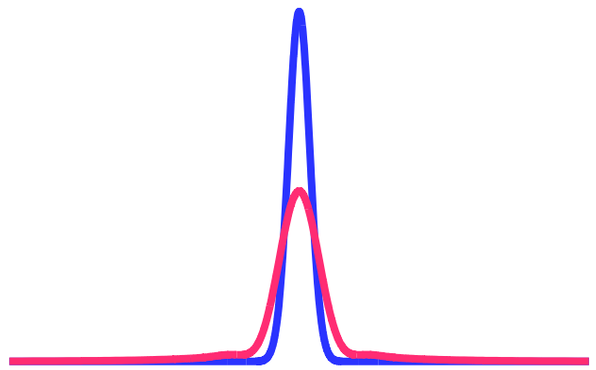


$$\frac{1}{f} e^{-ik(f+W)}$$

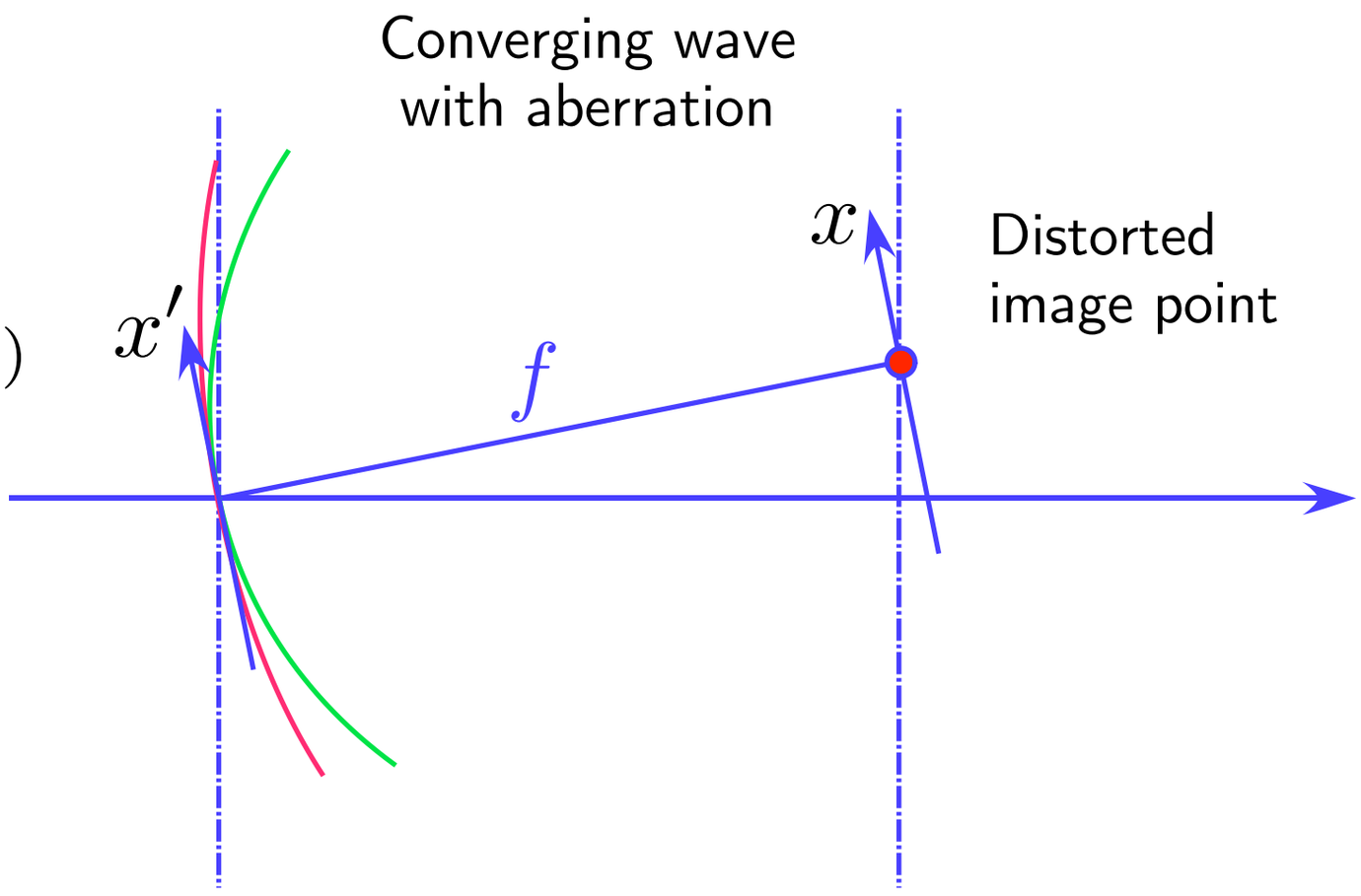


# Examples

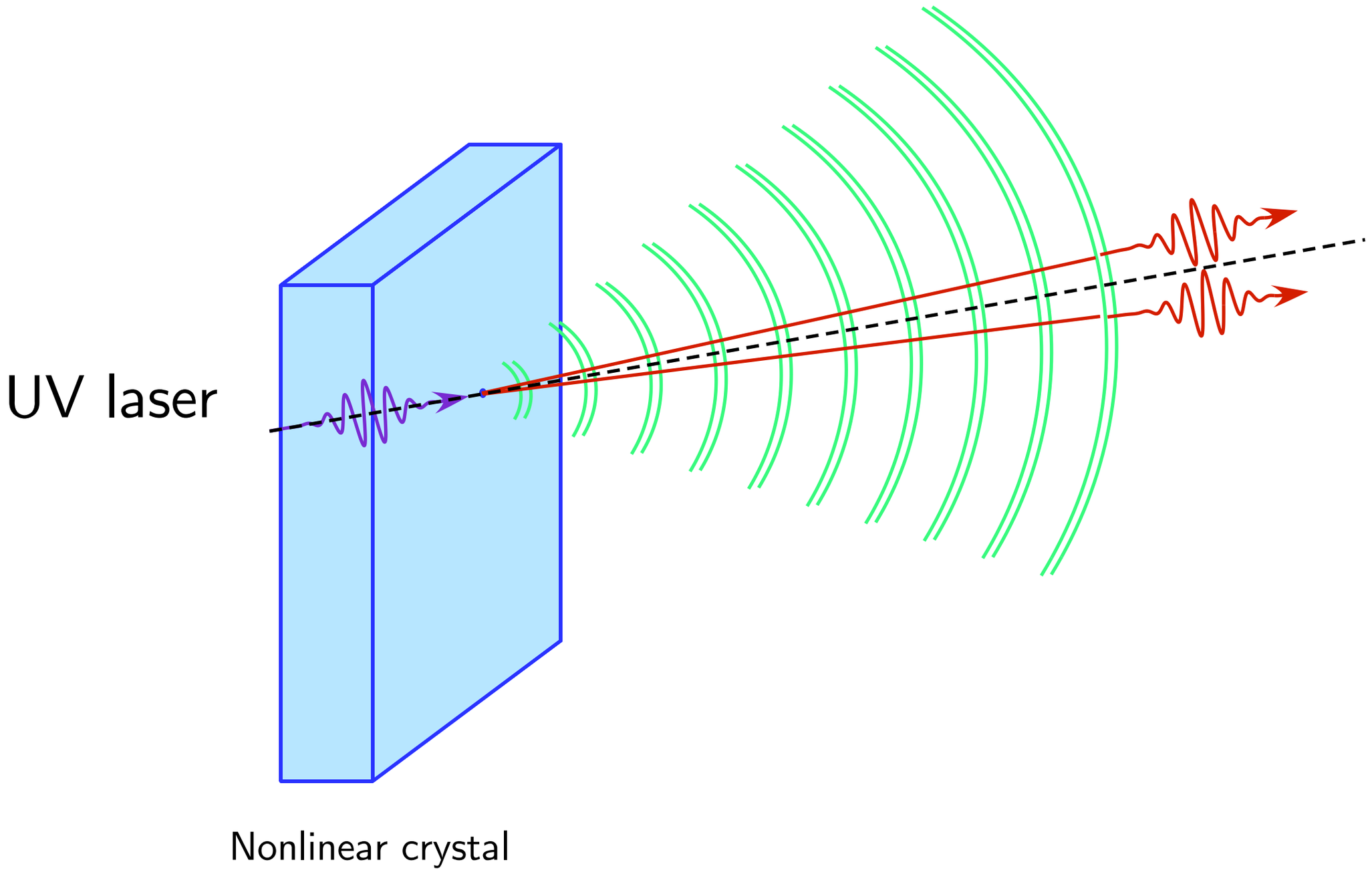
Spherical $W(x') = \alpha x'^4$



$$\frac{1}{f} e^{-ik(f+W)}$$



# Spontaneous Parametric Down-Conversion



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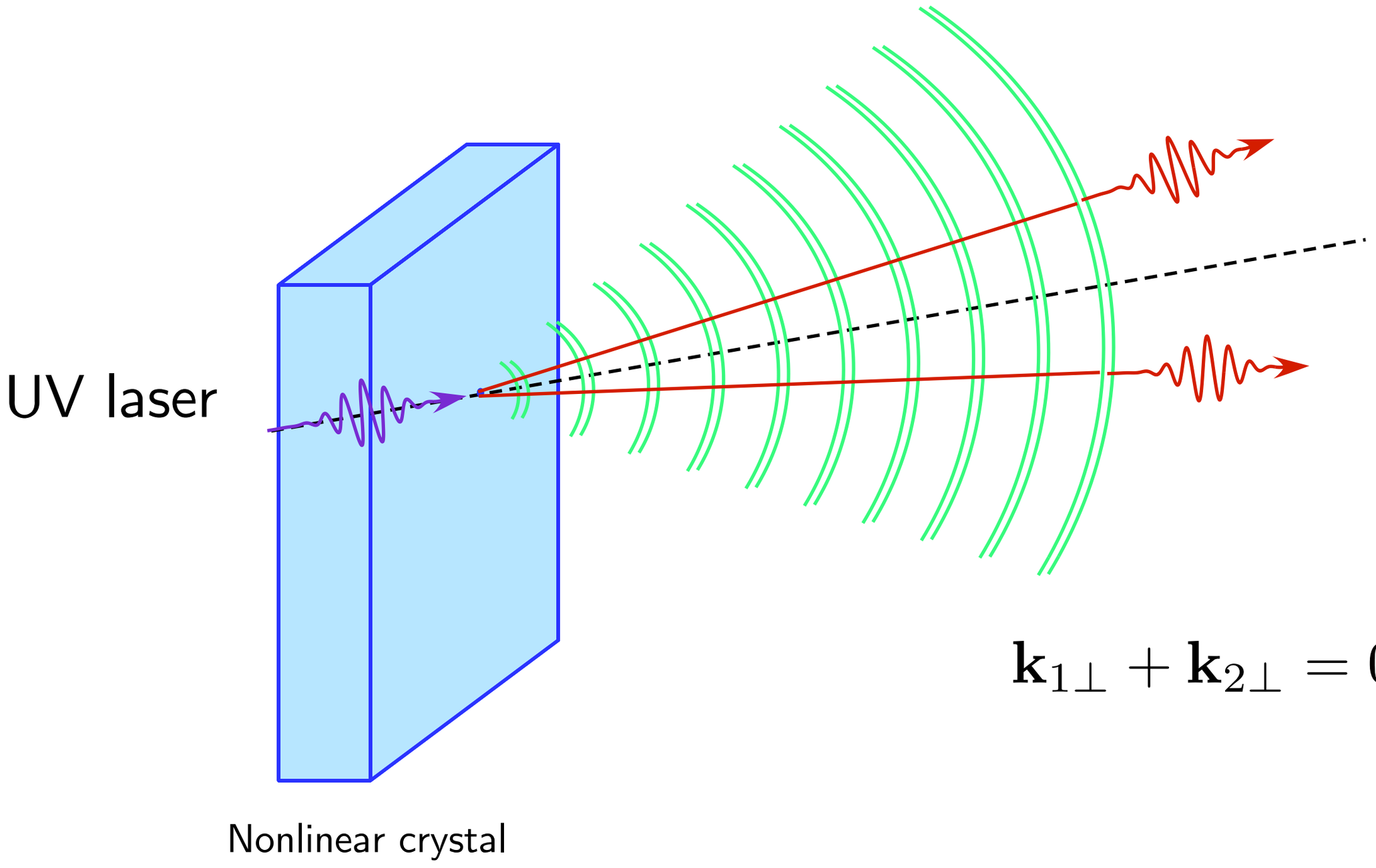
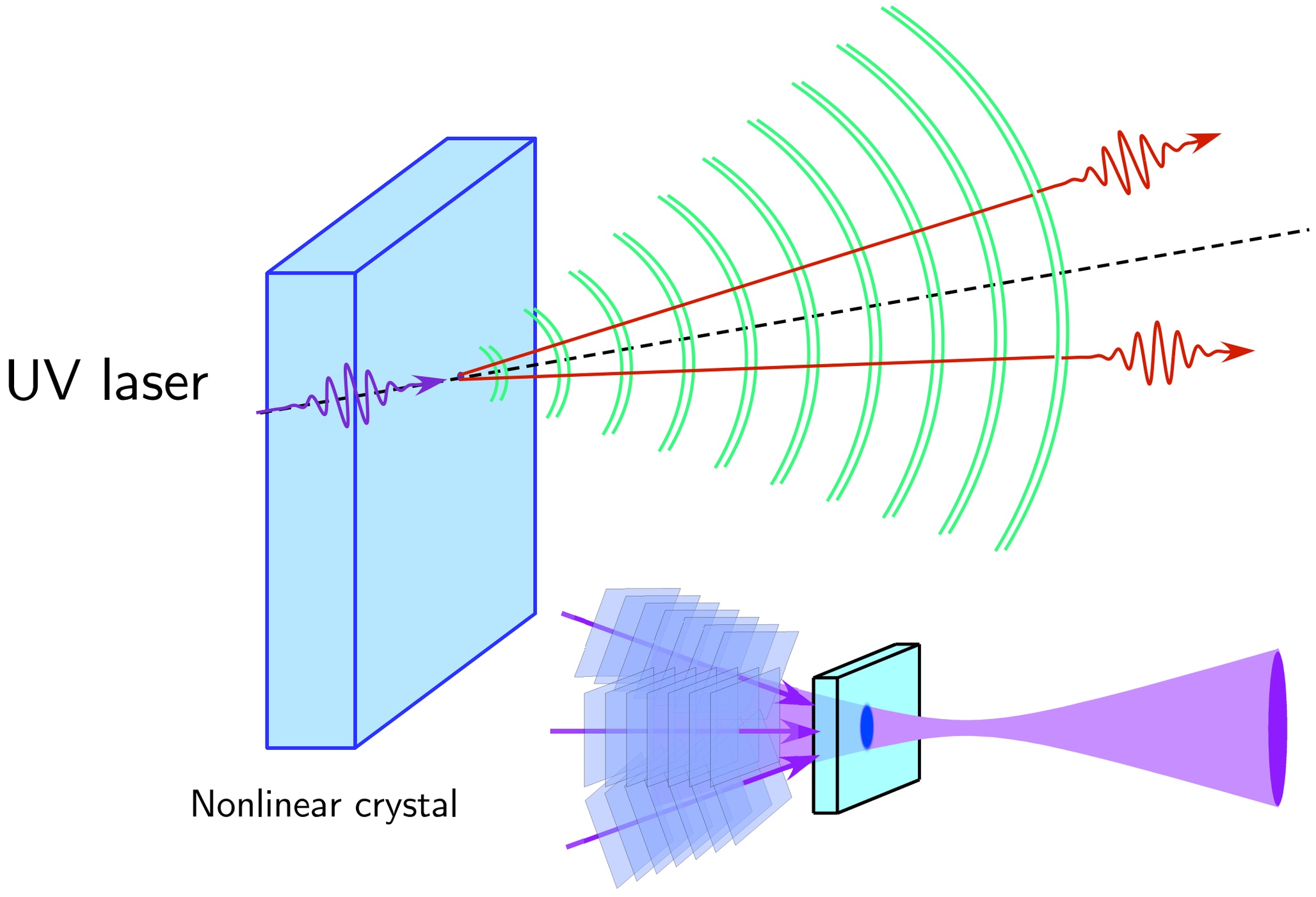
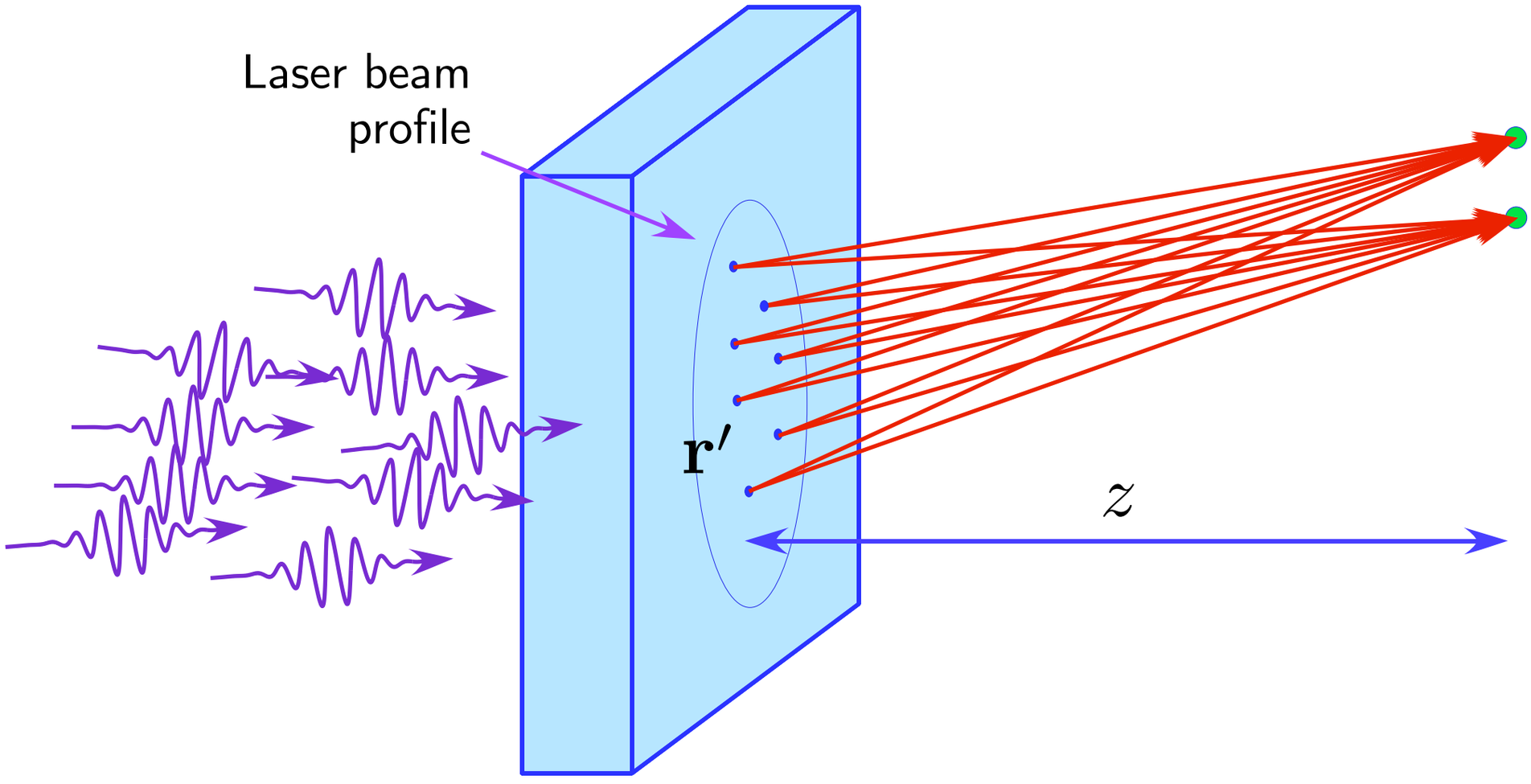


# Spontaneous Parametric Down-Conversion



# Spatial correlations



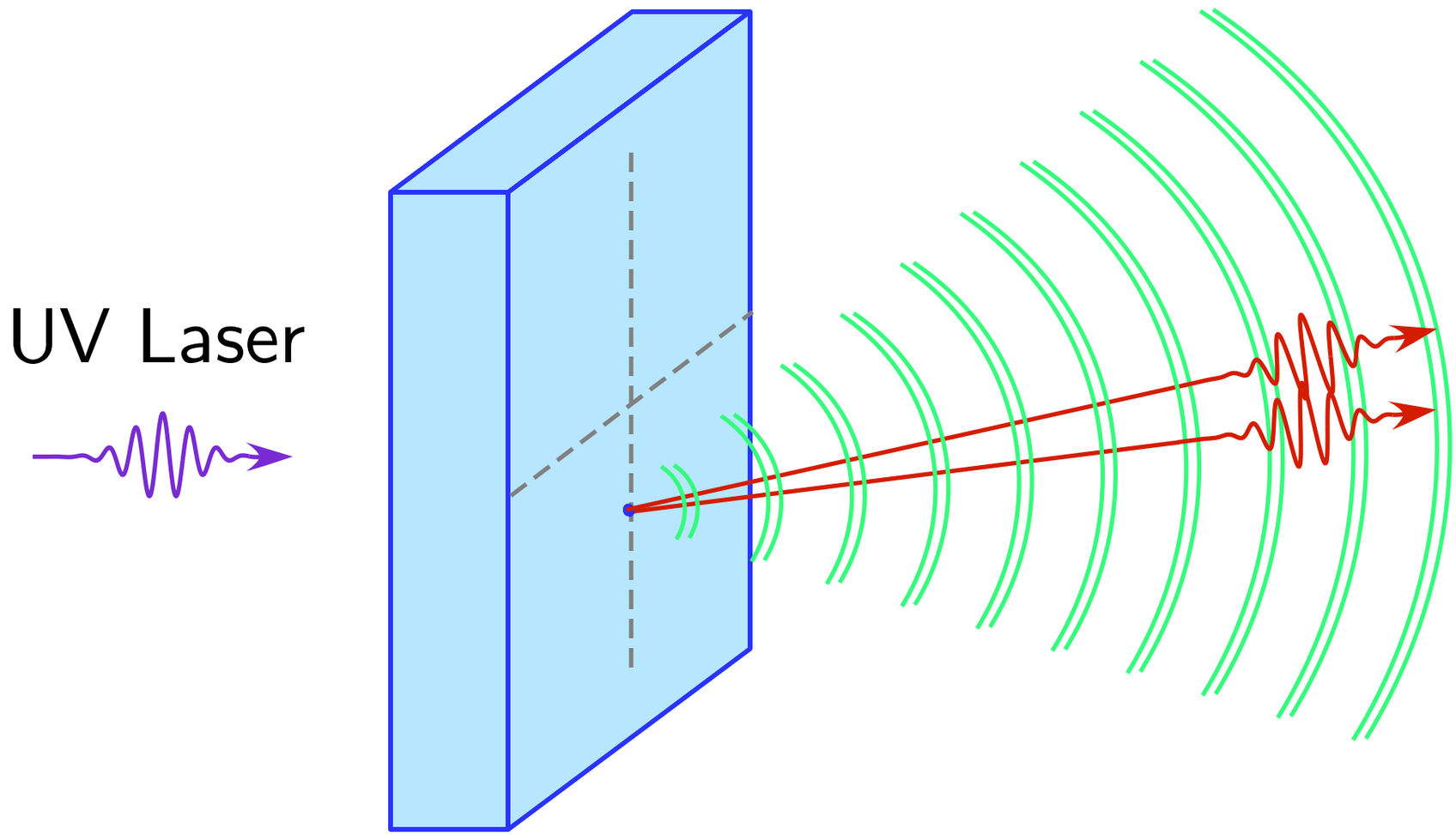

$$\Phi(\mathbf{r}_1, \mathbf{r}_2) \propto \int d\mathbf{r}' \; E(\mathbf{r}') \; \frac{e^{ik|\mathbf{r}'-\mathbf{r}_1|}}{|\mathbf{r}'-\mathbf{r}_1|} \frac{e^{ik|\mathbf{r}'-\mathbf{r}_2|}}{|\mathbf{r}'-\mathbf{r}_2|}$$

Two-photon detection probability amplitude

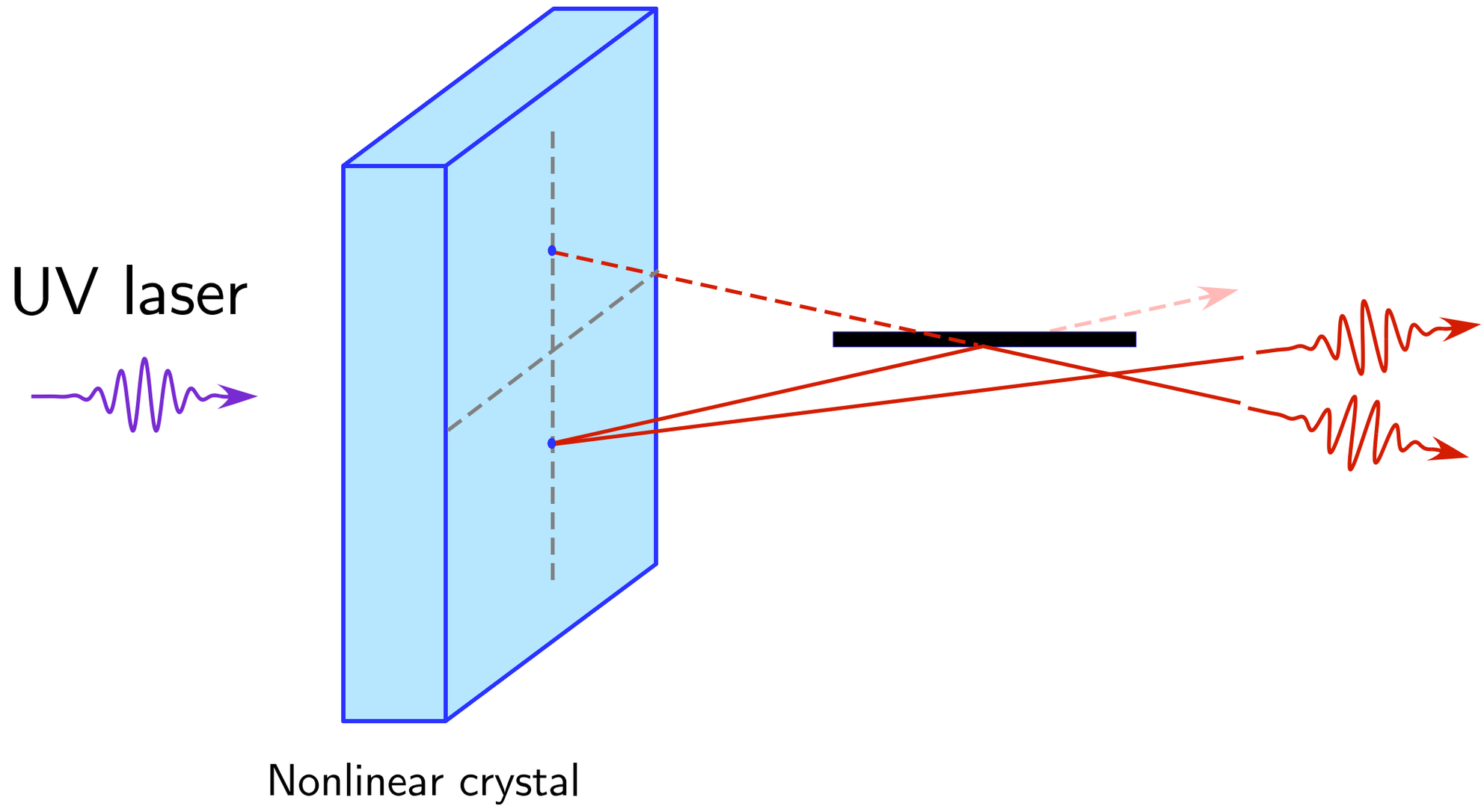
Laser field

One-photon spherical waves

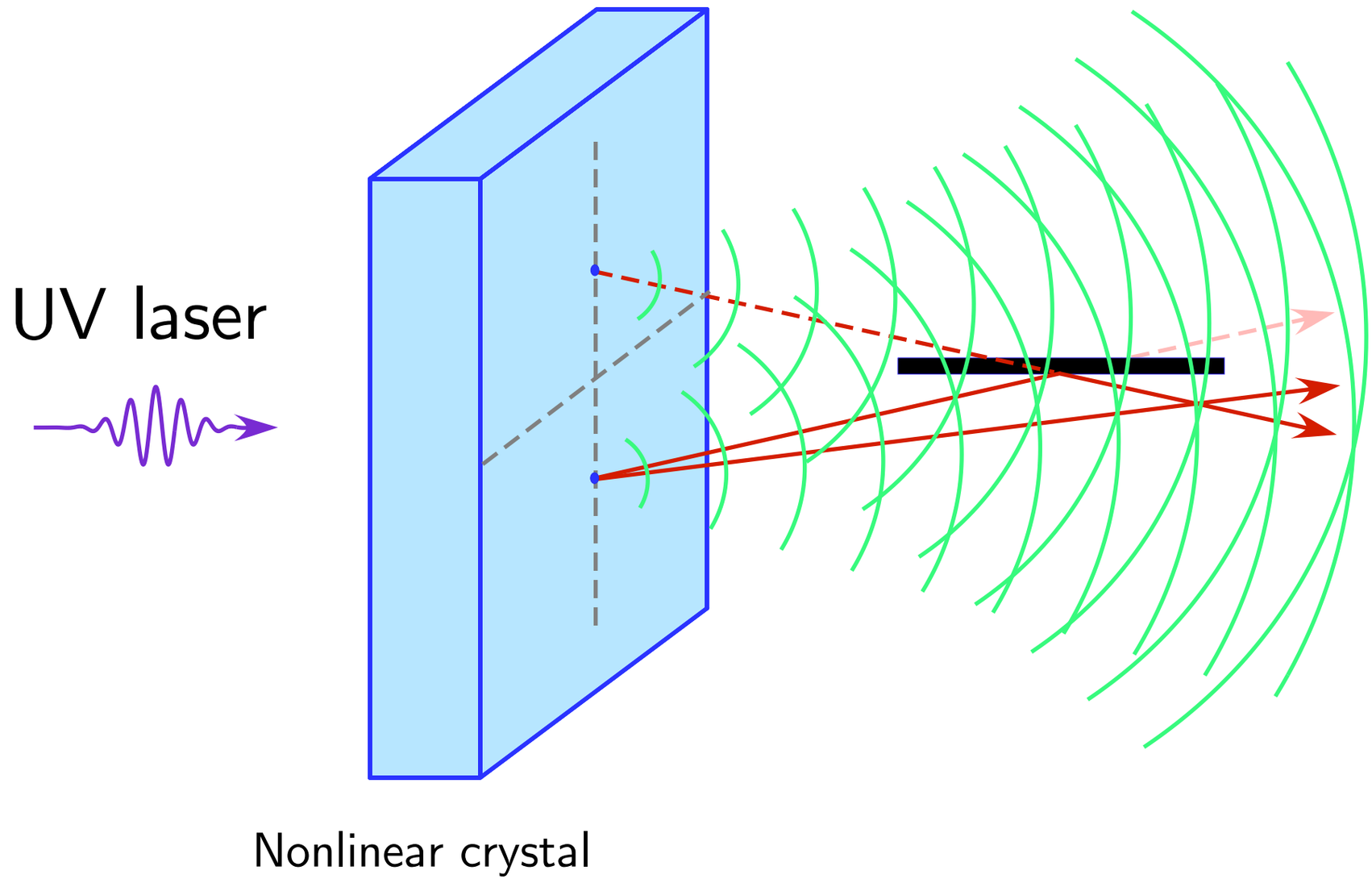
# Spontaneous Parametric Down-Conversion



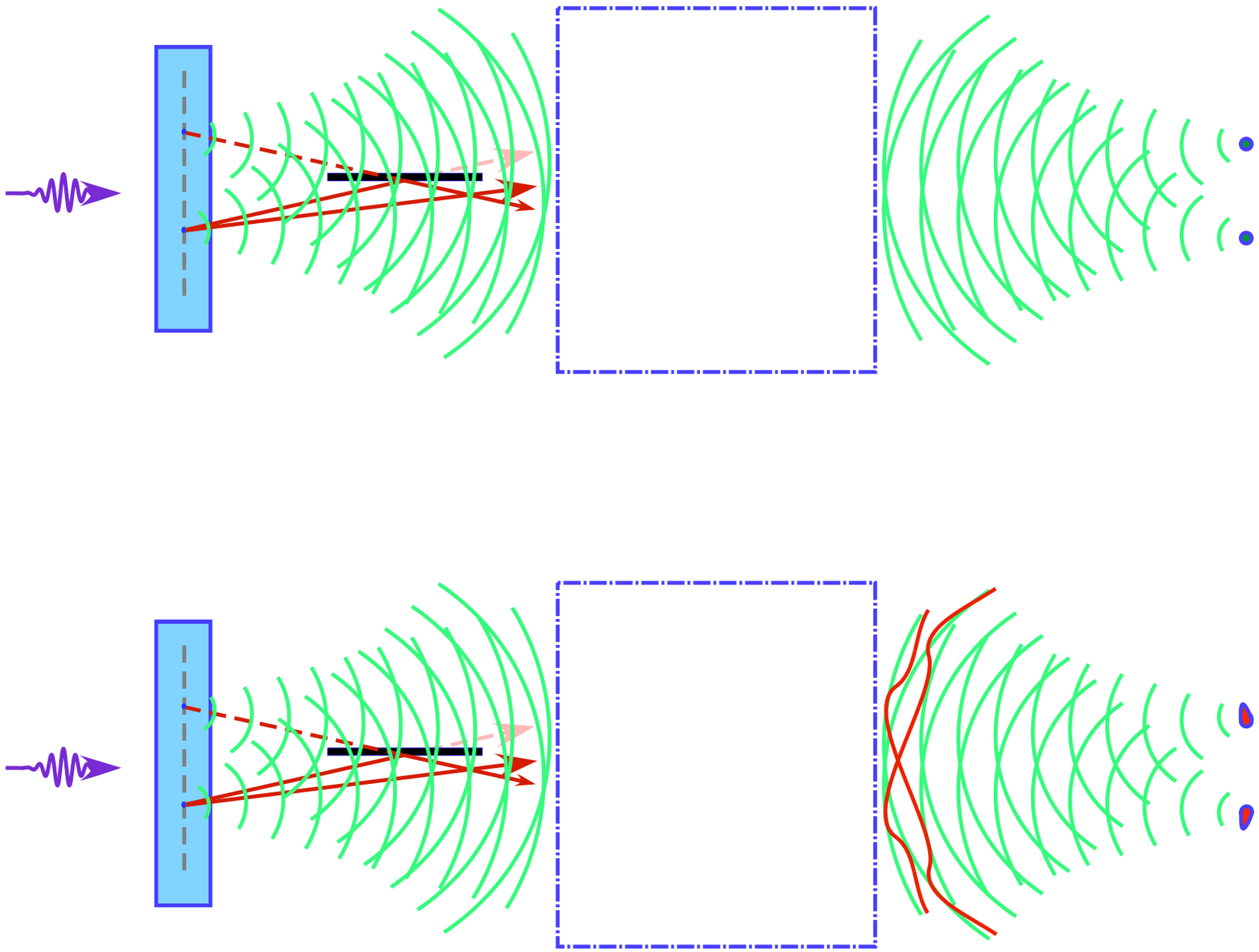
# Coordinate inversion



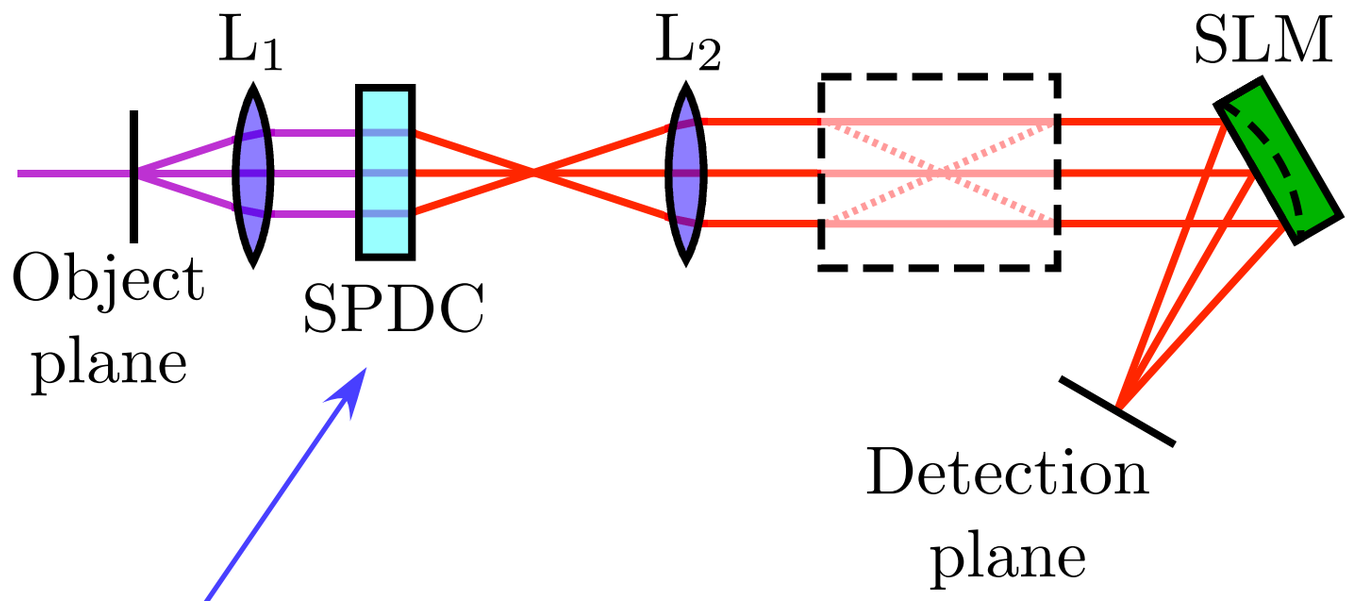
# Coordinate inversion



# Two-photon Imaging System



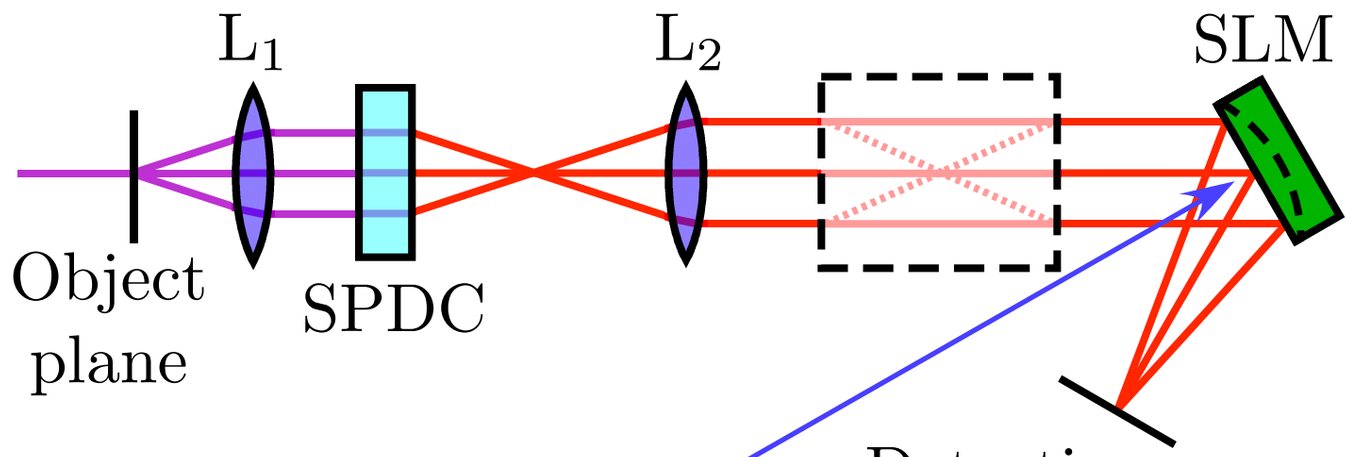
# Experiment




Optical Fourier transform of the object

$$A(\mathbf{r}_s, \mathbf{r}_i) \propto \int \mathrm{d}^2\rho_s'' \int \mathrm{d}^2\rho_i'' \, U\left(\frac{\boldsymbol{\rho}_s'' + \boldsymbol{\rho}_i''}{2}\right) V\left(\frac{\boldsymbol{\rho}_s'' - \boldsymbol{\rho}_i''}{2}\right) \times \exp\left[\frac{ik}{4z}\left(\left|\boldsymbol{\rho}_s - \boldsymbol{\rho}_s''\right|^2 + \left|\boldsymbol{\rho}_i - \boldsymbol{\rho}_i''\right|^2\right)\right]$$

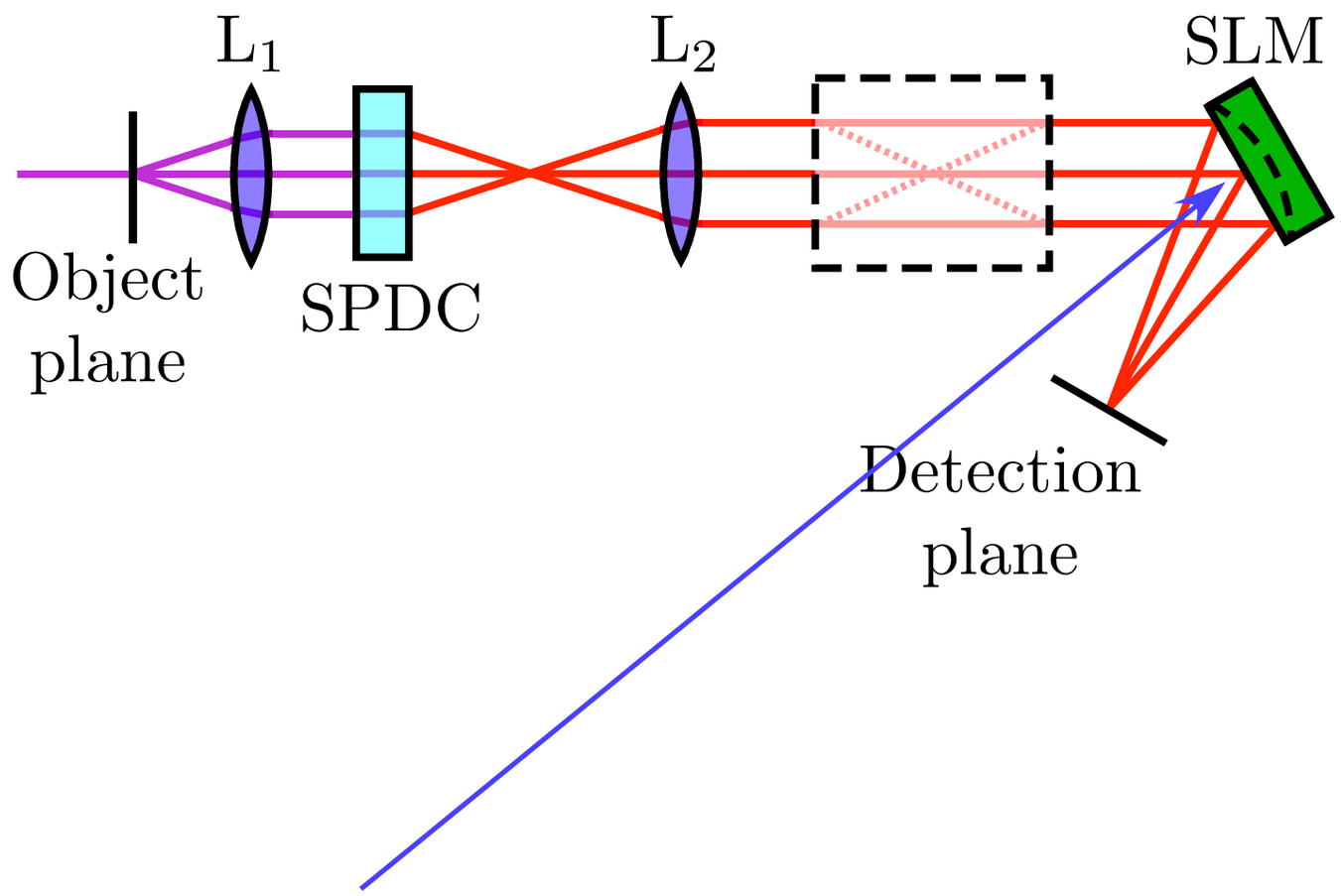
# Experiment




Very narrow function

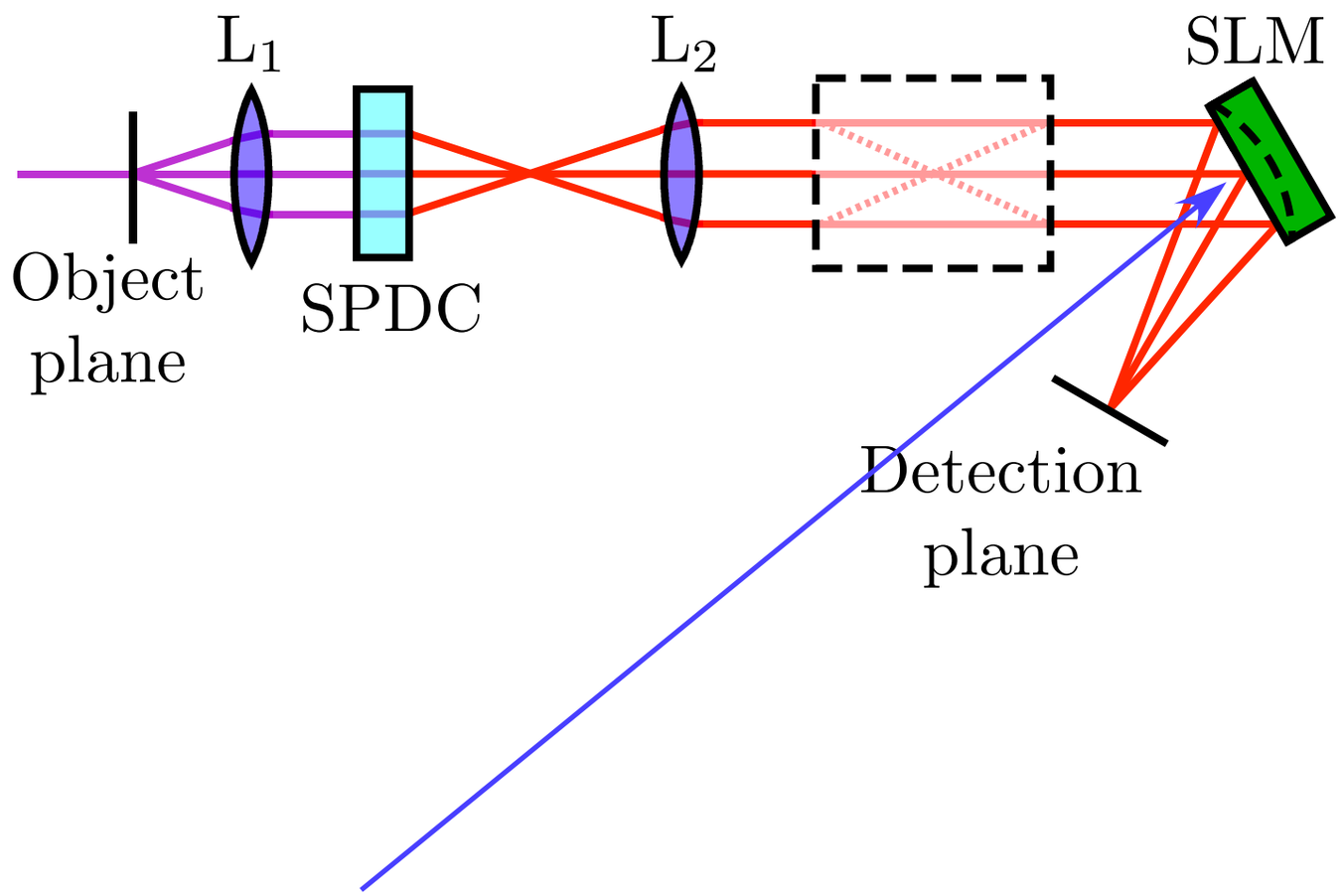
$$A(\mathbf{r}_s,\mathbf{r}_i) \propto \int \mathrm{d}^2\rho_s' \int \mathrm{d}^2\rho_i'\, U^{(i)}\left(\frac{\boldsymbol{\rho}_s'-\boldsymbol{\rho}_i'}{2}\right) V^{(i)}\left(\frac{\boldsymbol{\rho}_s'+\boldsymbol{\rho}_i'}{2}\right)$$
$$\times \exp\left[i\phi(\boldsymbol{\rho}_s') + i\phi(\boldsymbol{\rho}_i') + \frac{ik}{4z'}\left(\left|\boldsymbol{\rho}_s-\boldsymbol{\rho}_s'\right|^2 + \left|\boldsymbol{\rho}_i-\boldsymbol{\rho}_i'\right|^2\right)\right]$$

# Experiment



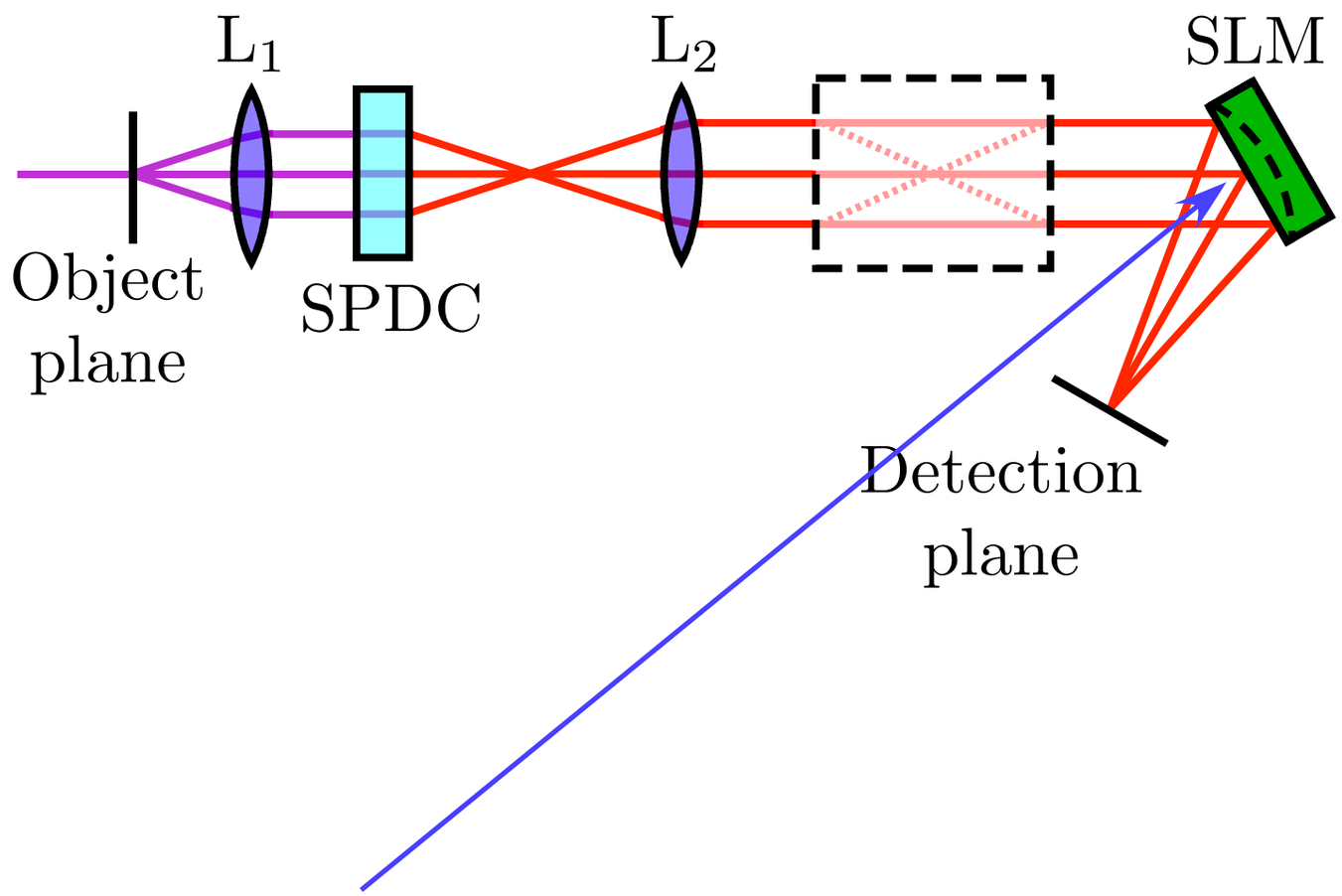

$$A(\mathbf{r}_s, \mathbf{r}_i) \quad \propto \quad \int \mathrm{d}^2\rho' \, U^{(i)}\left(\boldsymbol{\rho}'\right)$$
$$\times \exp\left[ i\phi(\boldsymbol{\rho}') + i\phi(-\boldsymbol{\rho}') + \frac{ik}{4z'}\left( \left|\boldsymbol{\rho}_s - \boldsymbol{\rho}'\right|^2 + \left|\boldsymbol{\rho}_i - \boldsymbol{\rho}'\right|^2 \right) \right]$$

# Experiment




$$A(\mathbf{r}_s, \mathbf{r}_i) \propto e^{i\frac{k}{2f}|\boldsymbol{\rho}_s - \boldsymbol{\rho}_i|^2} \int \mathrm{d}^2\rho'\, U^{(i)}(\boldsymbol{\rho}')\, e^{-\frac{ik}{f}\boldsymbol{\rho}'\cdot(\boldsymbol{\rho}_s - \boldsymbol{\rho}_i)}$$

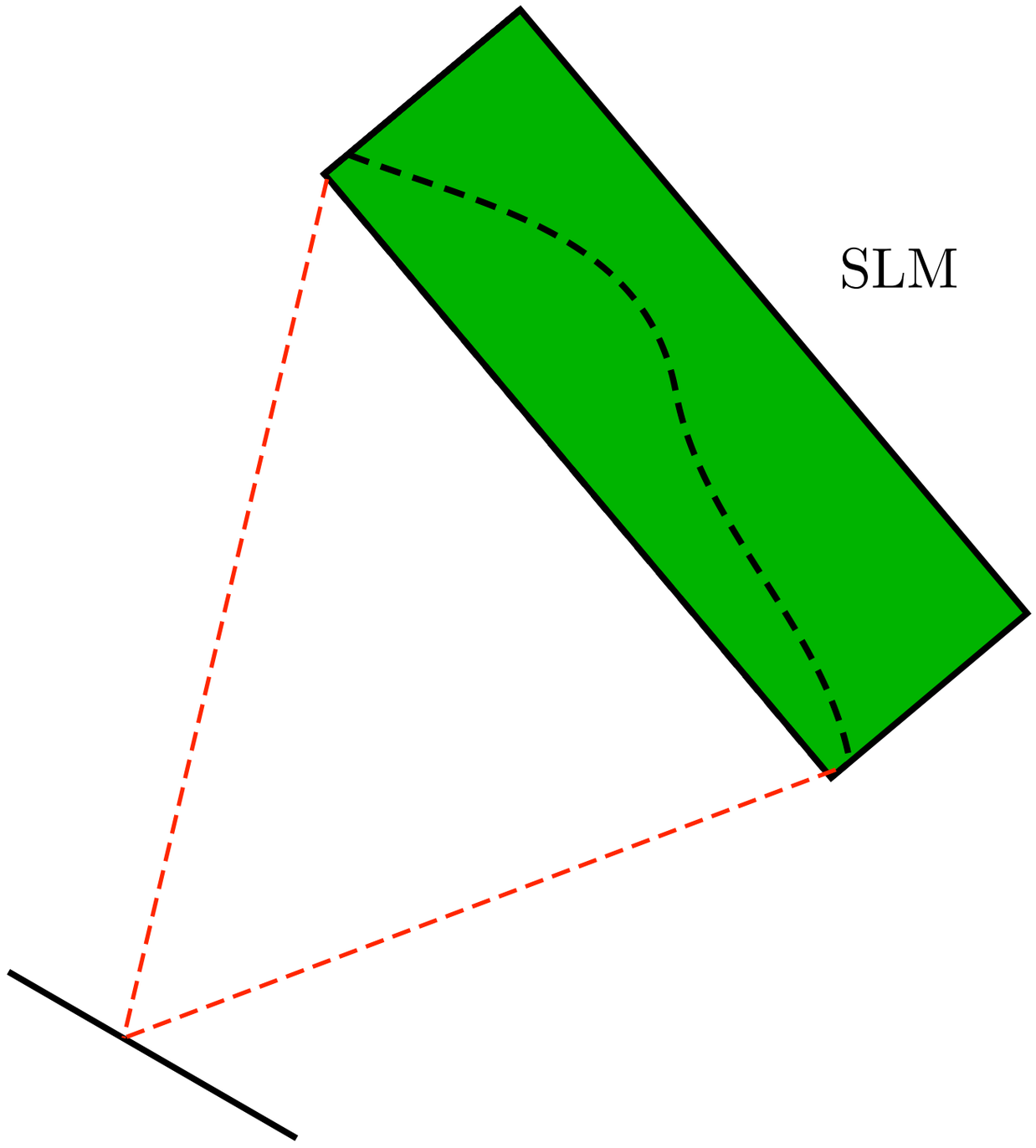
# Experiment

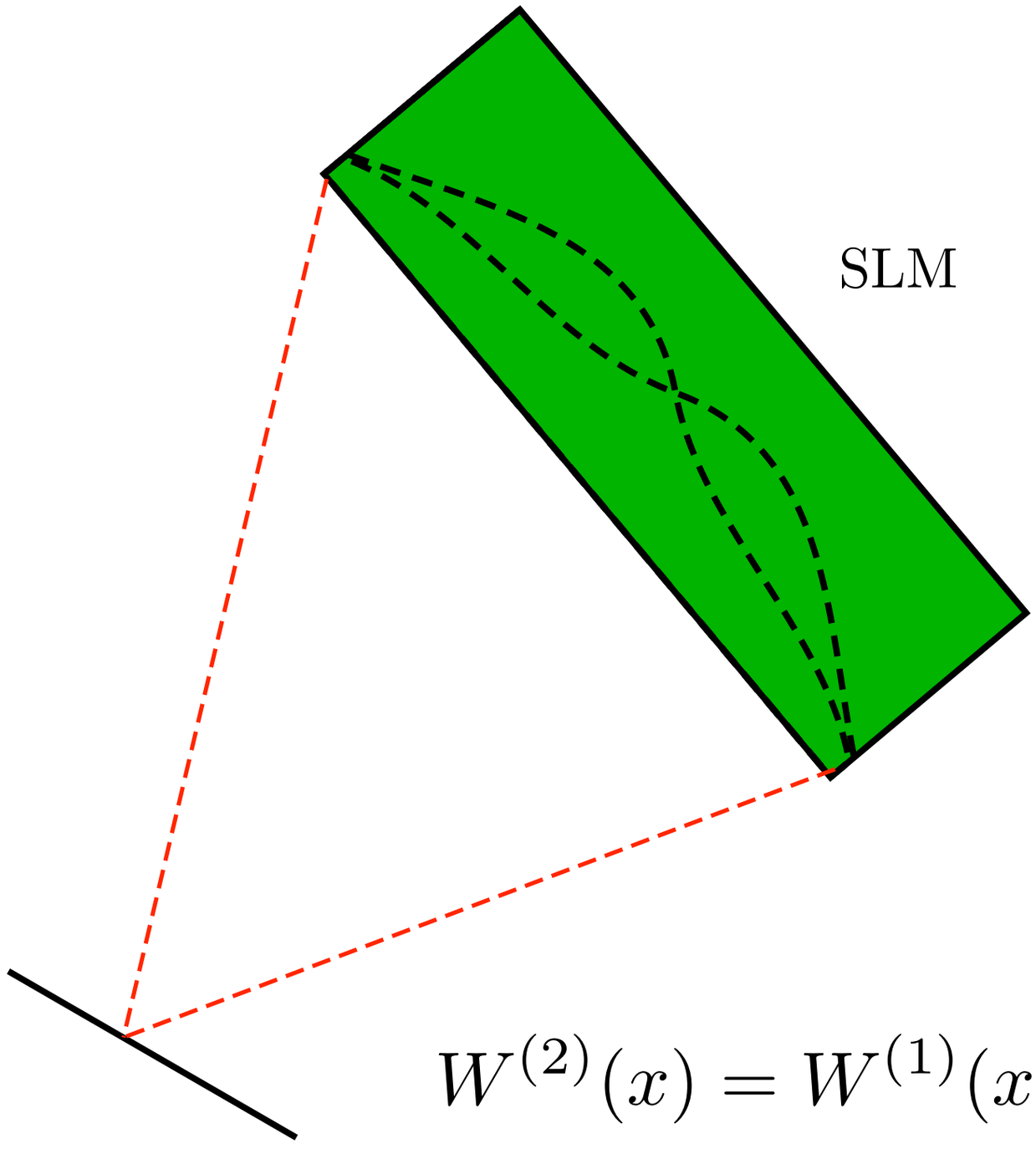



$$A(\mathbf{r}_s, \mathbf{r}_i) \propto e^{i\frac{k}{2f}|\boldsymbol{\rho}_s - \boldsymbol{\rho}_i|^2} \int \mathrm{d}^2\rho'\, U^{(i)}(\boldsymbol{\rho}')\, e^{-\frac{ik}{f}\boldsymbol{\rho}'\cdot(\boldsymbol{\rho}_s - \boldsymbol{\rho}_i)}$$

## With aberrations

$$A(\mathbf{r}_s, \mathbf{r}_i) \propto e^{i\frac{k}{2f}|\boldsymbol{\rho}_s - \boldsymbol{\rho}_i|^2} \int \mathrm{d}^2\rho'\, U^{(i)}(\boldsymbol{\rho}')\, e^{iW(\boldsymbol{\rho}')+iW(-\boldsymbol{\rho}')}\; e^{-\frac{ik}{f}\boldsymbol{\rho}'\cdot(\boldsymbol{\rho}_s - \boldsymbol{\rho}_i)}$$

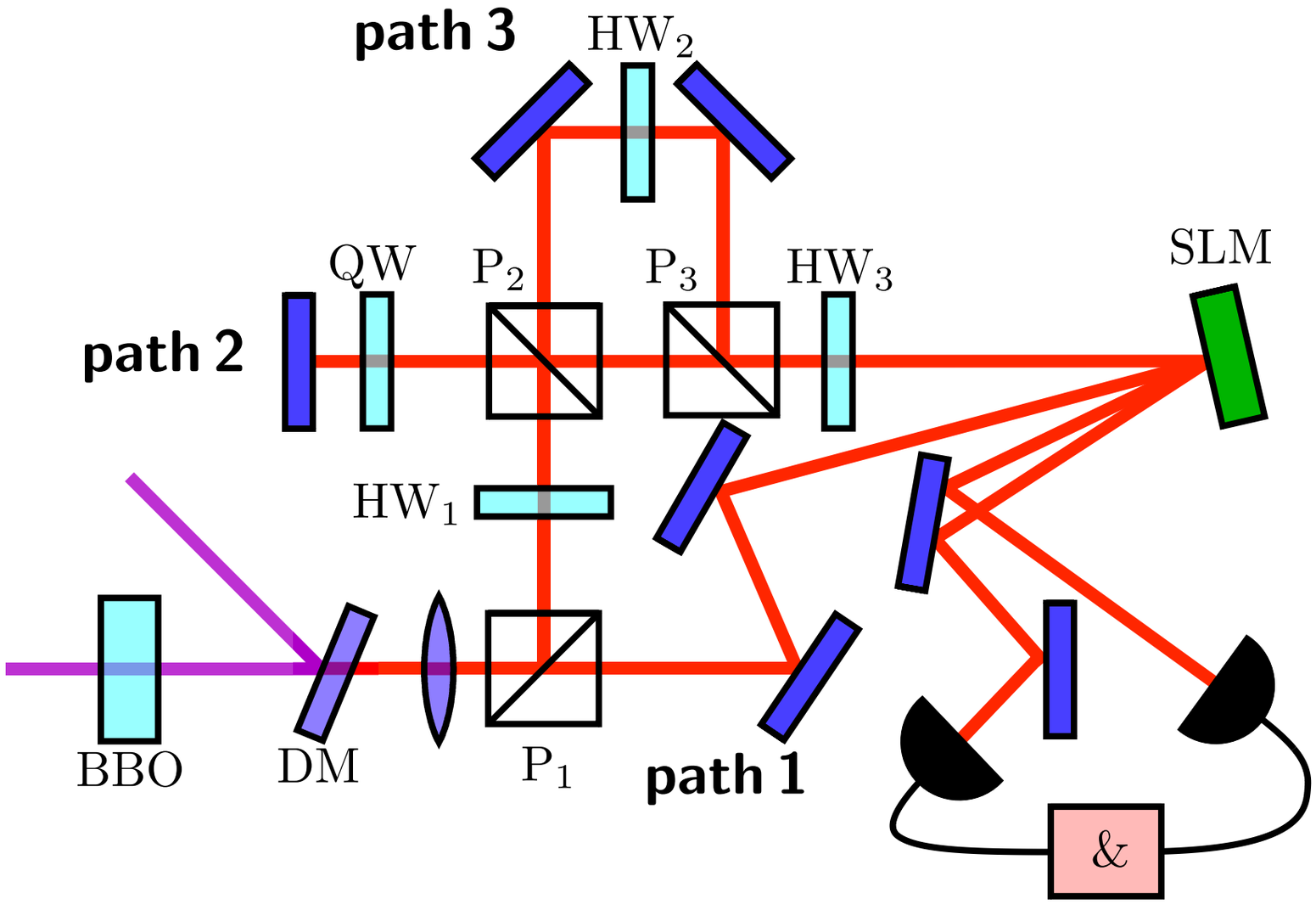

SLM



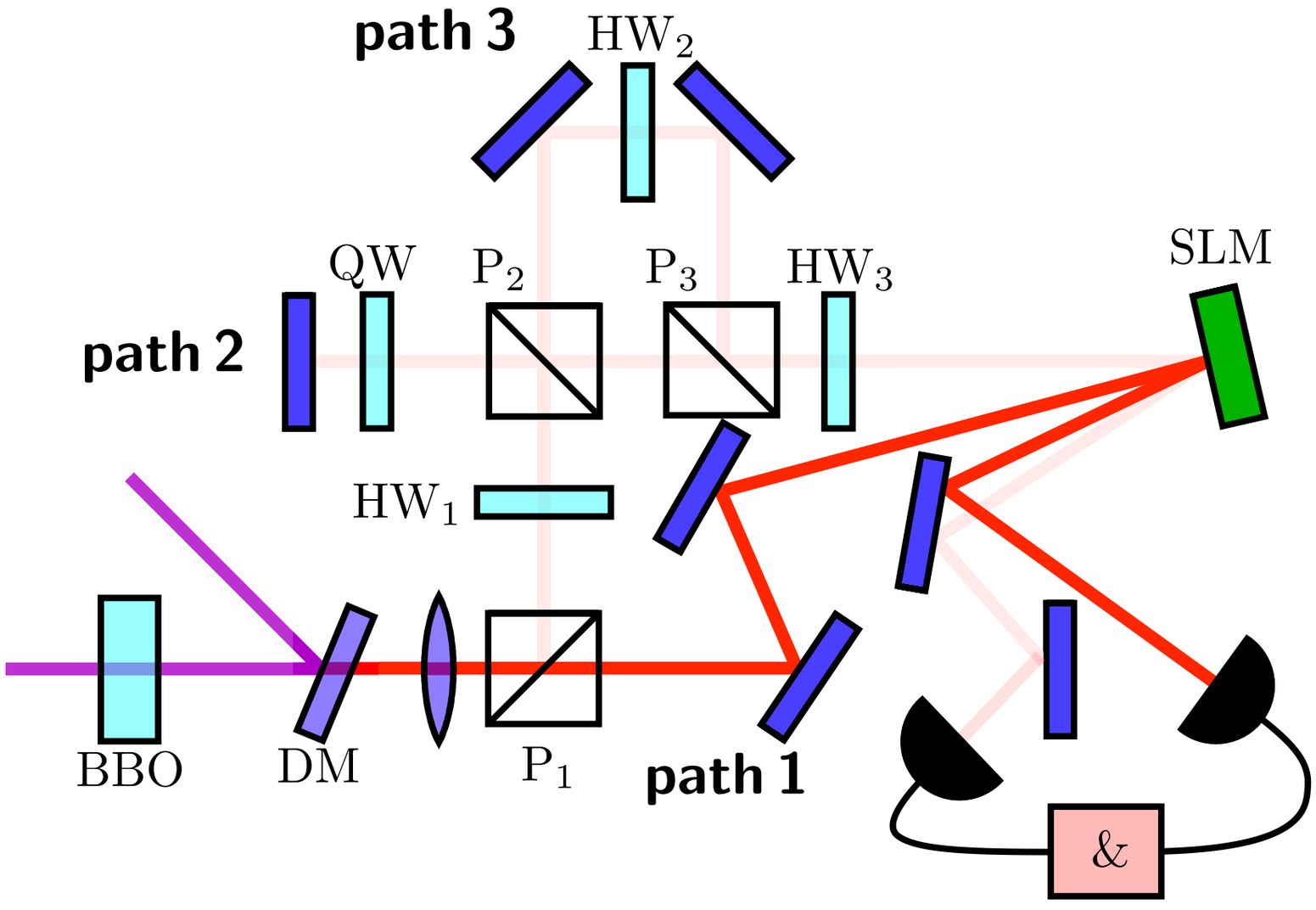

$$W^{(2)}(x) = W^{(1)}(x) + W^{(1)}(-x)$$

The odd part cancels out

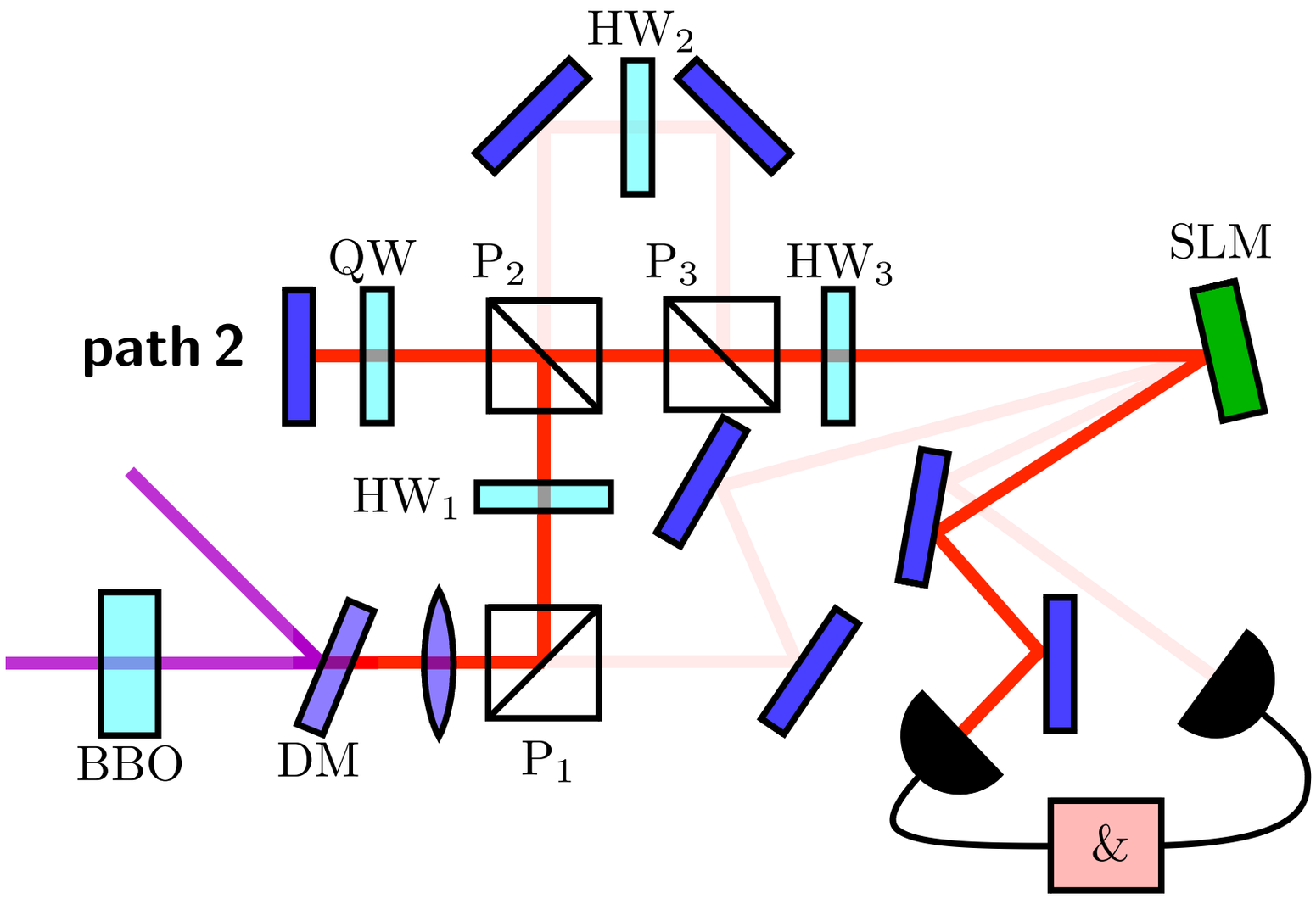
# Experiment



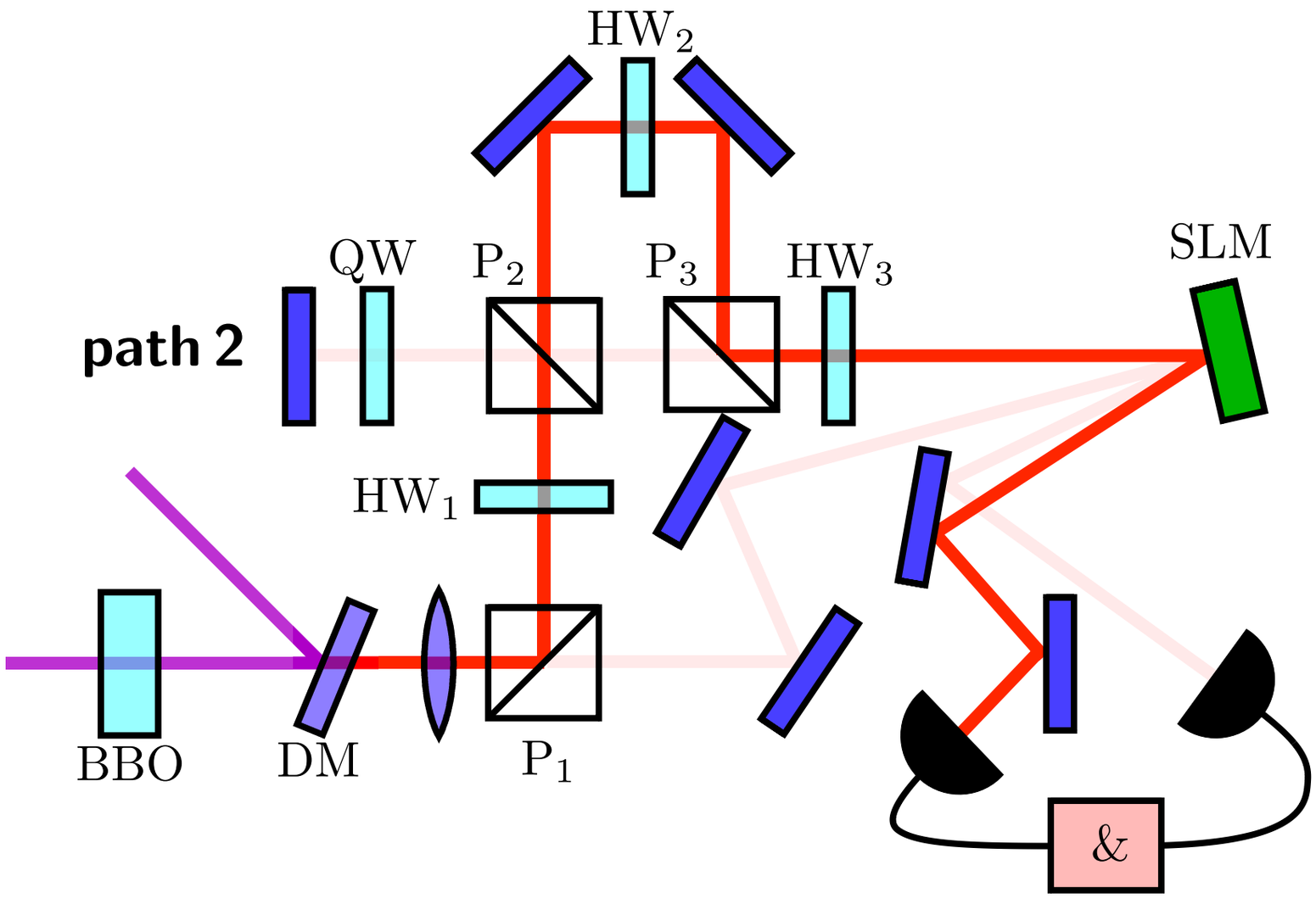
# Experiment



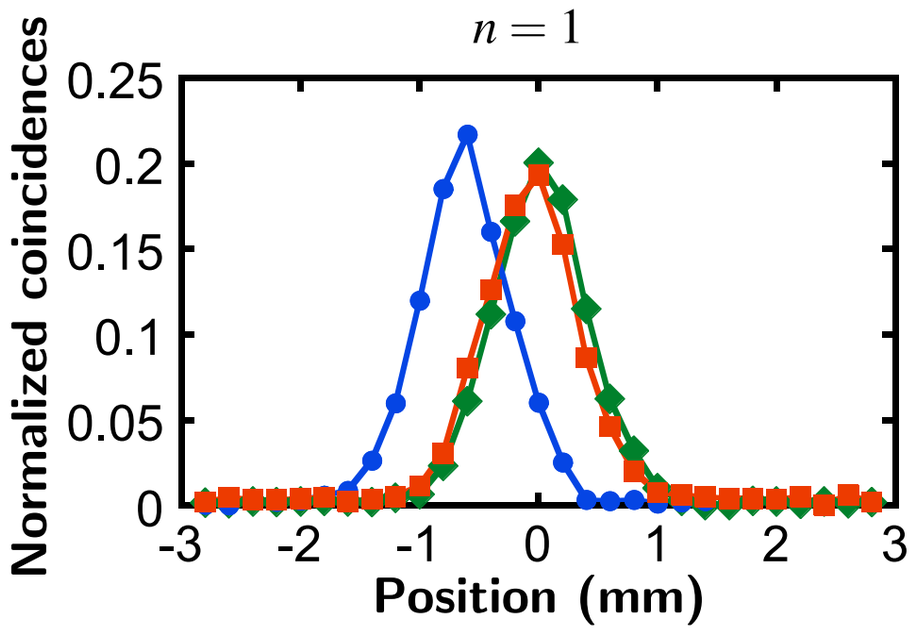
# Experiment

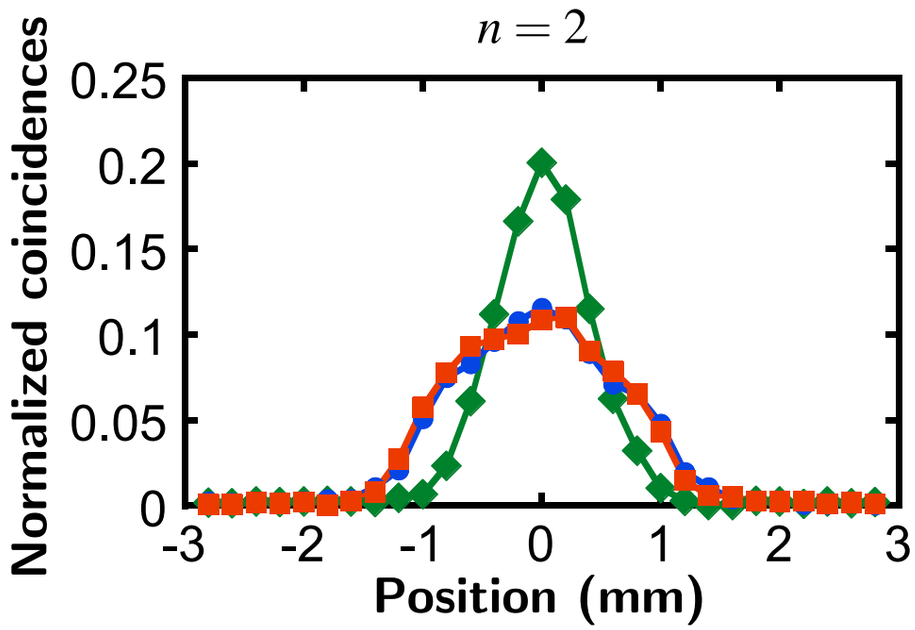


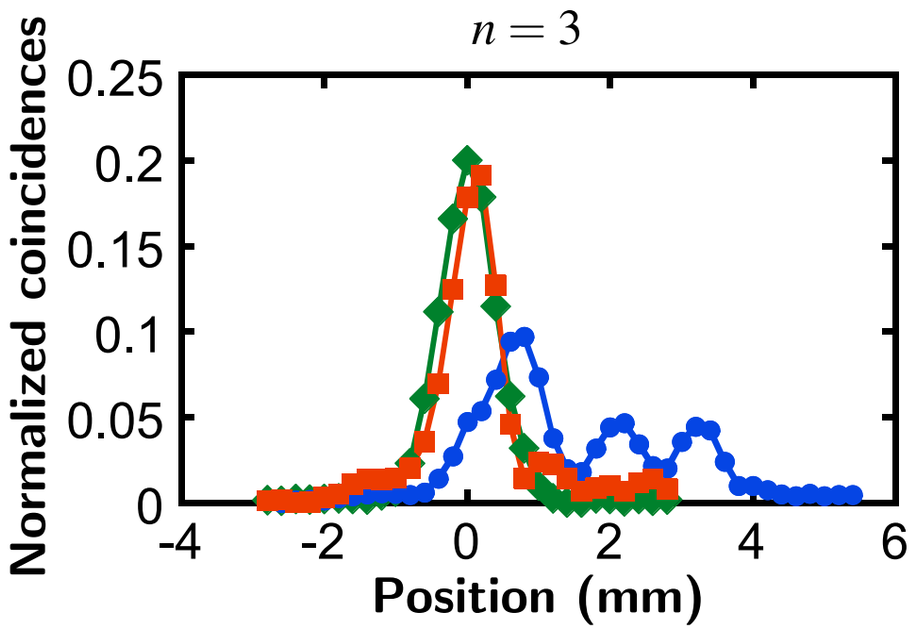
# Experiment

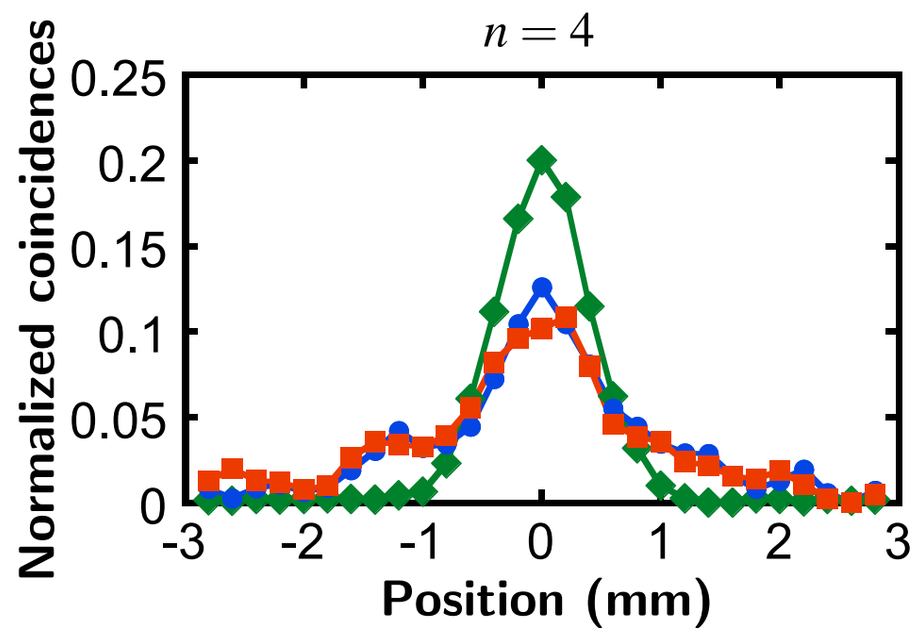


# Results




Opt. Express **23**, 3841 (2015)

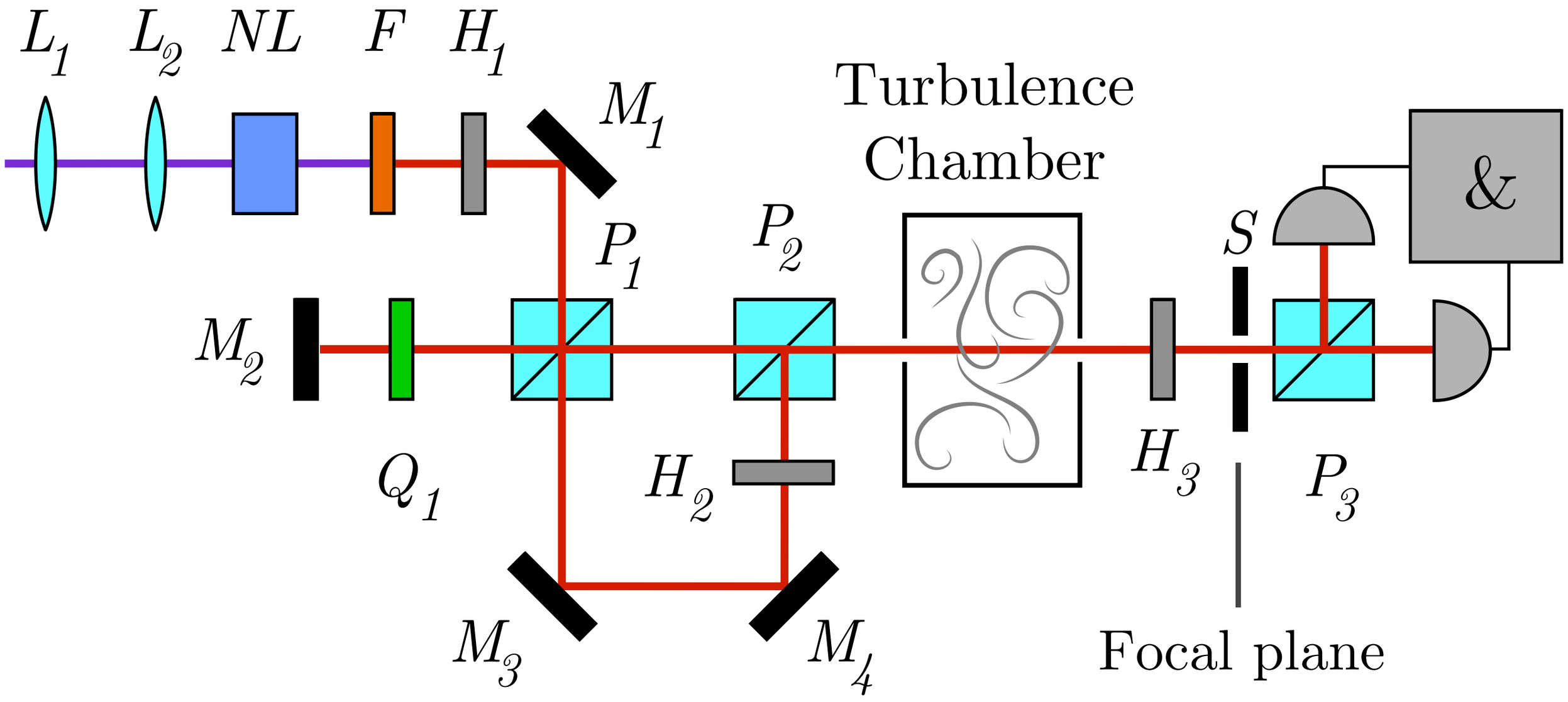
## Conclusion

Optical aberrations can be mitigated with correlation beams.

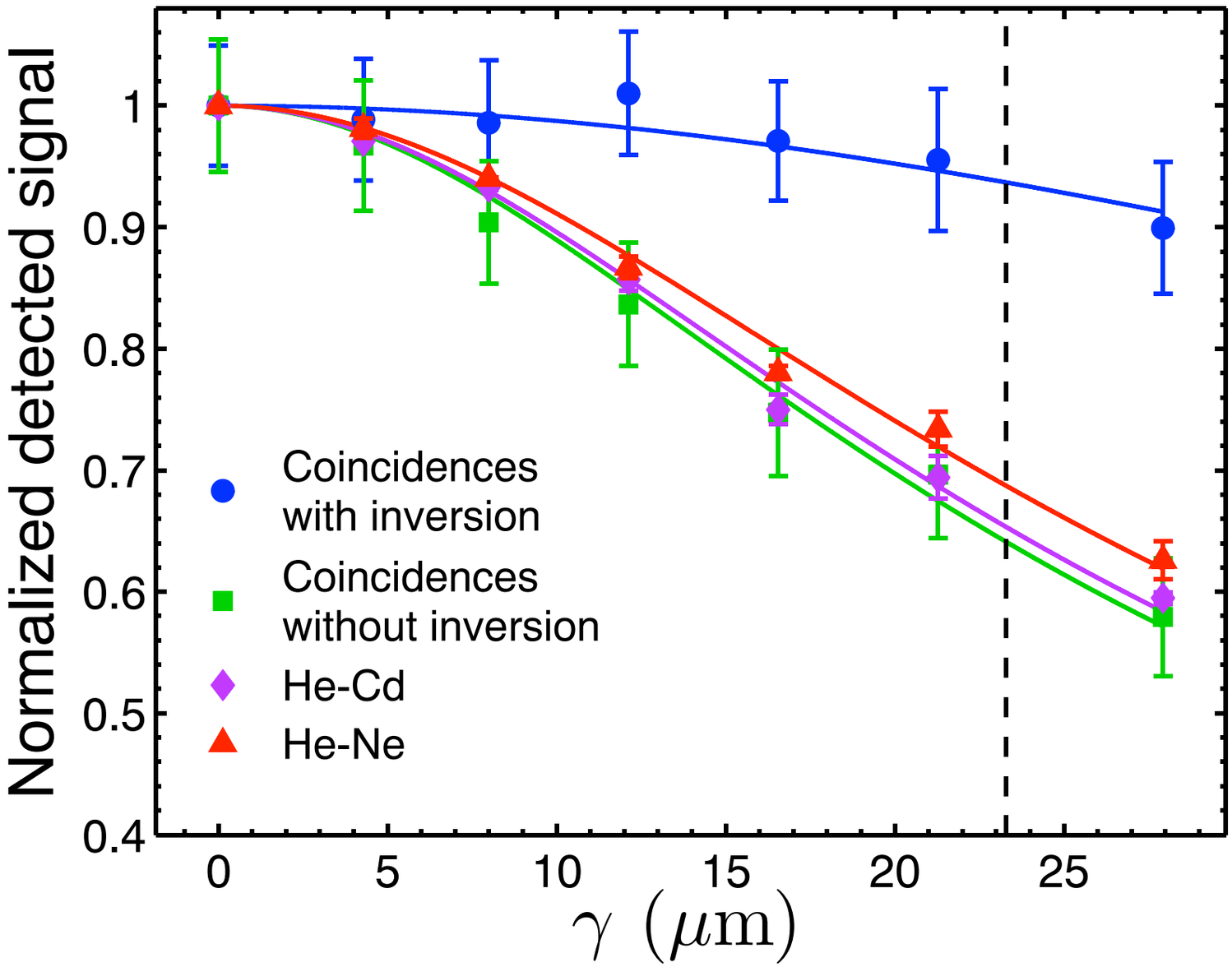
## Perspectives

Is it possible to have the same effect with classical light?

Does it have a practical application?




PRA **88**, 053836 (2013)




PRA **88**, 053836 (2013)