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U.S. DEPARTMENT OF ENERGY

A cross-check of wakefield simulations by GdfidL and ECHO3D codes

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The research described herein is Fundamental Research as described in National Security Decision Directive 189, dated September 21, 1985, and the USD (AT&L) memoranda on Fundamental Research, dated May 24, 2010, and on Contracted Fundamental Research, dated June 26, 2008.

Outline

- Motivation
- Overview of wakefields
- Simulations Tools: GdfidL and ECHO3D
- Cross-check studies for
  - NSLS-II flange absorbers
  - NSLS-II RF bellows
  - Low-gap In-vacuum undulator

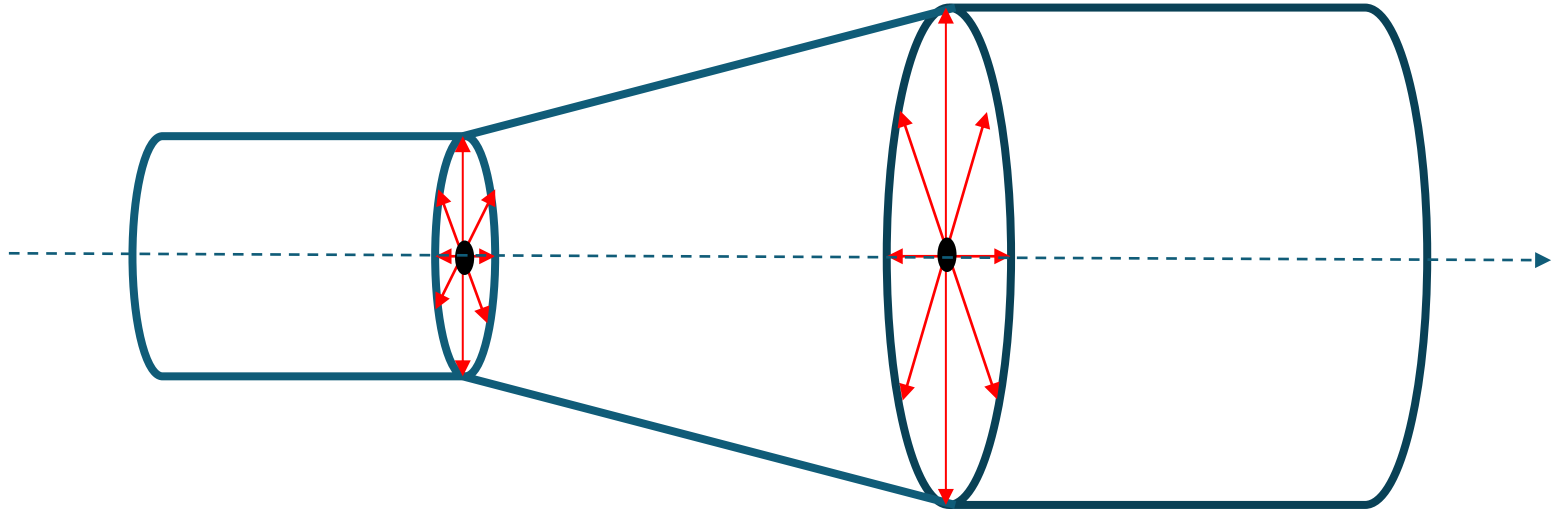
Motivation

- **Performance of low-emittance light sources is limited by**
  - The short-range wakefields or impedance, especially beam-induced heating of the vacuum chamber components

- **Presented study discuss**
  - Cross-checking of two electromagnetic solvers, GdfidL and ECHO3D
  - Convergence studies of wake potential and geometric impedance in the NSLS-II flange absorber, bellows and IVU

Basic Definitions

- **Wake function:** The **wake function** is the **electromagnetic response** of a beam pipe/chamber/object to a charge pulse.
- The response depends on the boundary conditions and can occur e.g., due to **finite conductivity** (**resistive wall**) or sudden **changes in the geometry** of the vacuum chamber cross section.



Basic Definitions

- **Wakefield codes:** direct solution of Maxwell's equations in the time-domain

$$\frac{\partial B}{\partial t} = -\nabla \times E,$$

$$\frac{\partial \varepsilon E}{\partial t} = \nabla \times \frac{1}{\mu} B \; - j,$$

rigid, ultra-relativistic bunch

$$j = qc\lambda_z \rho(x, y, z - ct)$$

- **Post processing**: wake potentials and coupling impedances by simulated field data

$$W_z(r_\perp, s) = -\frac{1}{q} \int_{-\infty}^{\infty} dz\, E_z\left(r_\perp, z, t = \frac{z+s}{c}\right)$$

$$Z_z(r_\perp, \omega) = \frac{1}{c\lambda_z(\omega)} \int_{-\infty}^{\infty} dz W_z(r_\perp, s)\, e^{-\frac{i\omega s}{c}}$$

$$\frac{\partial}{\partial s} W_\perp(r_\perp, s) = -\nabla_\perp W_s(r_\perp, s)$$

Panofsky-Wenzel theorem

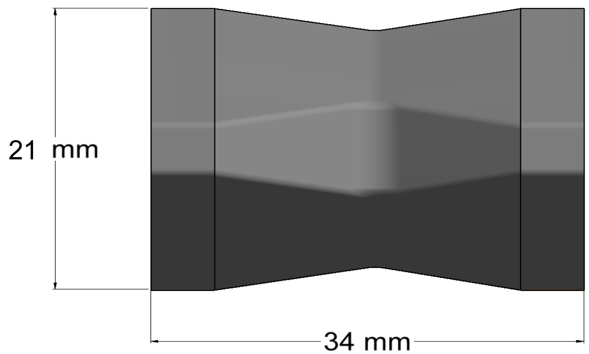
Simulation Tools

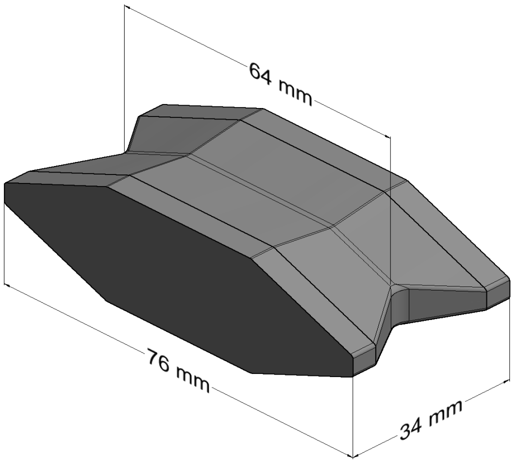
Parameter	GdfidL	ECHO3D
Input geometry	STL file, Text description of the device	STL file
Numerical method	Yee's finite-difference time-domain method, window-wake technique	"Transversal-electric/transversal-magnetic" splitting of the field components in time
Mesh size	$\Delta \leq \sigma_s/15$ Equal mesh in longitudinal and transverse plan	$\Delta \leq \sigma_s/5$ Good accuracy is achievable with coarse transverse mesh
Parallelization	Parallelized for multi-core clusters	Thread parallelized with OPENMI

NSLS-II Flange Absorbers

NSLS-II flange geometries configs to protect the vacuum components from synchrotron radiation:

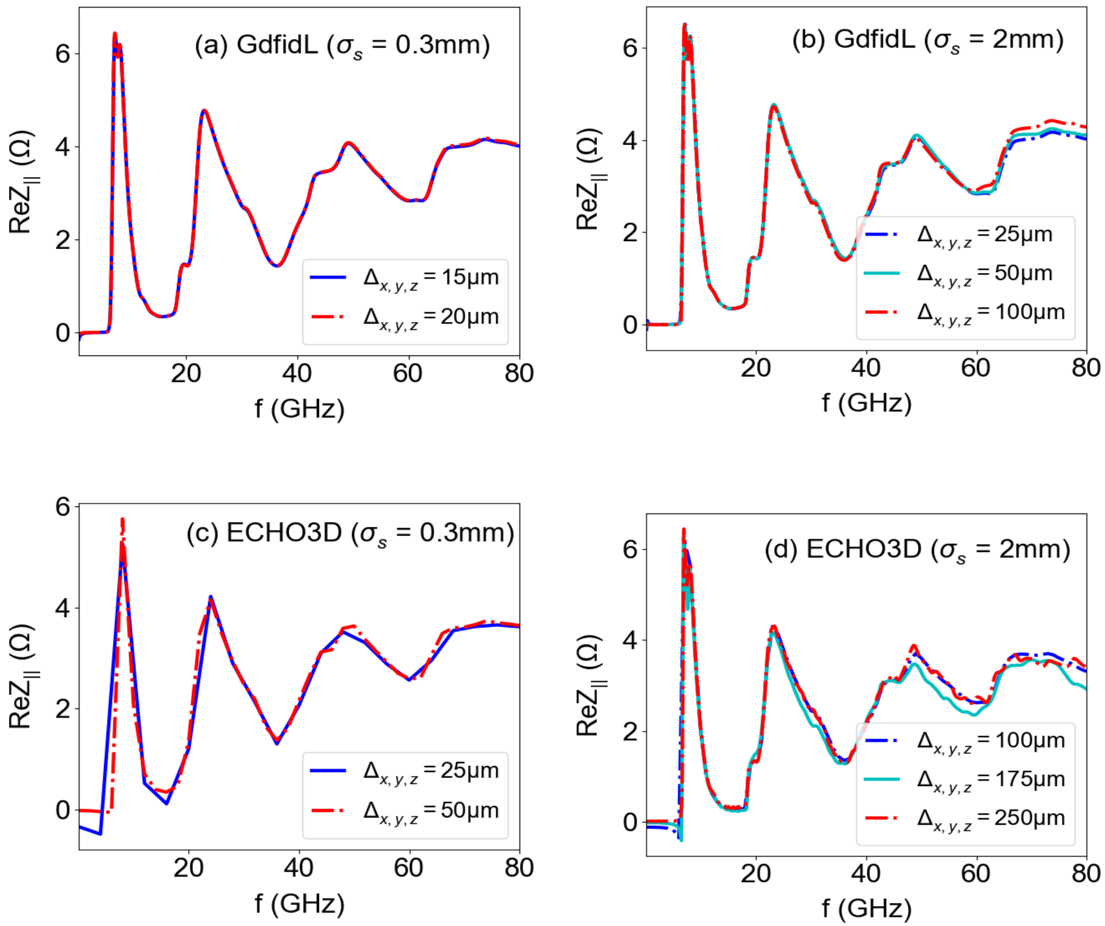
1. ABS3001–21mm × 64mm – 67
2. ABS3018 – 21mm × 64mm – 39
3. ABS3022 – 21mm × 44mm – 1
4. ABS3024 – 21mm × 50mm – 1
5. ABS3026 – 21mm × 54mm – 1
6. ABS3028 – 21mm × 58mm – 1
7. ABS3030 – 21mm × 60mm – 2
8. ABS3040 – 25mm × 50mm –1
9. DG-CHM-1029 – 25mm × 40mm – 1





The full height of the vertical aperture: 21mm,
The horizontal full aperture: 44 mm to 64 mm
The standard horizontal aperture: 76 mm

Longitudinal impedance Convergence Studies – NSLS-II Flange Absorbers



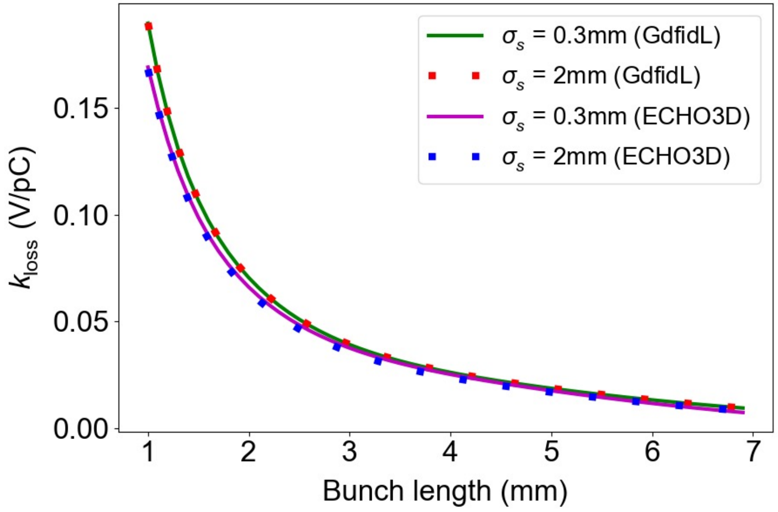
- Accurate results for a bunch length of 0.3mm requires a GdfidL mesh spacing $\Delta \leq \sigma_s/15$
- ECHO3D gives accurate results with coarse mesh $\Delta \leq \sigma_s/5$
- ECHO3D works well even if we use only 5 mesh steps on bunch sigma longitudinally and ten times more coarse mesh transversely

Comparison of Loss Factor

Loss factor: estimates the beam-induced heating

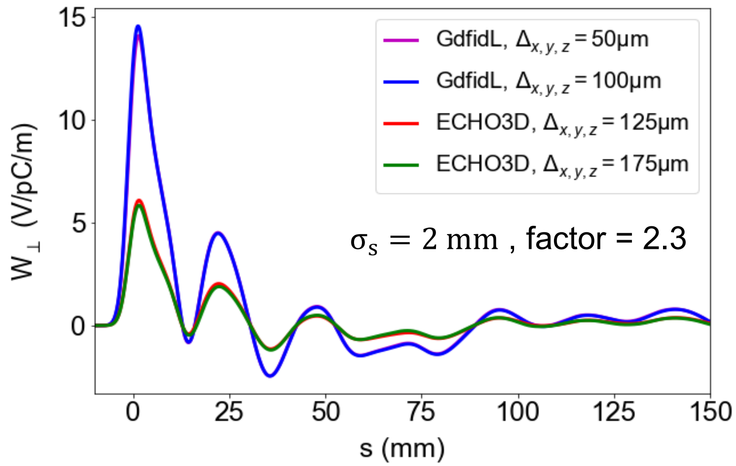
$$k_{\mathrm{loss}} = \frac{1}{\pi}\int_0^\infty d\omega\ \mathrm{ReZ}_\parallel(\omega) e^{-\omega^2\sigma_b^2/c^2}$$

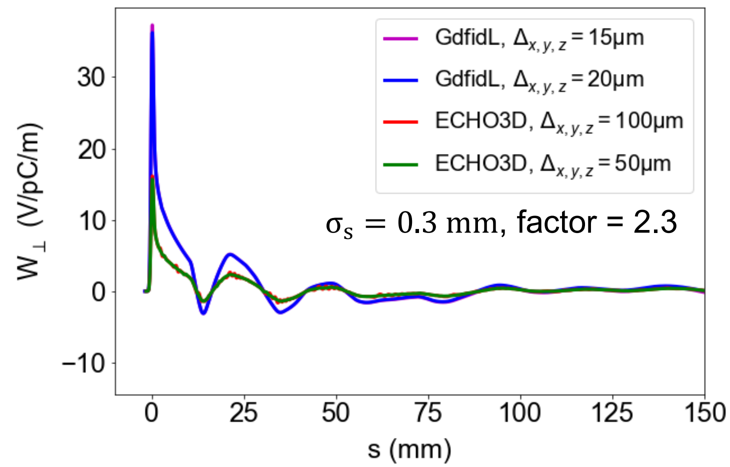
$\mathrm{Z}_\parallel$: longitudinal impedance, σ_b: bunch length

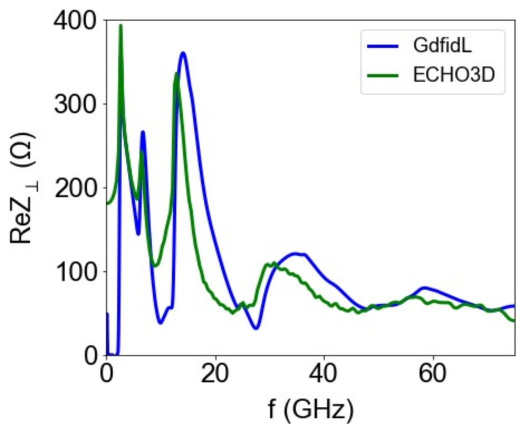


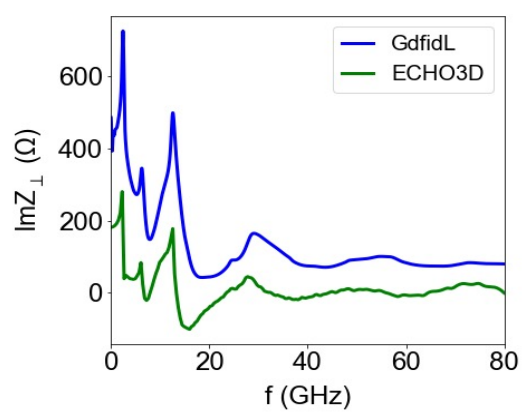
- As the nominal bunch length of NSLS-II is approximately 3mm, the heat load calculations can be performed with a long bunch rather than a point-like bunch of 0.3mm length

Transverse Wakepotential and Impedance Studies – NSLS-II Flange Absorbers









There is a discrepancy of approx. factor 2 in the transverse wakefields.

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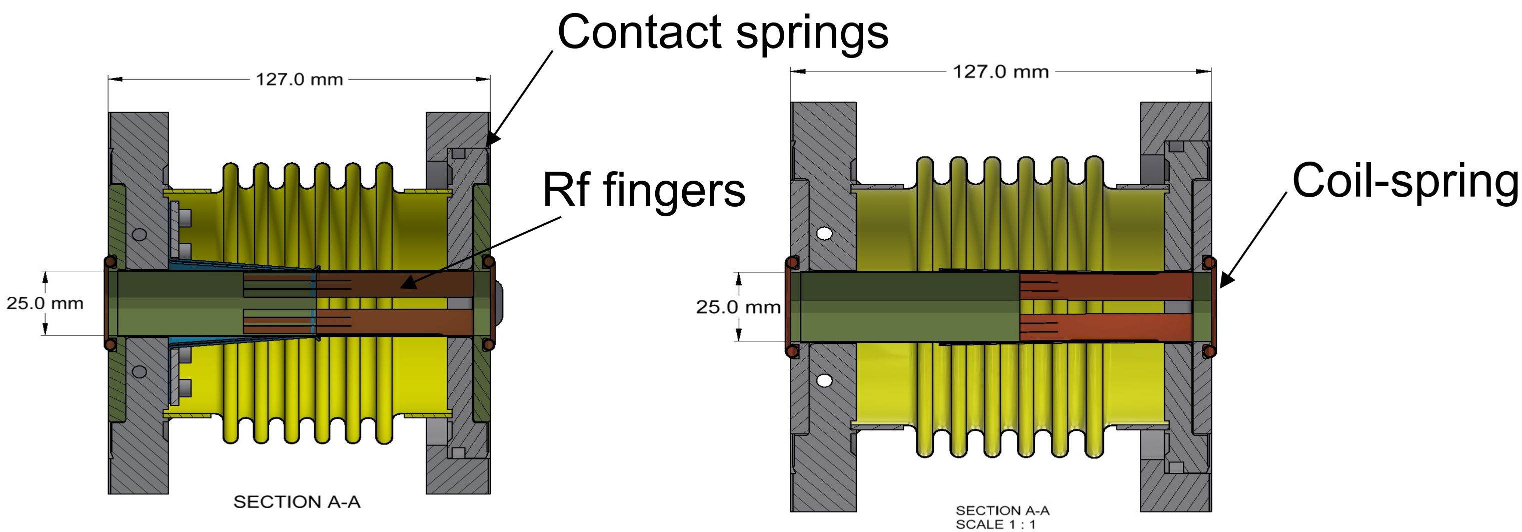
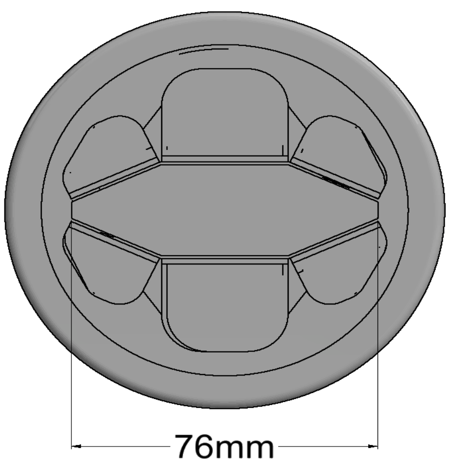
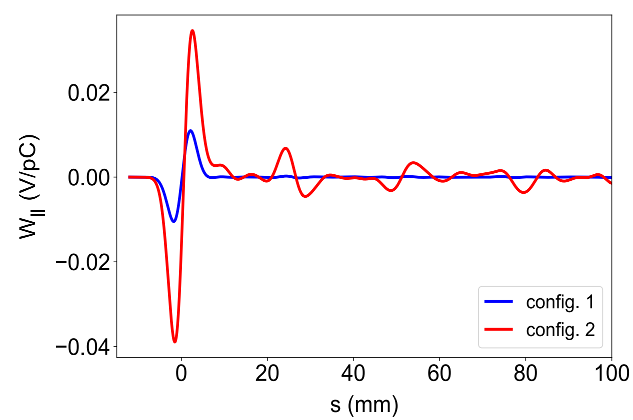
NSLS-II RF Bellows

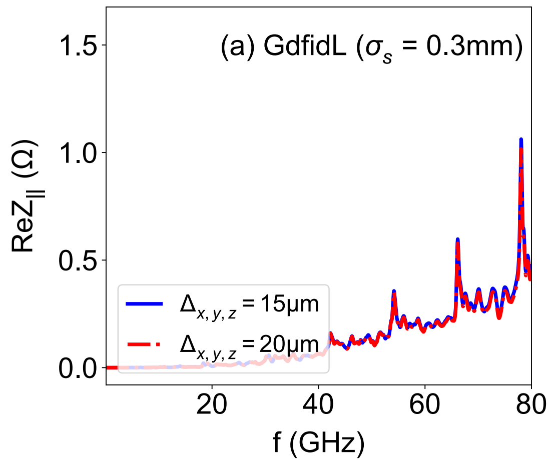


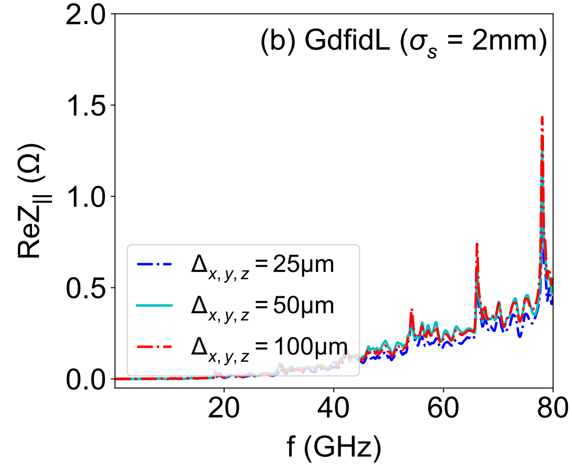


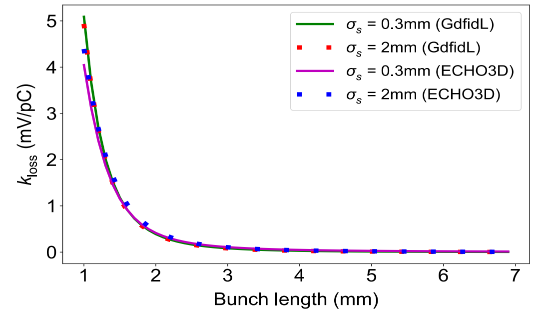


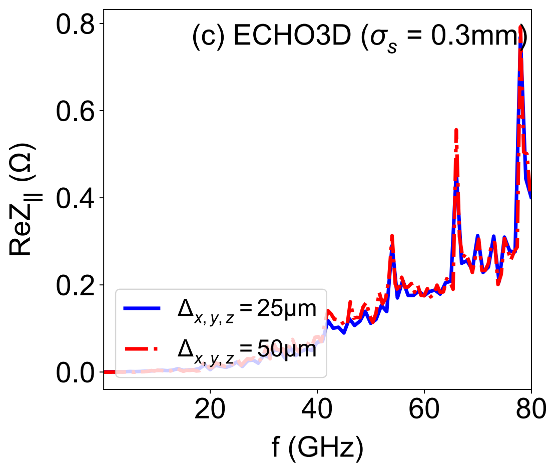
The location of the RF contact fingers relative to the regular vacuum chamber plays a significant role in producing the short-range wakepotential.

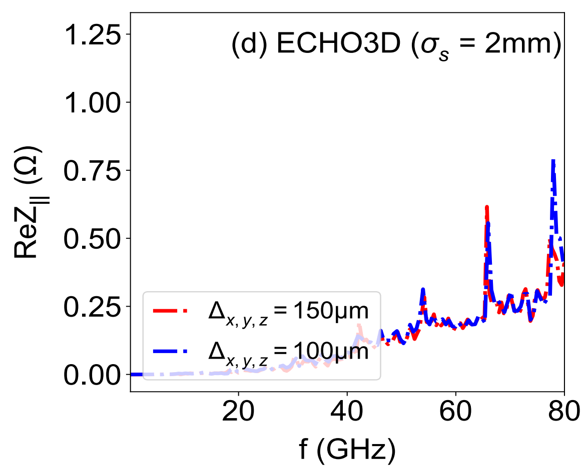
Longitudinal Impedance – NSLS-II Bellows







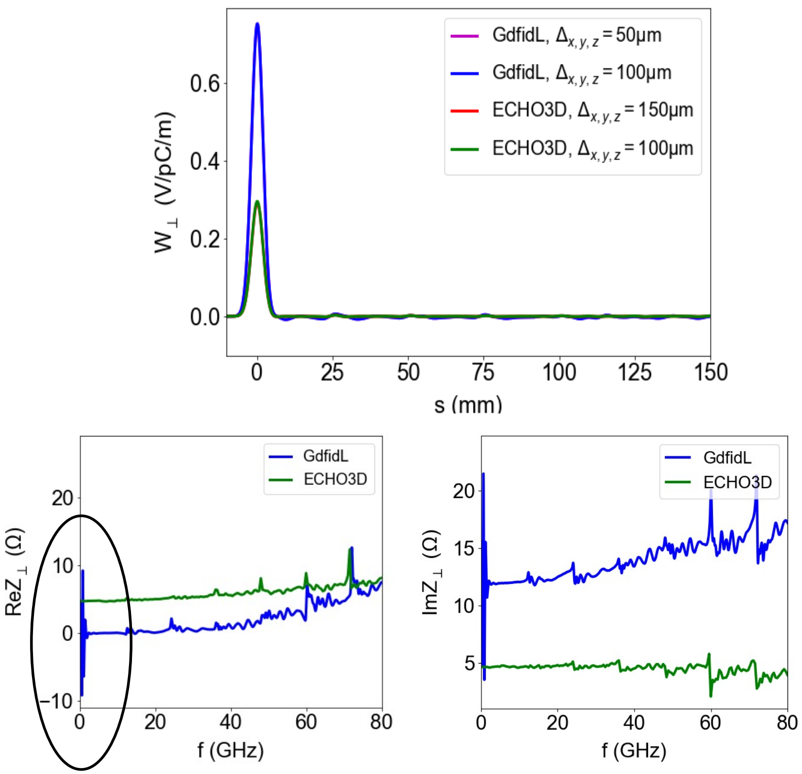




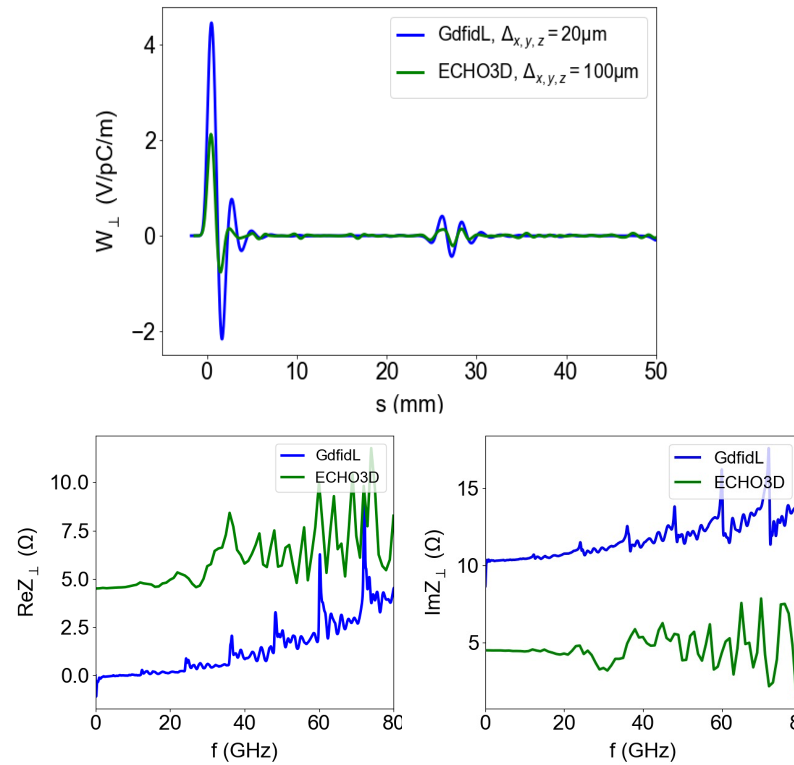
- For this 124 mm long rf-shielded bellows: GdfidL takes about 42 hrs to simulate for the bunch length of 0.3mm with a Δ=20μm for s=1m on the NSLS-II cluster using 8 nodes.
- Contrary, ECHO3D takes about 8 hrs for Δ = 25 μm with 96 threads on a single node.

Transverse Wakepotential and Impedance Studies – NSLS-II RF Bellows

$\sigma_s = 2$ mm, factor = 2.6

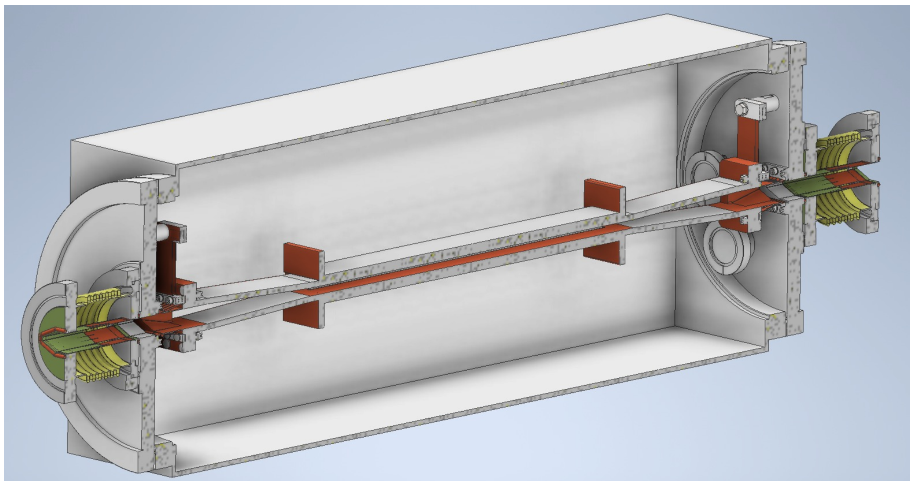


$\sigma_s = 0.3$ mm, factor = 2.1

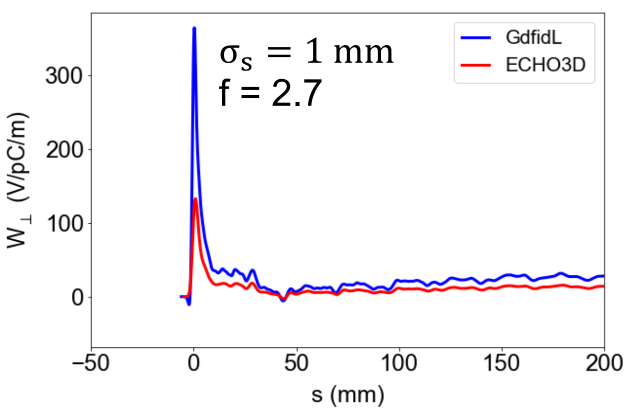


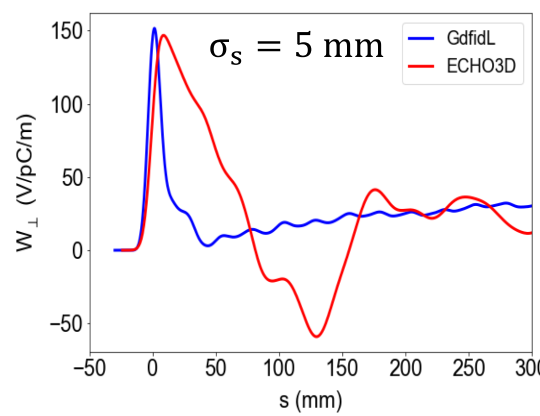
- Dispersion errors even for $\Delta \leq \sigma_s/20$

In-Vacuum Undulator



- Small-gap ID chambers significantly affect the beam dynamics in modern light sources
- NSLS-II to have a large number of in-vacuum ID chambers with gap down to 6mm
- Studied 1.2m ID with taper-transition enclosed in a chamber





- Further studies are required for $\sigma_s = 5$ mm case.

Conclusion

- A well-estimated impedance budget is a crucial part of estimating the performance of facilities with intense beams, and such estimates should be based on vacuum component designs as installed in the ring.
- For high- resolution wakefields in complex 3D geometries, we observed that GdfidL is computationally heavy and RAM consuming, contrary it is doable in ECHO3D with a coarse mesh.
- The only limitation of ECHO3D is in the limit of wake length due to the huge size of output files, which is troublesome for post-processing.
- The longitudinal impedance and loss factor calculated by GdfidL and ECHO3D show very good agreement. Whereas there is a discrepancy of factor of approx. 2 in the transverse wake computation.

Thank you!

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