Practical guidance / Edition 2

Solver and Mesh Selection

Beam wakes: initial fields, time stepping and resolution

Recommended starting point

Use the **explicit dispersion-free** method for both stationary and moving calculations. Select it before using the step-selection buttons in **Mesh Setup**, then refine the mesh to resolve the bunch and geometry.

1. Initial field in waveguide mode

With an open longitudinal entrance, `waveguide` starts with the bunch field in the entrance cross-section, before the structure, as in a PEC waveguide. For a beam travelling at the speed of light ($\beta = 1$), this initial field has $E_x = 0$. A longitudinal PEC entrance instead starts with zero field.

Finite-conductivity walls then respond to the bunch field. Their material history starts at zero; the initial field does not include a pre-existing conductive-wall response. A longitudinal field and a startup transient can therefore appear even in a geometrically closed entrance pipe. In that region, transverse PML is not the cause of this response.

2. Explicit dispersion-free: choose the mesh first

Write h_x for the longitudinal step and h_y, h_z for the transverse steps. With equal transverse steps, use

$$h_y = h_z = h_\perp, \qquad h_x = \frac{h_\perp}{1.5}.$$

For unequal transverse steps, use the transverse stability criterion with the implemented safety factor:

$$\boxed{h_x \le \frac{1}{1.05\sqrt{h_y^{-2} + h_z^{-2}}}.}$$

The dispersion-free time step is $c\,\Delta t = h_x$. Use the automatic time-step setting (`scaled_time_step: auto`); reducing the time step independently is not the intended way to satisfy this mesh criterion.

In Studio, select **Dispersion-free** and **Explicit**, then use:

Mesh Setup button	Result
Recommended Steps from σ	$h_x = \sigma/5$; $h_y = h_z = 1.5h_x$.
Y/Z from X	Keeps h_x; sets $h_y = h_z = 1.5h_x$.
X/Z from Y	Keeps h_y; sets $h_z = h_y$ and $h_x = h_y/1.5$.

Here σ is the RMS bunch length. These buttons provide a starting mesh; small apertures, material interfaces and other geometric features may require finer steps. Stability alone does not establish wake accuracy.

3. Implicit dispersion-free: a fallback for instability

Use implicit dispersion-free when explicit stepping encounters stability problems. First check that the explicit mesh satisfies the criterion on page 1. Implicit stepping removes that transverse step restriction, while retaining $c\,\Delta t = h_x$.

Allow roughly twice the calculation time compared with explicit stepping as a practical planning estimate. The actual ratio depends on the case, mesh and execution settings.

4. FDTD: primarily for long-range wakes

Use stationary FDTD primarily to calculate long-range wake tails. Longitudinal numerical dispersion makes the wake near the bunch less accurate and can distort its shape and amplitude. Dispersion-free stepping is the preferred choice there.

If FDTD is nevertheless used near the bunch, use **more than ten mesh intervals per RMS bunch length**:

$$h_x < \frac{\sigma}{10}.$$

This is a resolution recommendation, not a universal accuracy guarantee. Compare the wake after further refinement. FDTD uses its own three-dimensional CFL time step; the dispersion-free relation $c\,\Delta t = h_x$ does not apply to FDTD.

5. Optional FDTD beam self-wake correction

For a stationary FDTD wake near the bunch, Studio offers **Enable beam self-wake correction**. Its case-file setting is

`field_solver.stationary.beam_self_wake_correction`.

The option subtracts an auxiliary reference-field residual. Restrict its recommended use to a **PEC background**; other backgrounds require independent qualification. This is an applicability recommendation, not an input restriction enforced by the software.

The correction is off by default and is generally not recommended as the route to an accurate near-bunch wake. Prefer explicit dispersion-free stepping and a mesh-convergence check. The option is inactive for dispersion-free methods and is separate from indirect wake integration.

Before starting a calculation

1. Select the method and stationary or moving execution.
2. Set the bunch length and use the matching **Mesh Setup** buttons.
3. Check the mesh criterion and resolve important geometric features.
4. Compare the wake on a finer mesh before relying on its quantitative values.

Further reading: the *Studio User Guide* for controls and the *Physics Guide* for wake definitions and interpretation. Current documentation: `https://emuzag.de/documentation.html`.