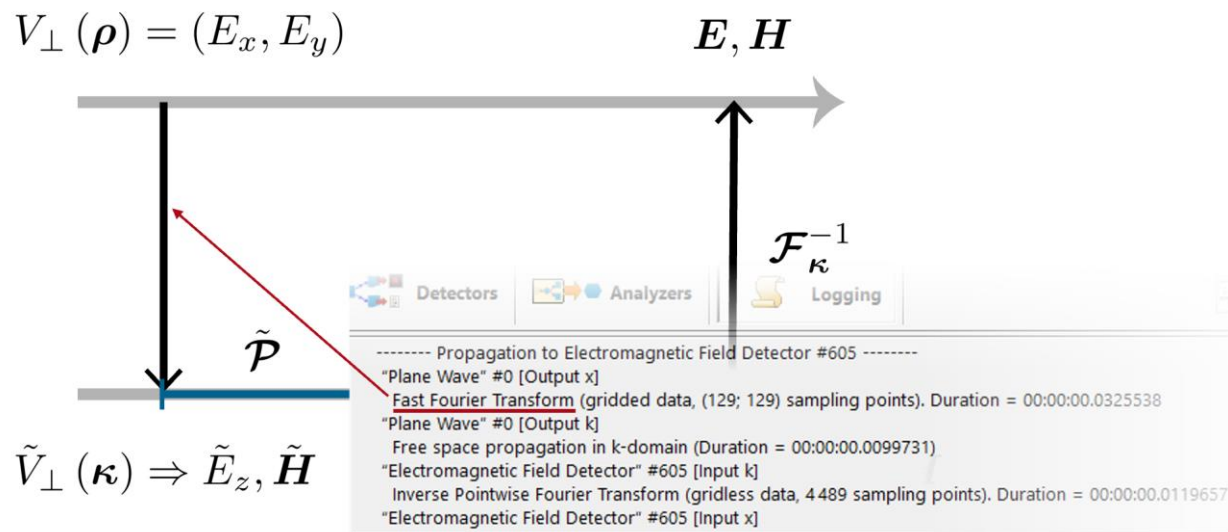


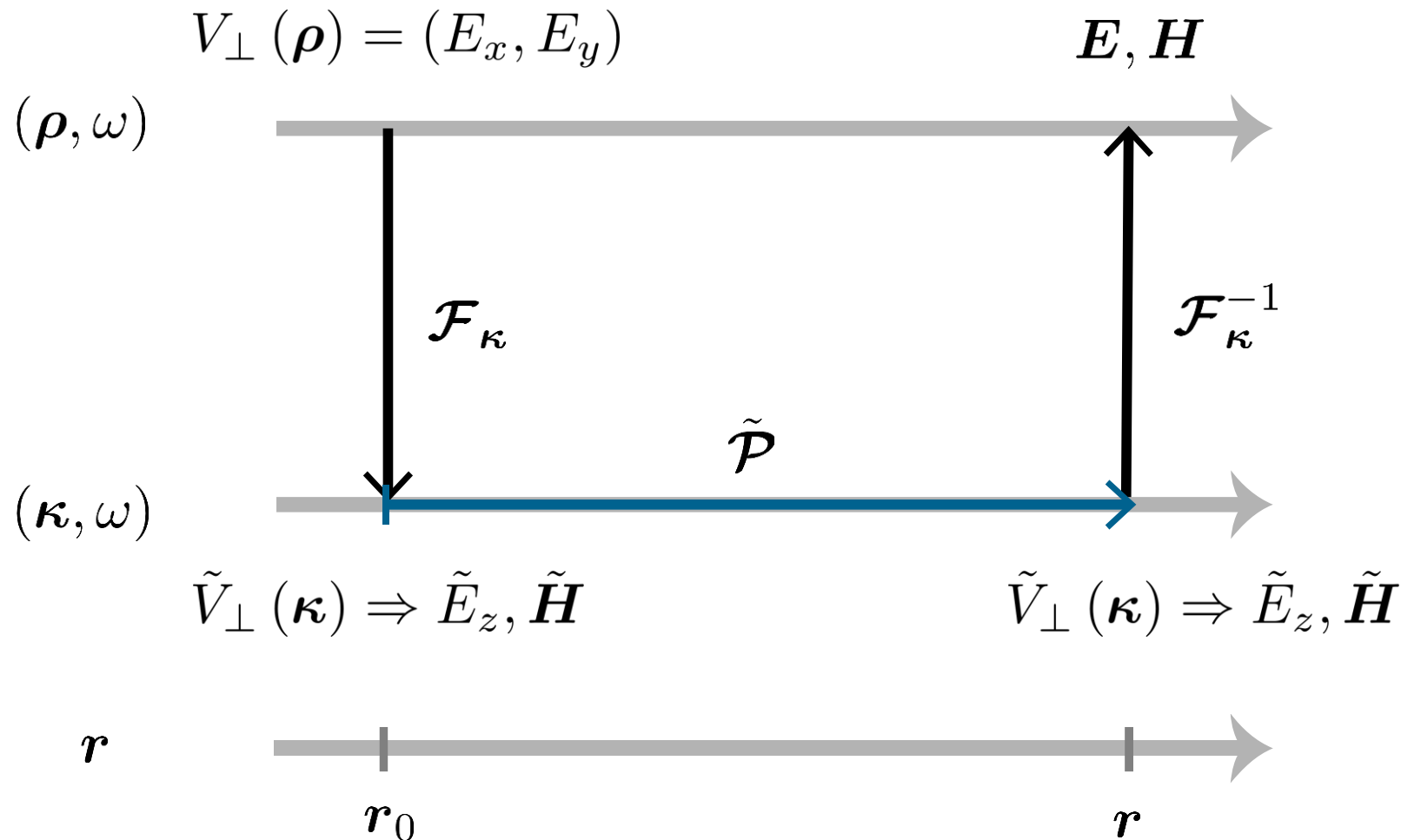
# **Automatic Selection of Fourier Transform Techniques in Free-Space Propagation Operator**

# Abstract



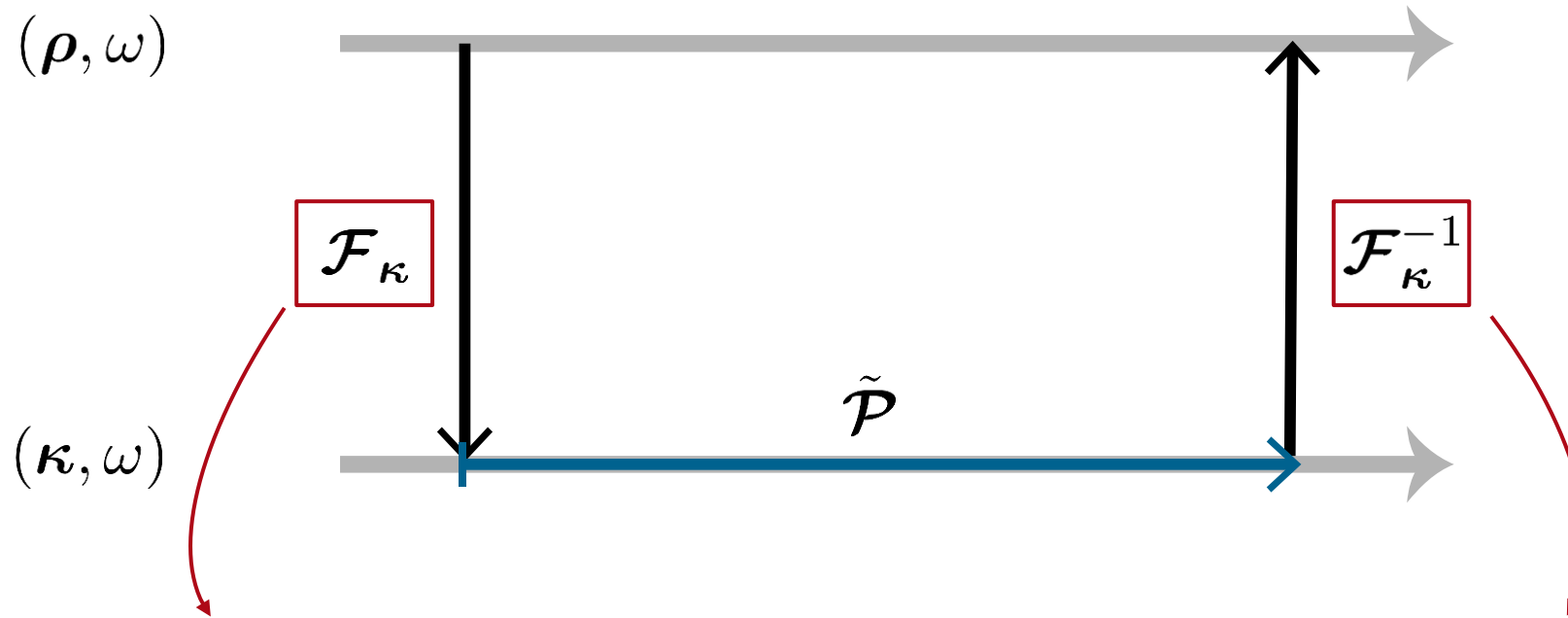
Accurate and efficient simulation of the free-space propagation of electromagnetic fields is essential for physical optics modeling and design. For this purpose, VirtualLab Fusion's modeling engine uses a unified free-space propagation concept based on spatial-frequency domain ( $k$ -domain) analysis. In combination with different Fourier transform techniques, it delivers numerically efficient solutions for different situations of free-space propagations. The selection of an appropriate Fourier transform algorithm is automatically done according to the specific situation.

# Concept of Free-Space Propagation Operator



- Unified propagation operator in the k-domain
- Applicable for arbitrarily oriented planes
- Switching between two domains via Fourier transform
- References
  - F. Wyrowski, "Unification of the geometric and diffractive theories of electromagnetic fields" Proc. DGaO, (2017)
  - Z. Wang *et al.*, "Application of the semi-analytical Fourier transform to electromagnetic modeling," Opt. Express 27, 15335-15350 (2019)

# Available Fourier Transform Techniques in VirtualLab Fusion

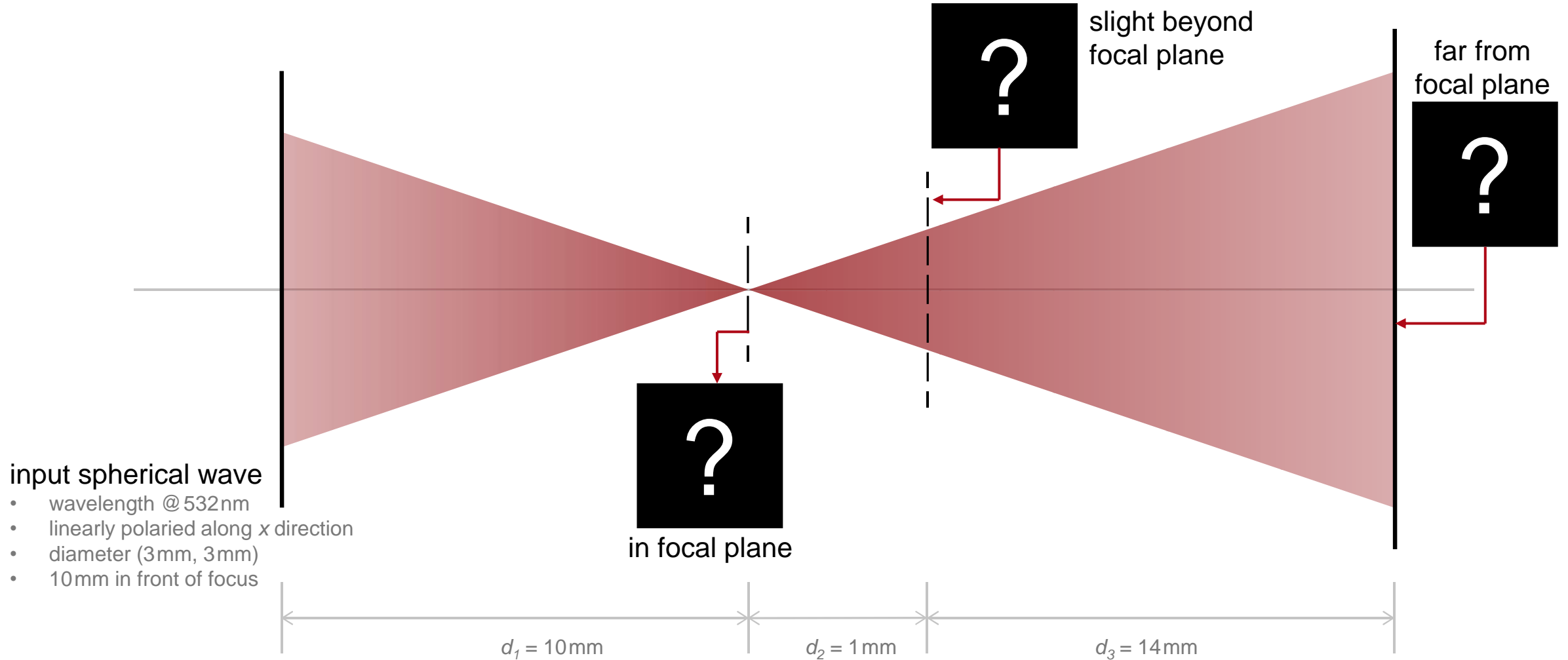


- $\mathcal{F}_\kappa$ : fast Fourier transform (FFT)
- $\mathcal{F}_\kappa^{\text{semi}}$ : semi-analytical Fourier transform (SFT)
- $\mathcal{F}_\kappa^{\text{p}}$ : Pointwise Fourier transform (PFT)

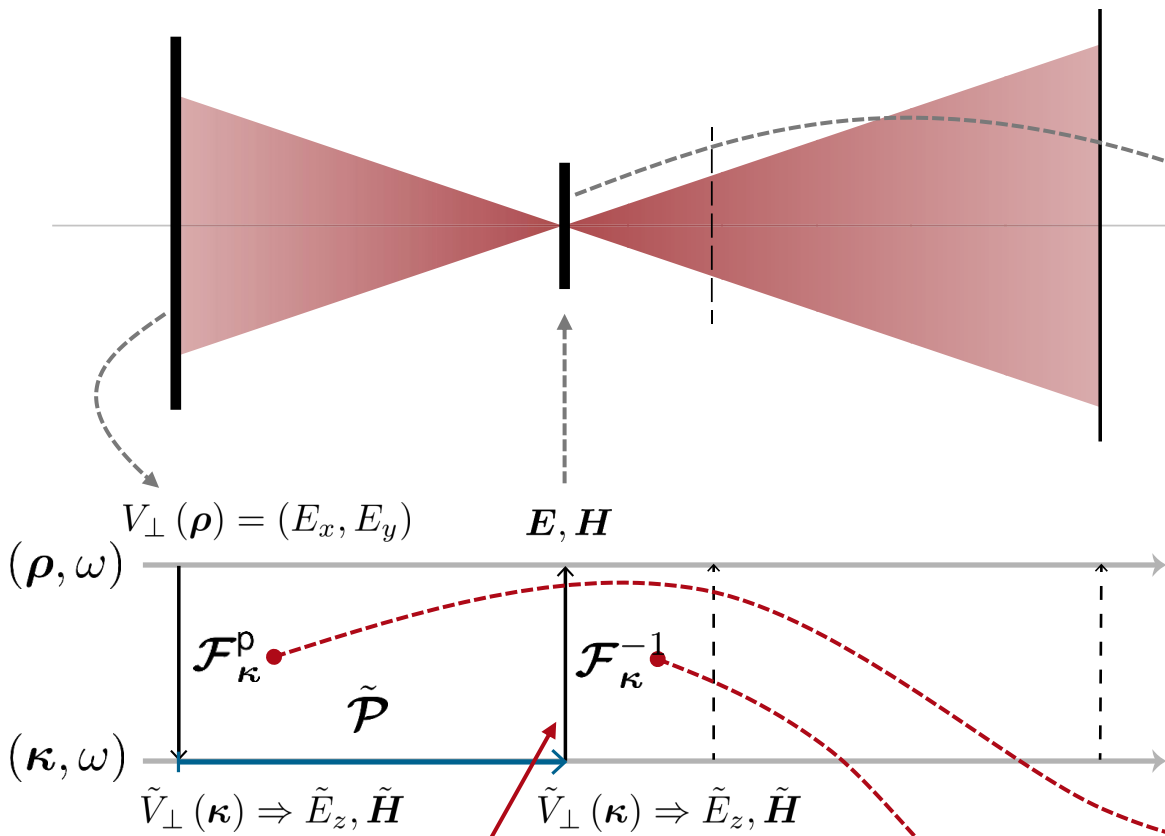
- $\mathcal{F}_\kappa^{-1}$ : inverse fast Fourier transform (IFFT)
- $\mathcal{F}_\kappa^{-1, \text{semi}}$ : inverse semi-analytical Fourier transform (ISFT)
- $\mathcal{F}_\kappa^{-1, \text{p}}$ : inverse Pointwise Fourier transform (IPFT)

## **Example 1: Propagation of a Spherical Wave**

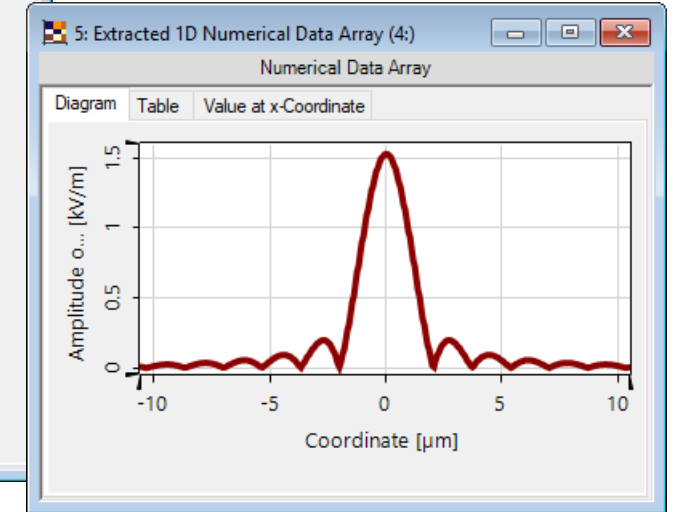
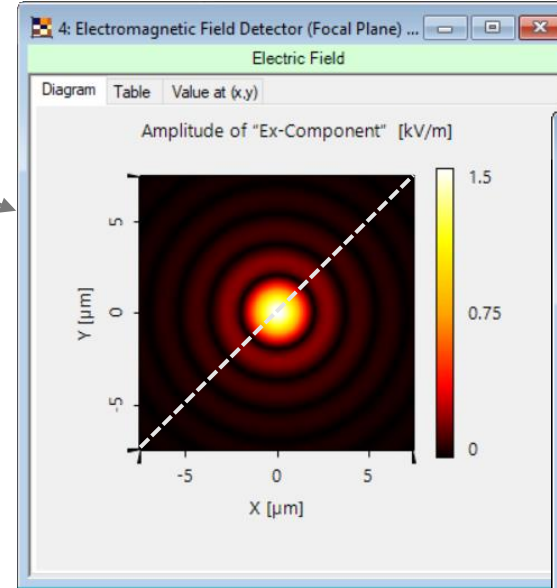
# Modeling Task



# Simulation Result: in Focal Plane



in a focal plane, a rigorous (inverse) Fast Fourier Transform is required



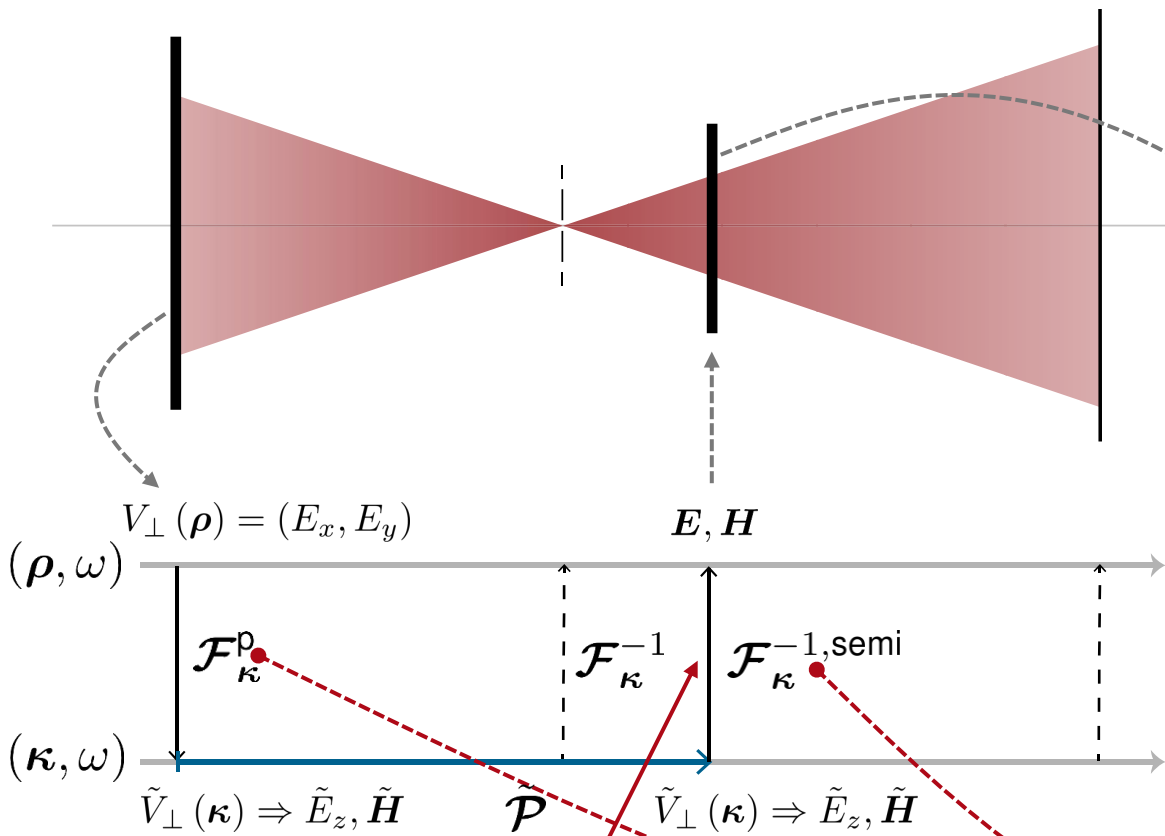
Detectors Analyzers Logging

----- Propagation to Electromagnetic Field Detector #605 -----

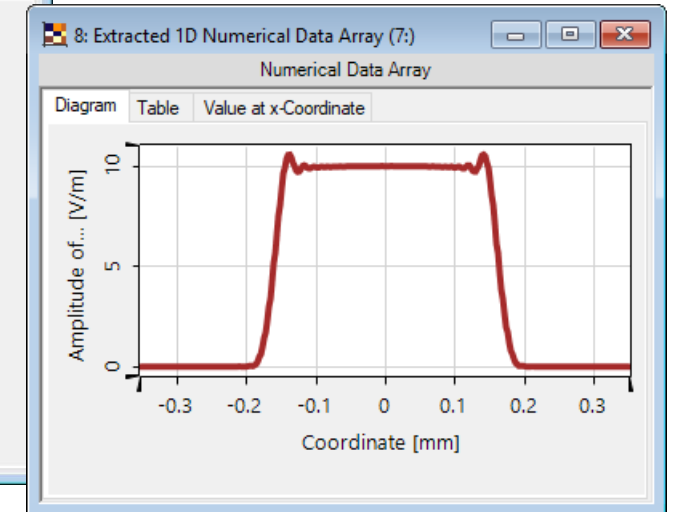
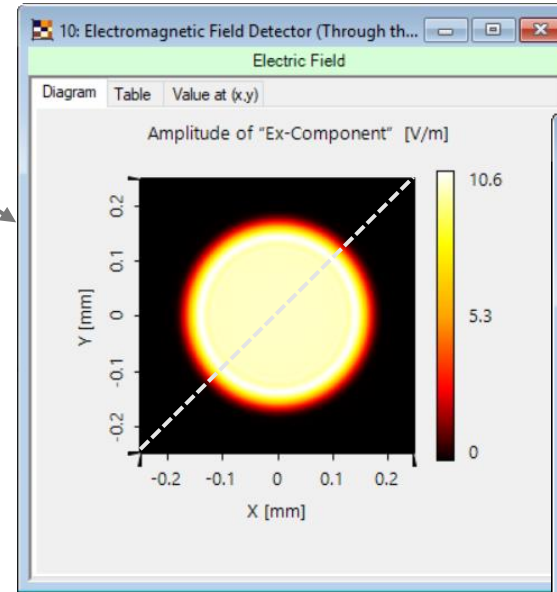
- "Spherical Wave" #0 [Output x]
- Pointwise Fourier Transform (gridless data, 1027 sampling points). Duration = 00:00:00.0029931
- "Spherical Wave" #0 [Output k]
- Free space propagation in k-domain (Duration = 00:00:00.0009963)
- "Electromagnetic Field Detector" #605 [Input k]
- Inverse Fast Fourier Transform (gridded data, (235; 235) sampling points). Duration =

automatic selection of Fourier transform

# Simulation Result: Slightly beyond Focal Plane



close to a focal plane, the proper Fourier Transform depends on the NA of the field, here: rigorous inverse SFT is chosen



Detectors Analyzers Logging

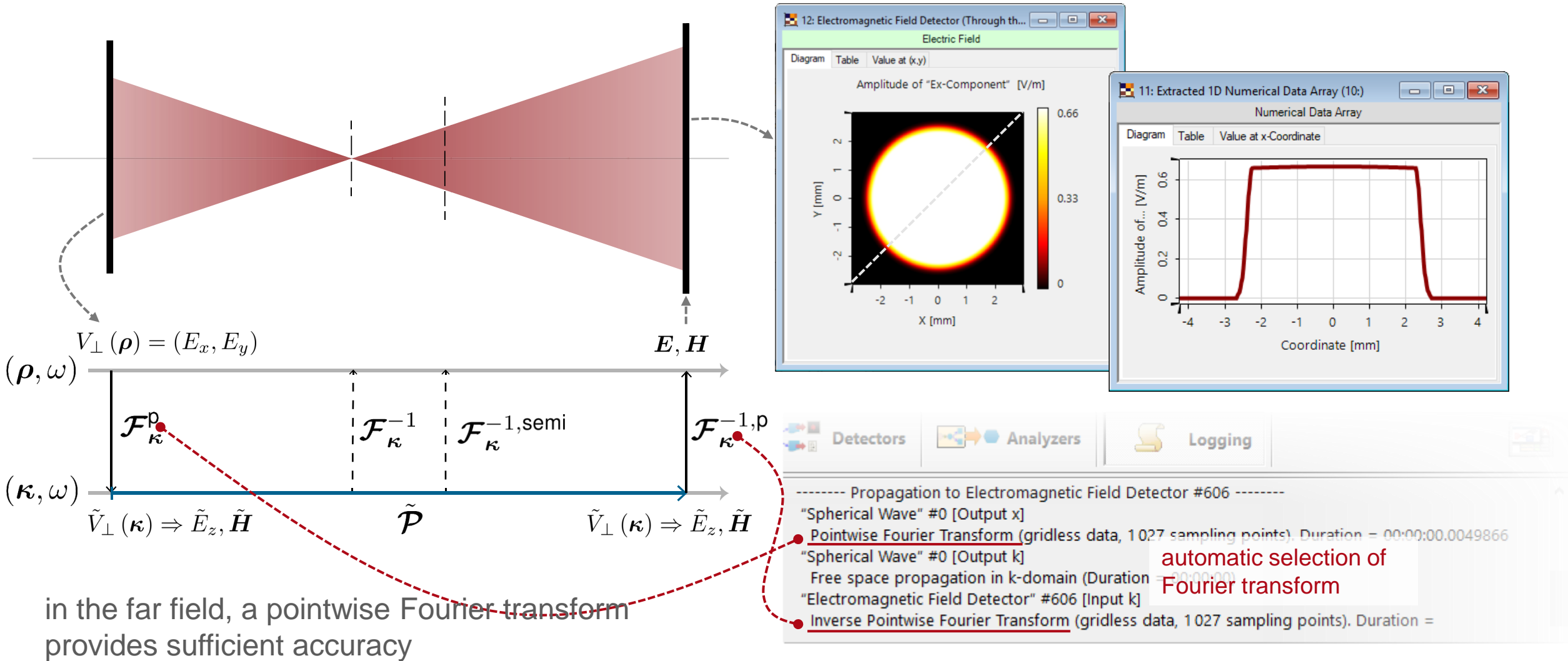
----- Propagation to Electromagnetic Field Detector #602 -----

- "Spherical Wave" #0 [Output x]
- Pointwise Fourier Transform (gridless data, 1027 sampling points). Duration = 00:00:00.0029386
- "Spherical Wave" #0 [Output k]
- Free space propagation in k-domain (Duration = 00:00:00)
- "Electromagnetic Field Detector" #602 [Input k]
- Inverse Semi-Analytical Fourier Transform (gridded data, (129; 129) sampling points). Duration =

automatic selection of Fourier transform



# Simulation Result: Far from Focal Plane

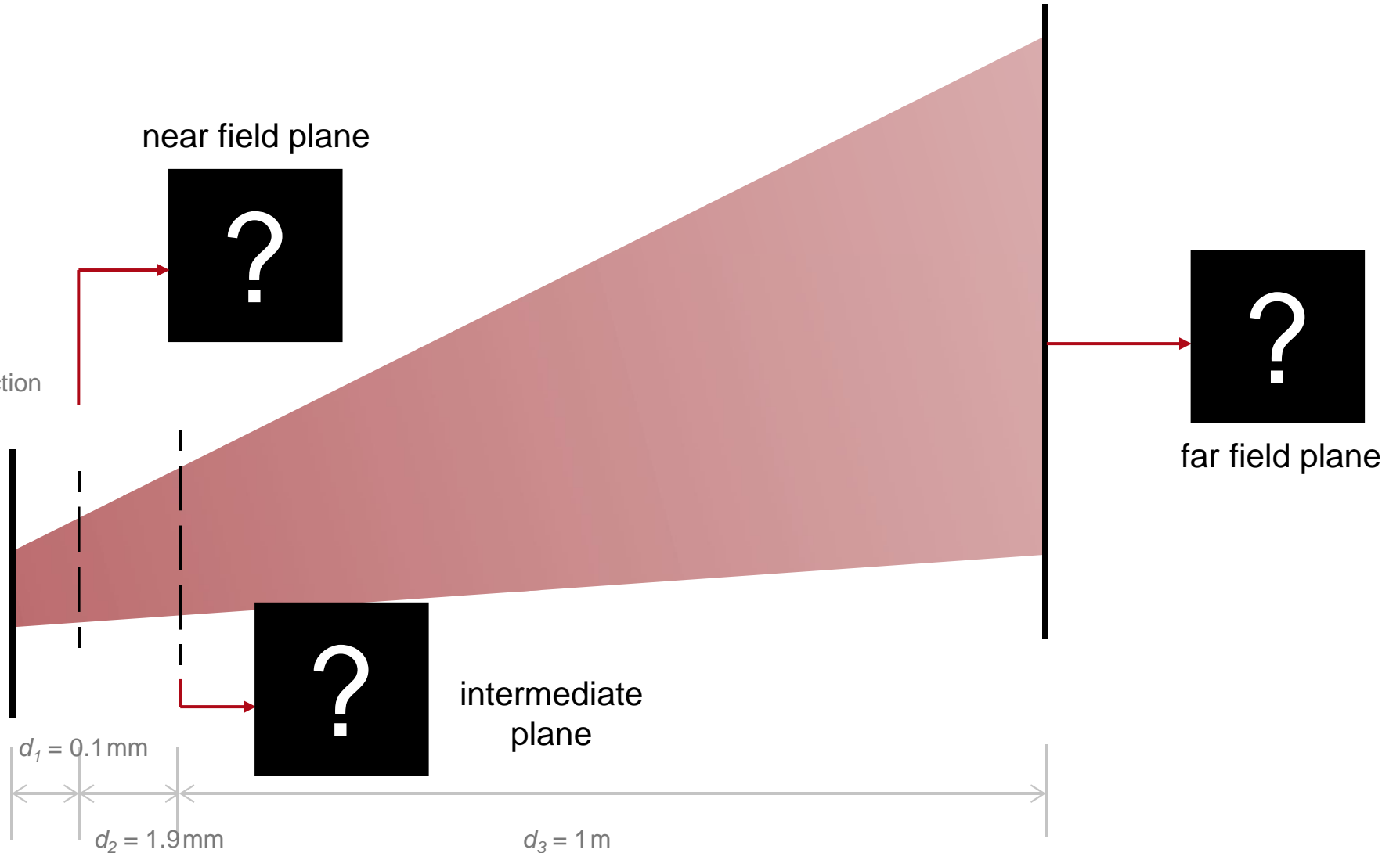


## **Example 2: Propagation of a Truncated Plane Wave**

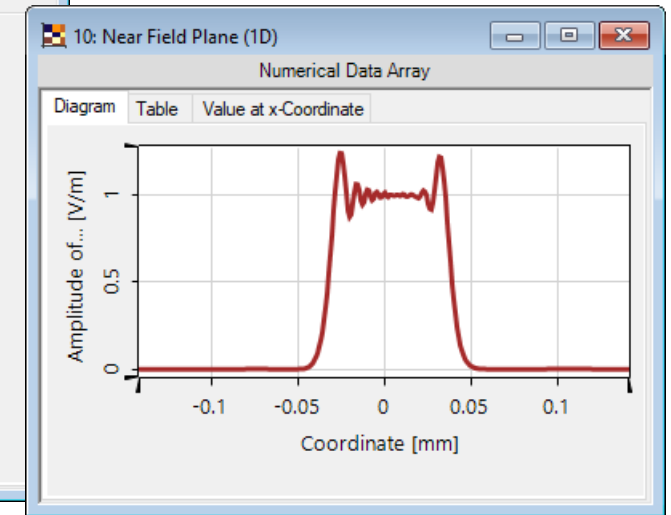
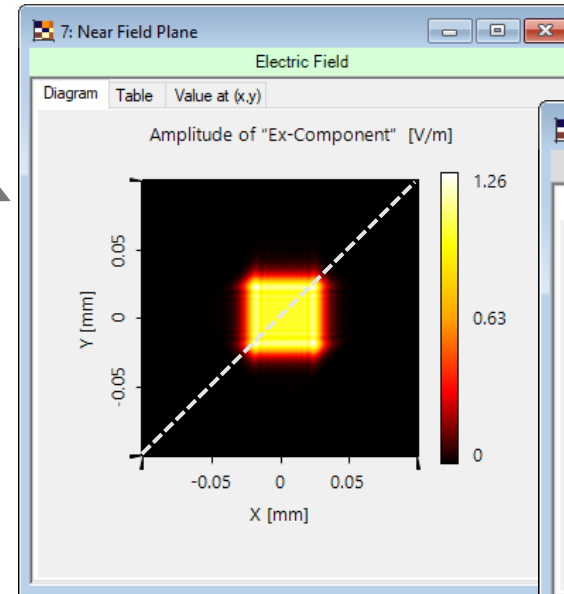
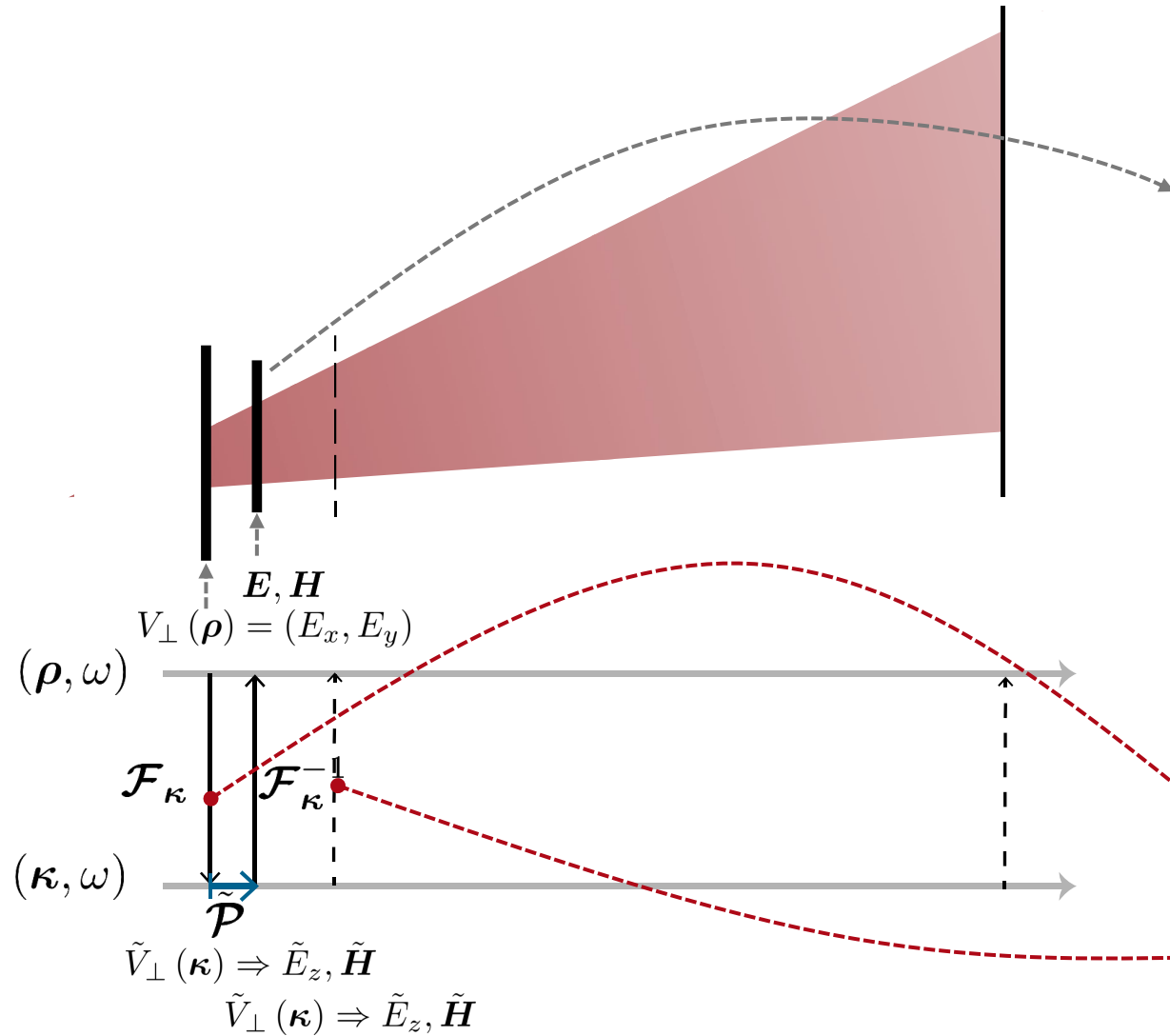
# Modeling Task

## truncated plane wave

- wavelength @ 532nm
- linearly polarized along x direction
- shape: rectangular
- diameter: (50  $\mu\text{m}$ , 50  $\mu\text{m}$ )
- inclination (10°, 20°)



# Simulation Result: Near Field Plane



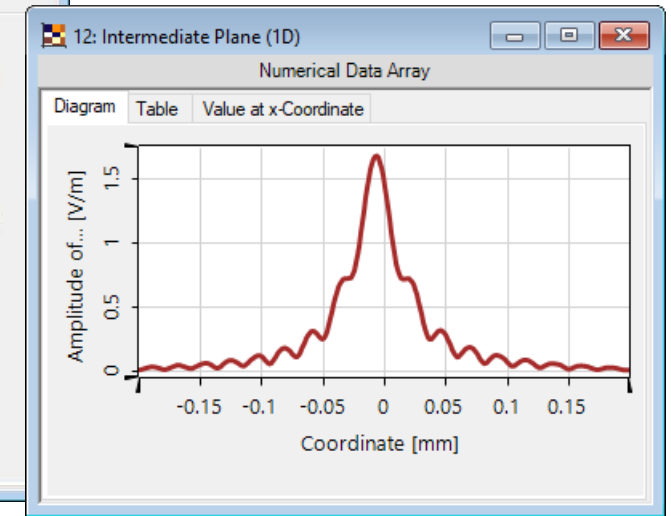
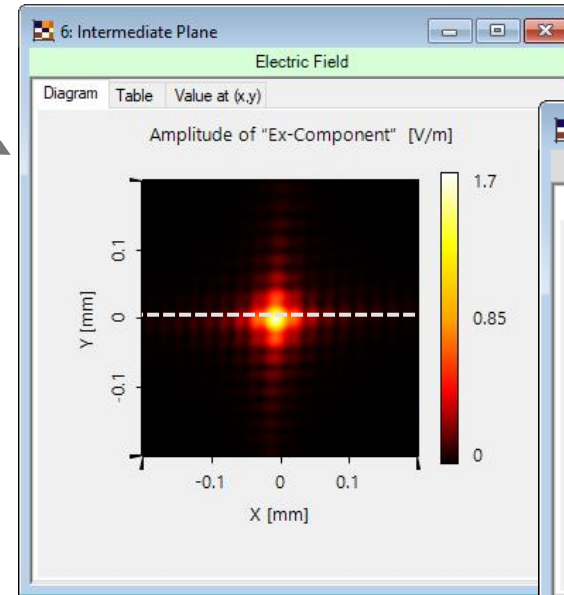
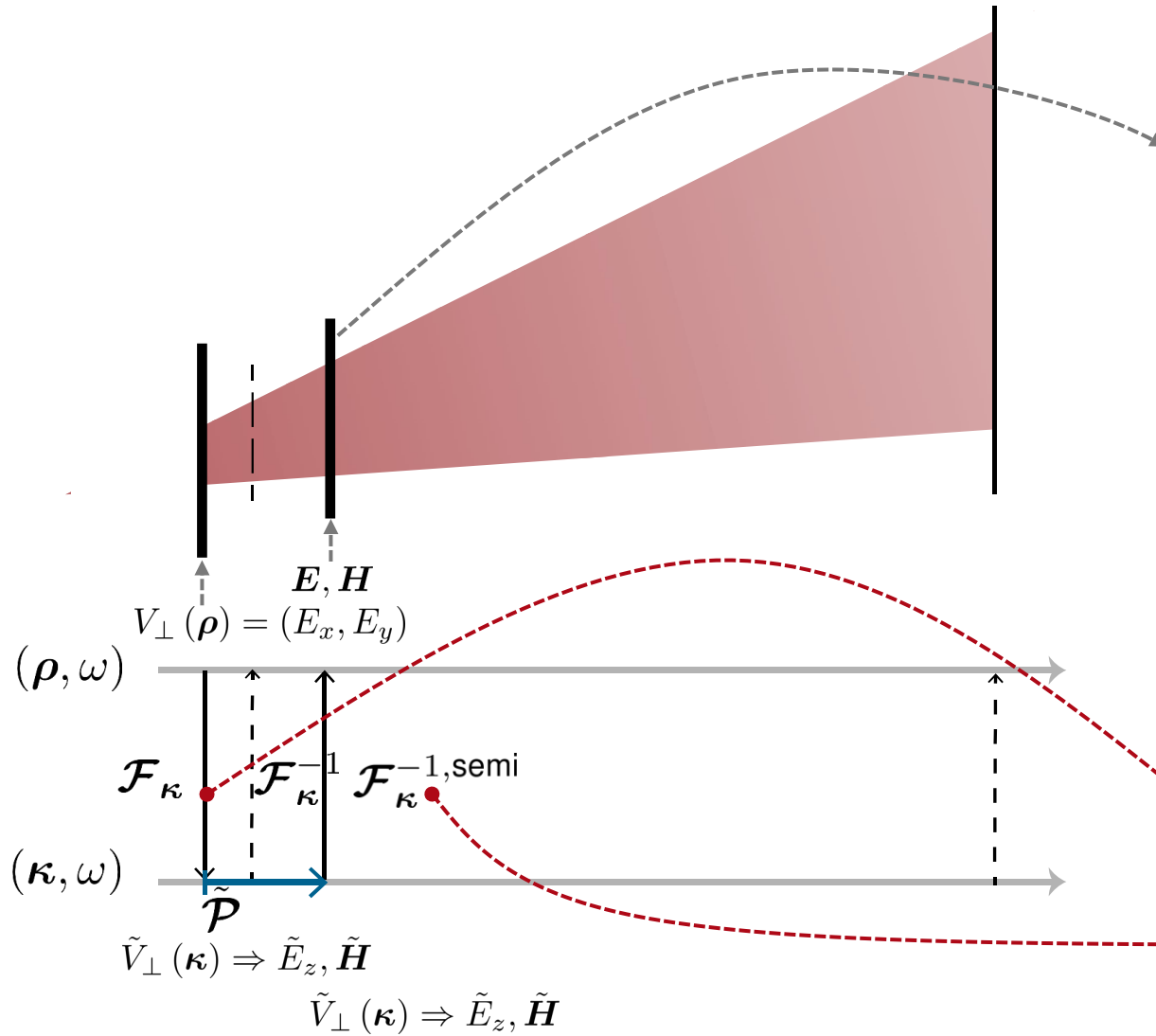
Detectors Analyzers Logging

----- Propagation to Electromagnetic Field Detector #607 -----

- "Plane Wave" #0 [Output x]
- Fast Fourier Transform (gridded data, (129; 129) sampling points). Duration = 00:00:00.0093214
- "Plane Wave" #0 [Output k]
- Free space propagation in k-domain (Duration = 00:00:00.0019845)
- "Electromagnetic Field Detector" #607 [Input k]
- Inverse Fast Fourier Transform (gridded data, (719; 727) sampling points). Duration = 00:00:00.0734413
- "Electromagnetic Field Detector" #607 [Input x]

automatic selection of Fourier transform

# Simulation Result: Intermediate Plane



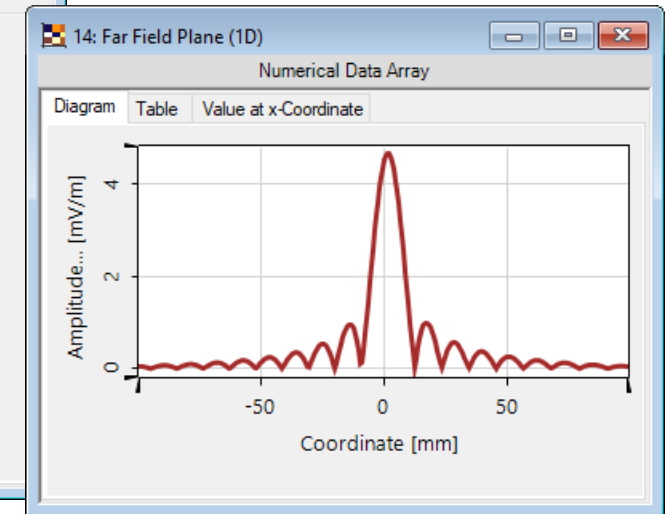
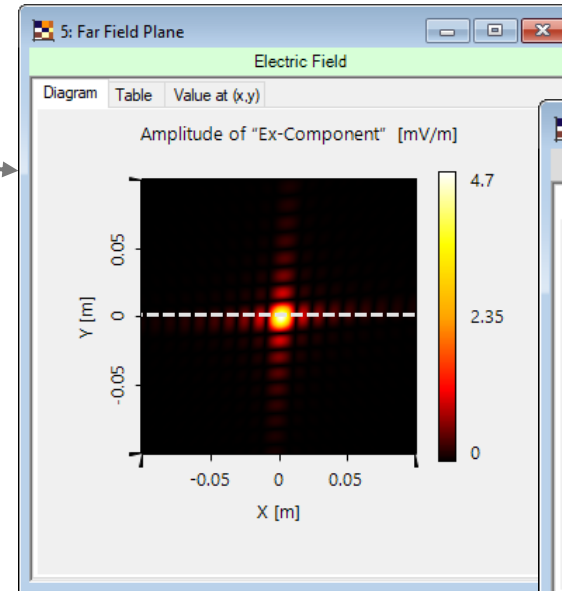
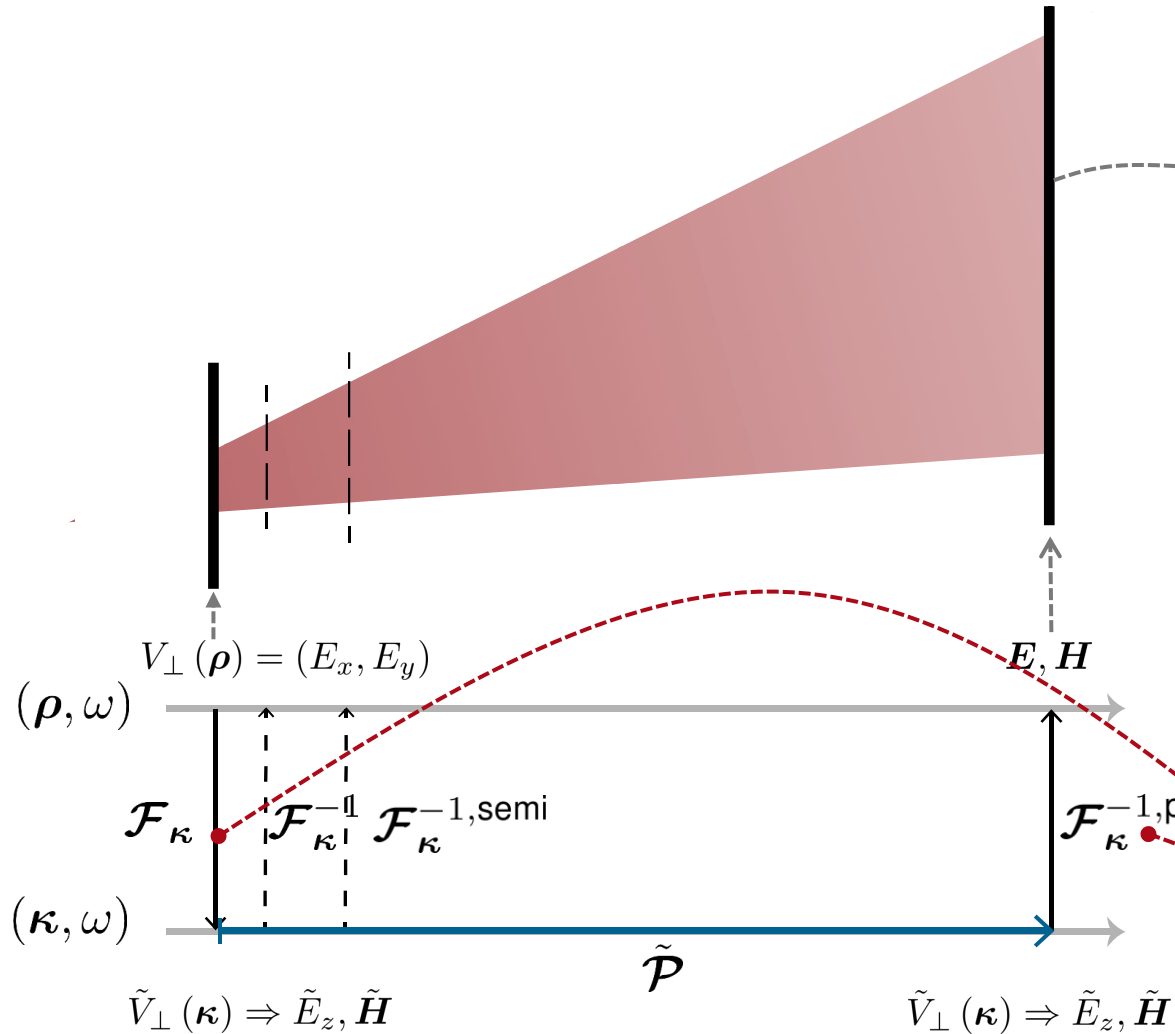
Detectors Analyzers Logging

----- Propagation to Electromagnetic Field Detector #606 -----

- "Plane Wave" #0 [Output x]
- Fast Fourier Transform (gridded data, (129; 129) sampling points). Duration = 00:00:00.0064972
- "Plane Wave" #0 [Output k]
- Free space propagation in k-domain (Duration = 00:00:00.0029555)
- "Electromagnetic Field Detector" #606 [Input k]
- Inverse Semi-Analytical Fourier Transform (gridded data, (1621; 1521) sampling points). Duration =

automatic selection of  
Fourier transform

# Simulation Result: Far Field Plane



Detectors Analyzers Logging

----- Propagation to Electromagnetic Field Detector #605 -----

- "Plane Wave" #0 [Output x]
- Fast Fourier Transform** (gridded data, (129; 129) sampling points). Duration = 00:00:00.0325538
- "Plane Wave" #0 [Output k]
- Free space propagation in k-domain (Duration = 00:00:00.0099731)
- "Electromagnetic Field Detector" #605 [Input k]
- Inverse Pointwise Fourier Transform** (gridless data, 4 489 sampling points). Duration = 00:00:00.0119657
- "Electromagnetic Field Detector" #605 [Input x]

**automatic selection of Fourier transform**

# Document Information

---

title	Automatic Selection of Fourier Transform Techniques in Free Space Propagation Operator
document code	MISC.0001
document version	1.1
software edition	VirtualLab Fusion Basic
software version	2021.1 (Build 1.180)
category	Feature Use Case

---