Impedance calculations of collimators with simple geometries

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Acknowledgements:

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W. Bruns, A. Blednykh

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0. Short update on impedance modeling

➤ **On recent work of updating wake calculations**

- **Shift of work mode:**
  - * Old: Hardware colleagues calculated short-bunch wakes and sent the data to DZ
  - * New: TI (and DZ) collects input files and set up GdfidL calculations
- **Numerical error due to crude mesh size (dx/dy/dz=0.2/0.2/0.1 mm for driving bunch $\sigma_z = 0.5$ mm)**
  - * Number of nodes of computing cluster reduced from 256 to ~80
  - * Refining mesh is not feasible
- **Standard "-fdtd" algorithm was used**
  - * "-windowwake" is better for short-range wake
- **Transverse wakes have more numerical errors than longitudinal**

➤ **Postpone the delivery until the wake data are reliable**

- **Communication with hardware colleagues to check consistency of old and new calculations**
- **Communication with W. Bruns for advice of improvements in GdfidL calculations**
- **Communication with A. Blednykh for advice of better understanding the wake data**

1. Introduction

➤ **This talk is to discuss ideas of reducing dipolar impedances (contribute to TMCI instability) based on:**

- **Impedance calculations for collimators with simple geometries**

➤ **Possible ideas of reducing dipolar impedances of collimators via geometry optimization**

- **Round collimator**
- **KEKB-type collimator**
- **Use exponential tapering**

1. Introduction

➤ **The transverse impedances need to be decomposed into monopolar, dipolar and quadrupolar parts in impedance calculations of 3D structures [1]**

- **Example of decomposition:**

$$W_x(s,x,0,x_0,0) \approx W_x(s,0,0,0,0) + \frac{\partial W_x}{\partial x_0}\Delta x_0 + \frac{\partial W_x}{\partial x}\Delta x$$

Monopolar part

Dipolar part

Quadrupolar part

Offset of driving beam

Offset of monitoring position

- **(x_0, y_0) are coordinates of the driving beam, (x, y) are coordinates of the monitoring position (or position of test particle)**
- **The monopolar transverse impedances cause beam tilt (growth of projected emittance) in x-z or y-z plane [2]. If the geometry has symmetry around x=0 and y=0 planes, transverse monopole impedance should be zero.**
- **Both dipolar and quadrupolar transverse impedances contribute to tune shift for the coherent dipolar oscillation [3].**
- **Only the dipolar transverse impedances contribute to transverse mode coupling instability (TMCI).**

1. Introduction

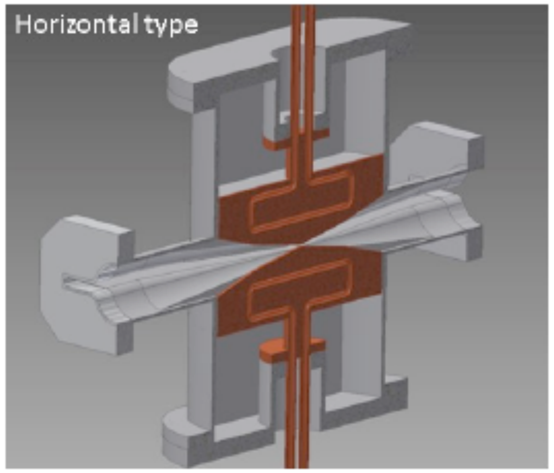
➤ **Collimators in SuperKEKB**

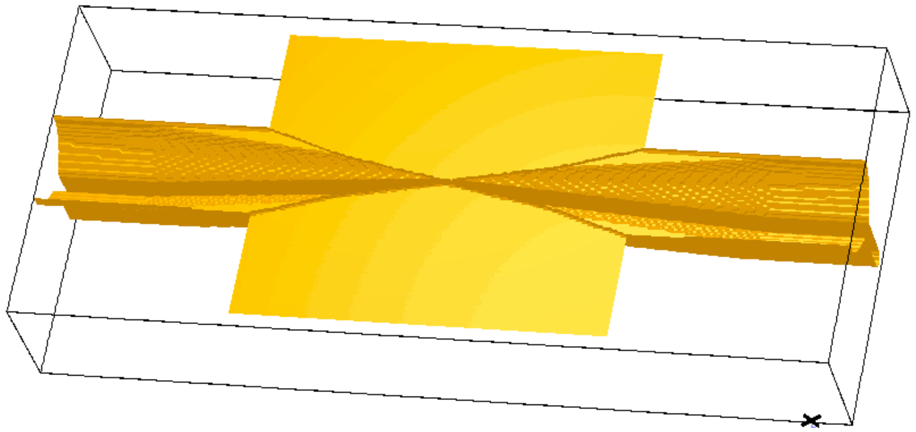
- **KEKB-type collimators (used in HER) are asymmetric and generate all three types of wakes**

  *** The KEKB-type collimators need to be properly paired (Ideal case: betatron phase advance N*π with N odd number, and equal β and α functions) to cancel the beam tilt [2]**

- **SuperKEKB-type collimators are symmetric in both x and y directions**

  *** If the closed orbit is offset from the chamber axis, there will also a beam-tilt effect**



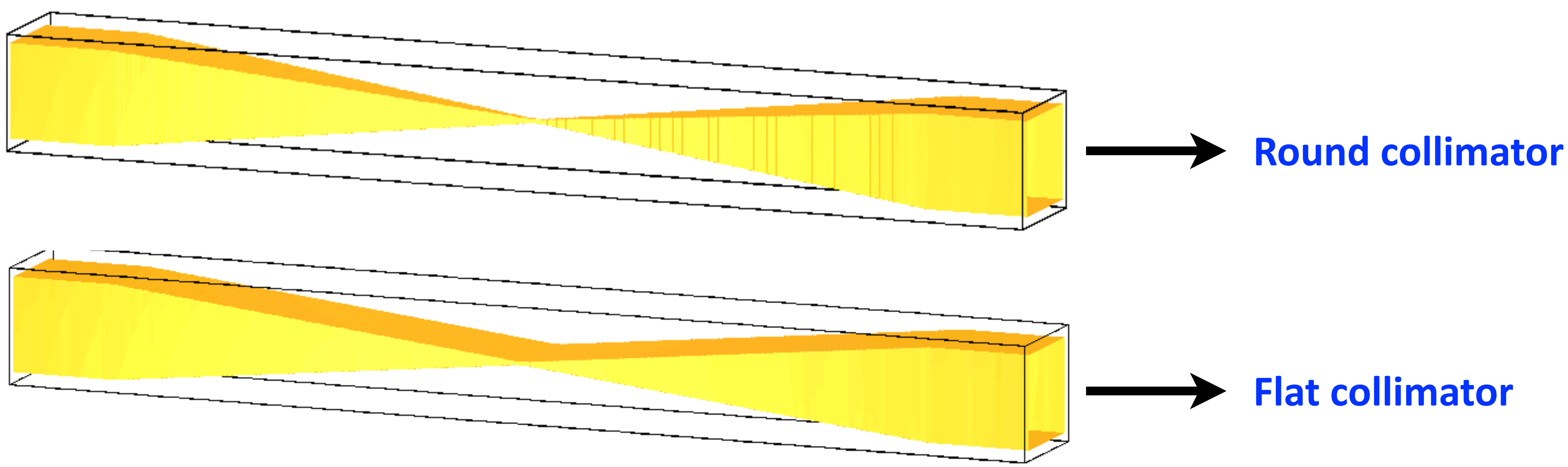


Courtesy of T. Ishibashi

1. Introduction

➤ Collimator with simple geometry:

- Vacuum chamber full width/height = 90/90 mm (Rectangular chamber)
- Taper length 400 mm (two tapers used)
- Chamber full width/height at the jaw: w/h = 4/4 mm (minimum values)
- Jaw length 10 mm (along the beam orbit)
- Vary the chamber full width from 4 mm (~round collimator) to 90 mm (~flat collimator)
- Gaussian driving beam with rms length 6 mm



➤ GdfidL settings

- Driving beam: -lcharge xposition=0, yposition=0
  Monitoring position: -wakes wxatxy=(0.5e-3,0.), wyatxy=(0.,0.5e-3)
  => Monopolar and Quadrupolar wakes
- Driving beam: -lcharge xposition=0.5e-3, yposition=0
  or -lcharge xposition=0, yposition=0.5e-3
  Monitoring position: -wakes wxatxy=(0.,0.)
  or -wakes wyatxy=(0.,0.)
  => Dipolar wakes
- Resistive wall is not taken into account in this study

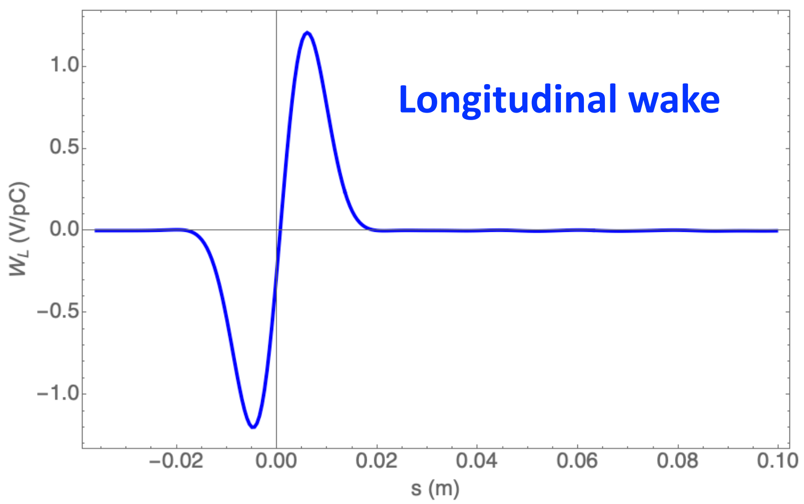
2. Calculation results

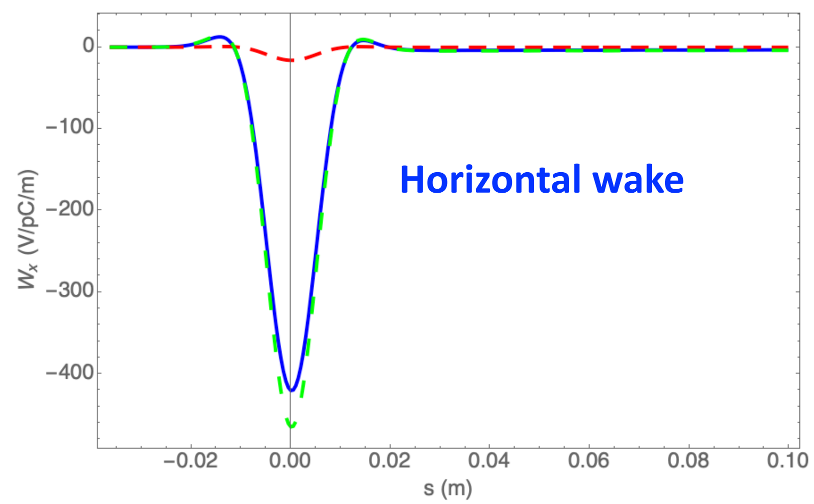
➤ Wake potentials with varied chamber width at the jaw

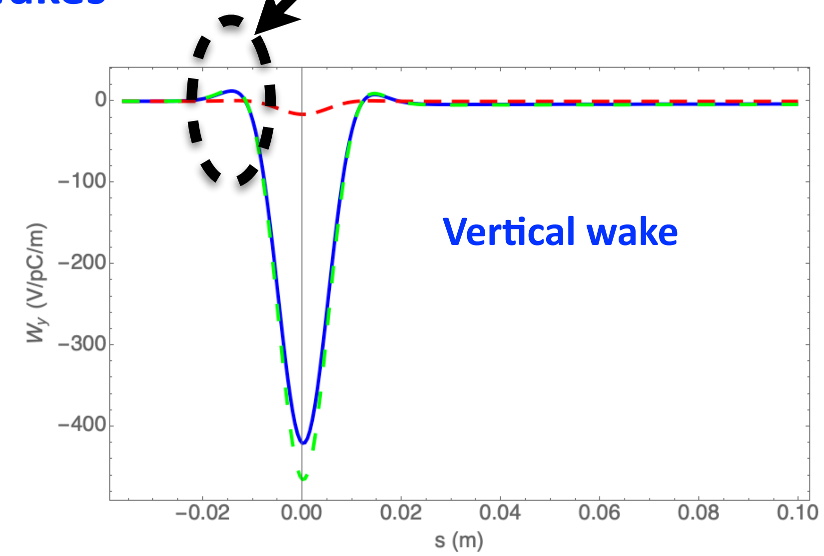
- **w/h = 4/4 mm (close to round collimator):**

  *** For round collimators, dipolar wakes dominates the quadrupolar wakes**

Numerical noise

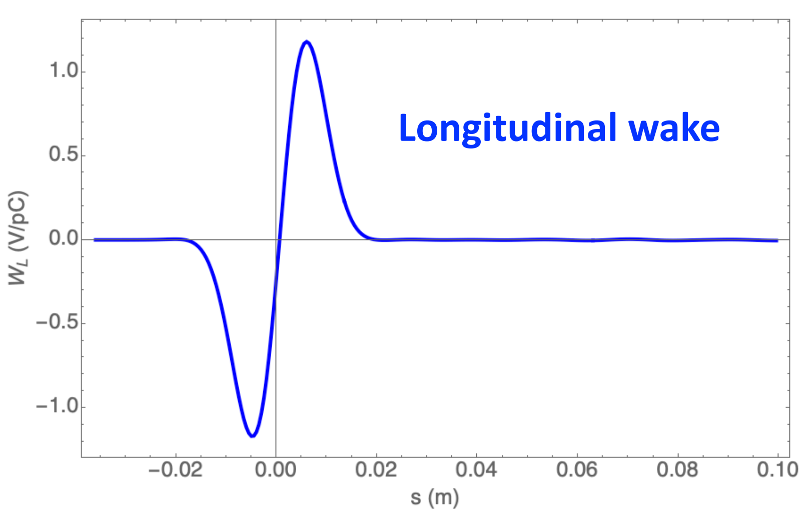


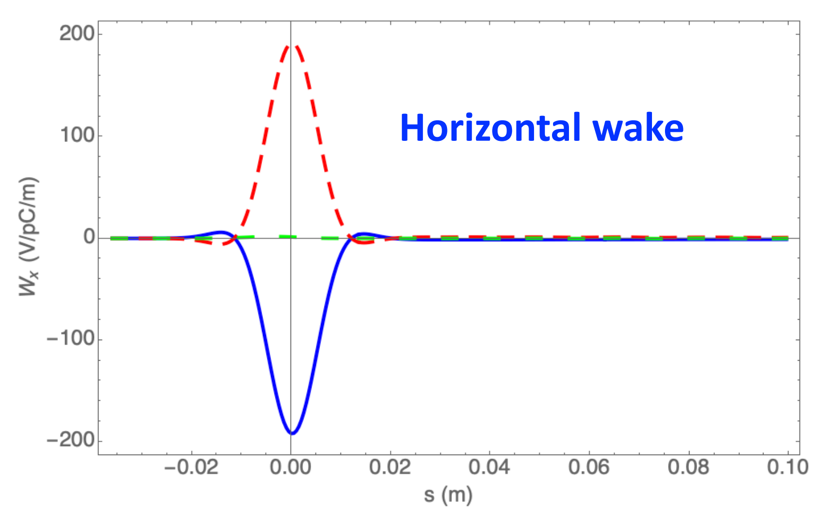


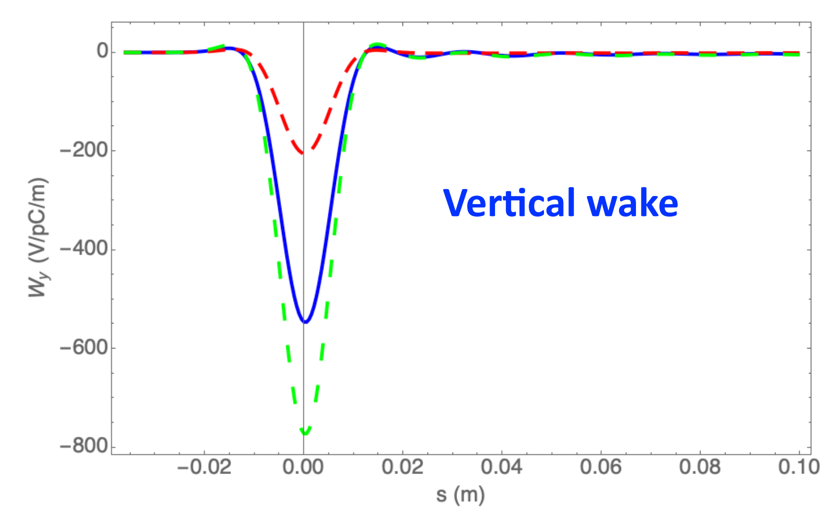


Blue: Dipolar
Red: Quadrupolar
Green: D + Q

- **w/h = 10/4 mm:**



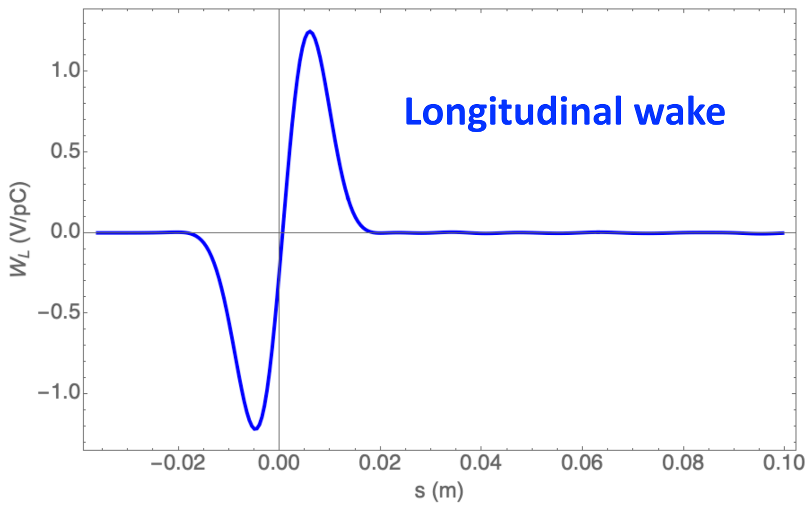


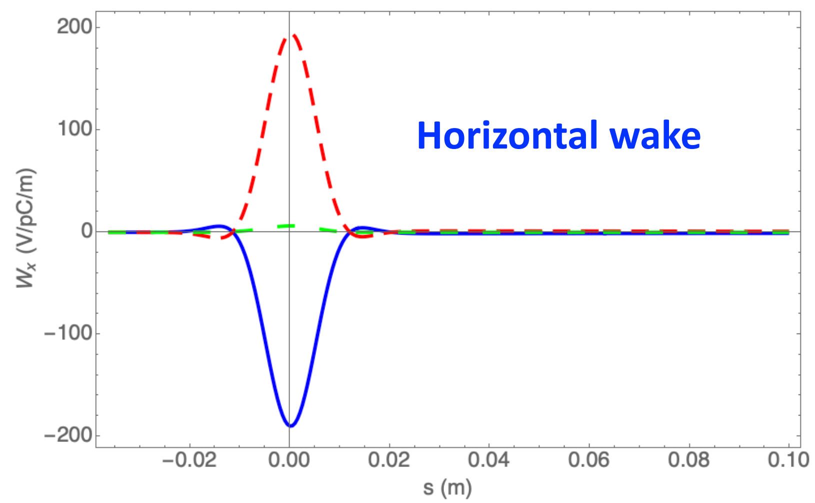


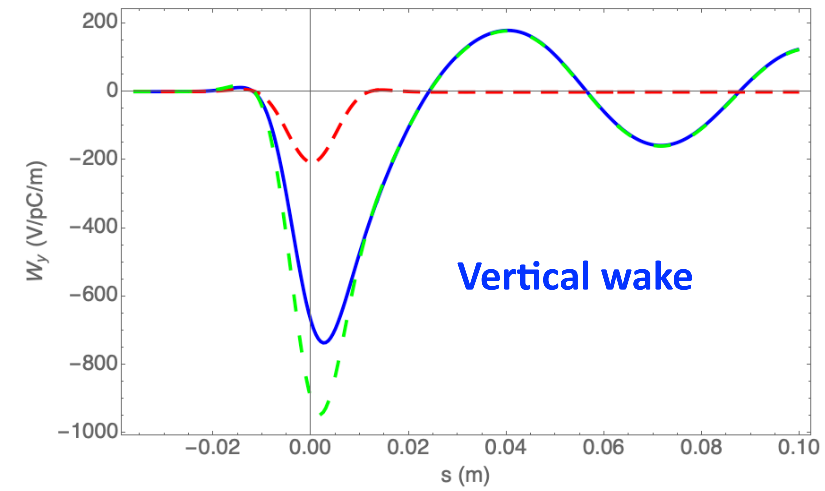
2. Calculation results

➤ Wake potentials with varied chamber width at the jaw

- **w/h = 30/4 mm:**





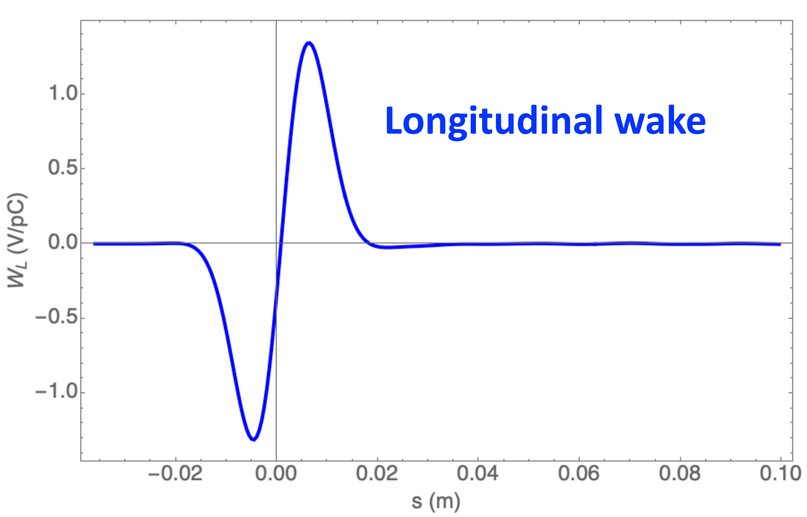


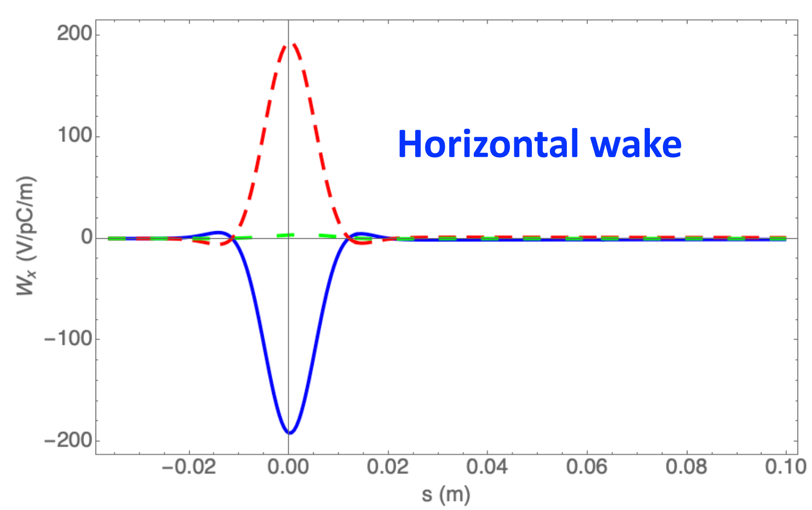
Blue: Dipolar
Red: Quadrupolar
Green: D + Q

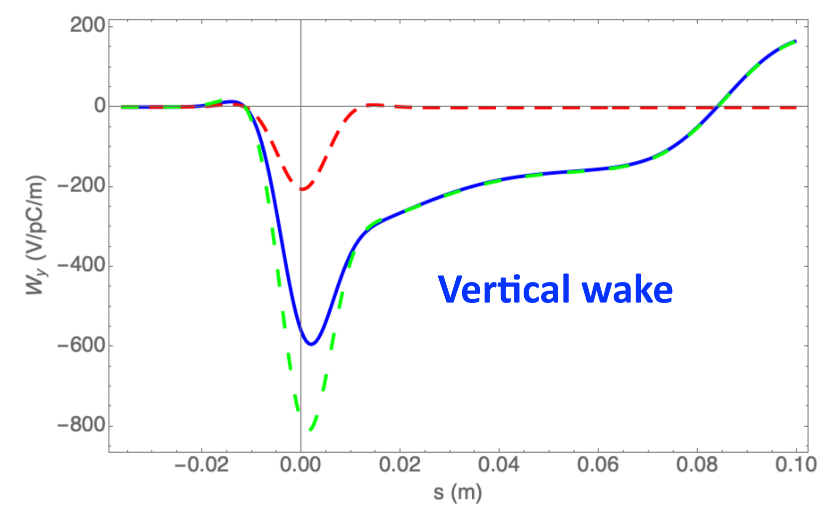
- **w/h = 90/4 mm (close to flat collimator):**

  * For vertical flat collimators, the horizontal total wake is close to zero; the horizontal dipolar and quadrupolar wakes have opposite signs

  * The quadrupolar wakes in vertical and horizontal wakes have opposite signs



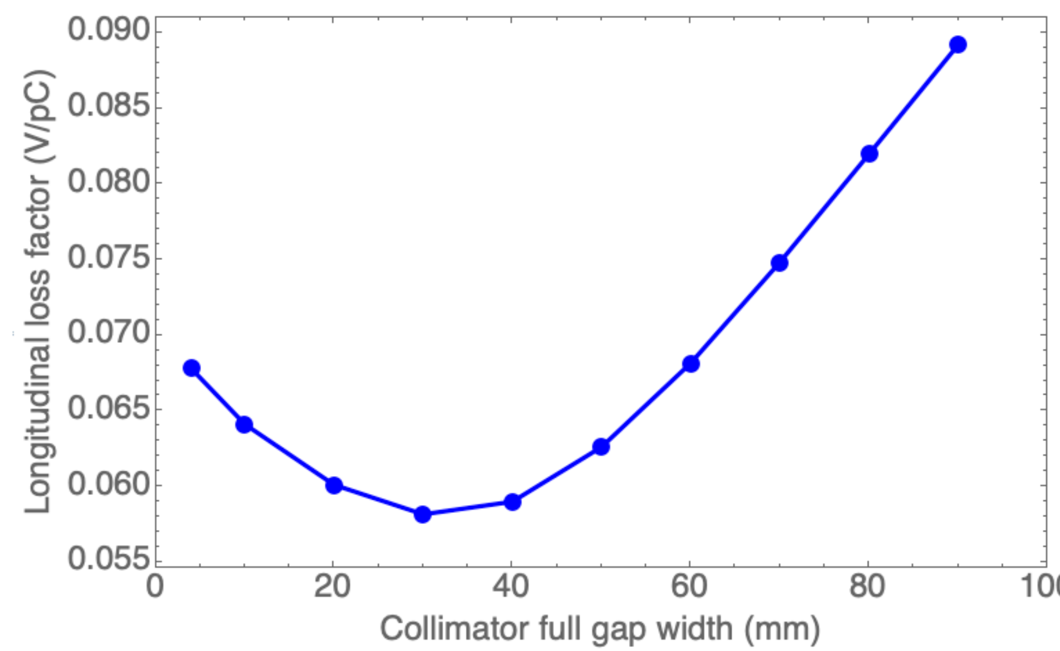


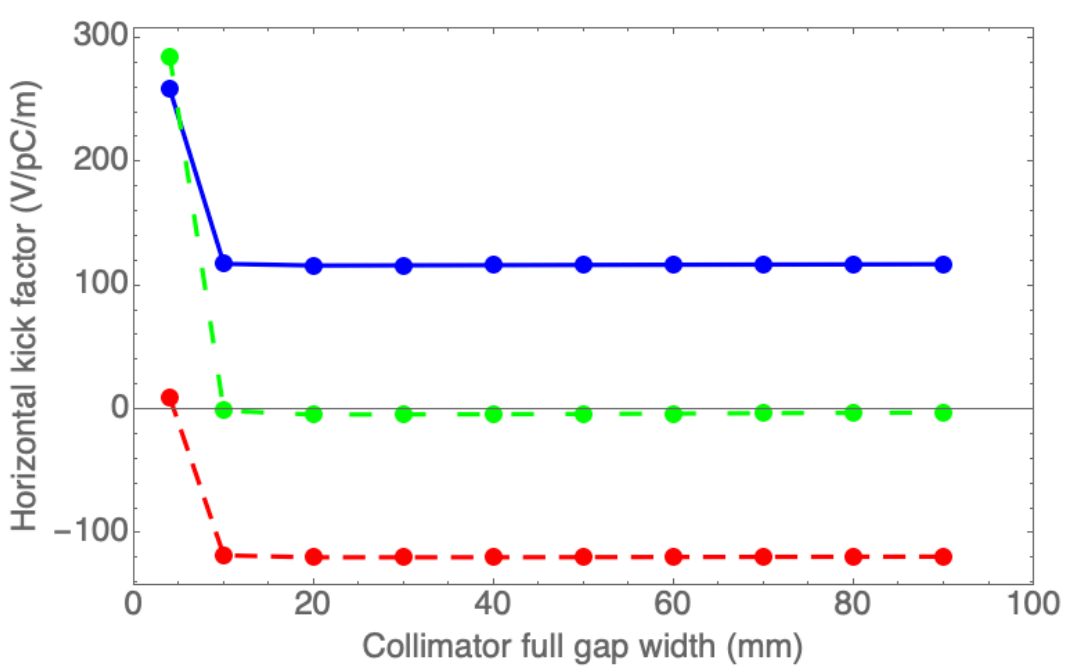


2. Calculation results

➤ Summary of loss factors and kick factors

- For flat collimators (or tapers), the dipolar and quadrupolar horizontal wakes cancel each other -> This is expected
- For flat collimators, the quadrupolar vertical wake should be separated from the dipolar part. This is because only the dipolar wake contribute to TMCI instability.
- To increase TMCI threshold, "round collimators" seems to be the "best" choice -> This can be considered in the optimization of collimator structures for SuperKEKB
  -> This observation is consistent with Shibata-san's findings [4].





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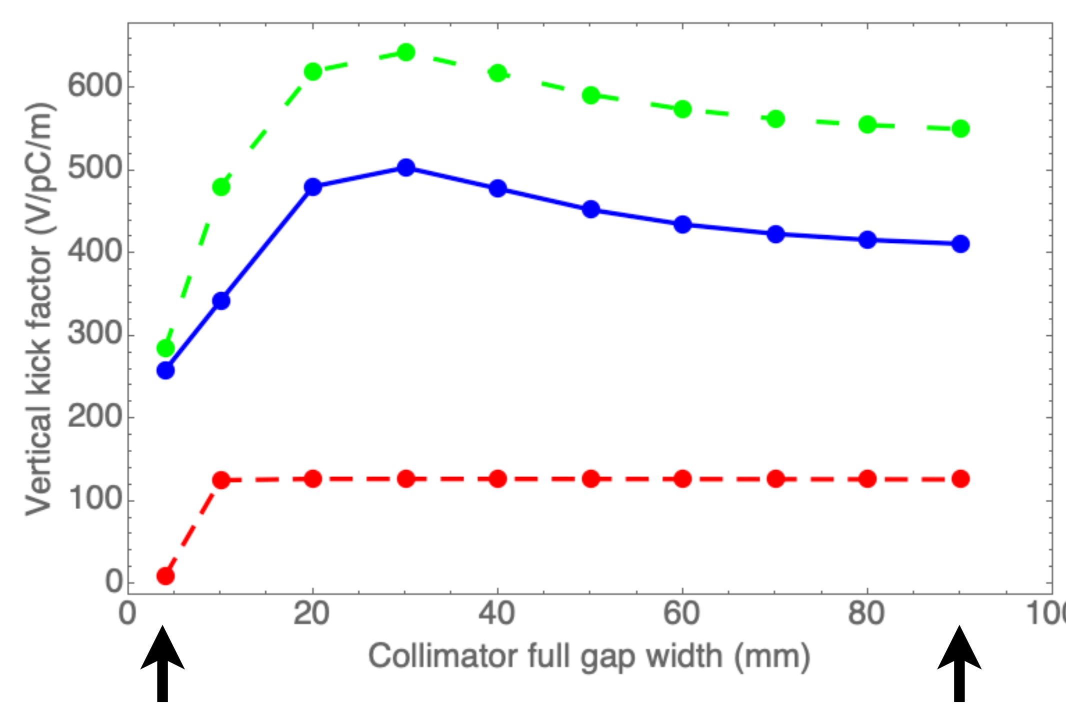


Round collimator
Flat collimator

3. Theories for collimator impedance

➤ **Impedance theories of collimators (or tapers) have been extensively investigated**

- **References:**
  [a] B. Podobedov and S. Krinsky, EPAC 2006, THPCH081
  [b] K. Yokoya, CERN SL/90-88 (AP)
- **From [a]: Round collimator has smaller dipolar impedance than flat collimator (Left figure)**
- **From [b]: Exponential taper has smaller dipolar impedance than linear taper (Right figure)**

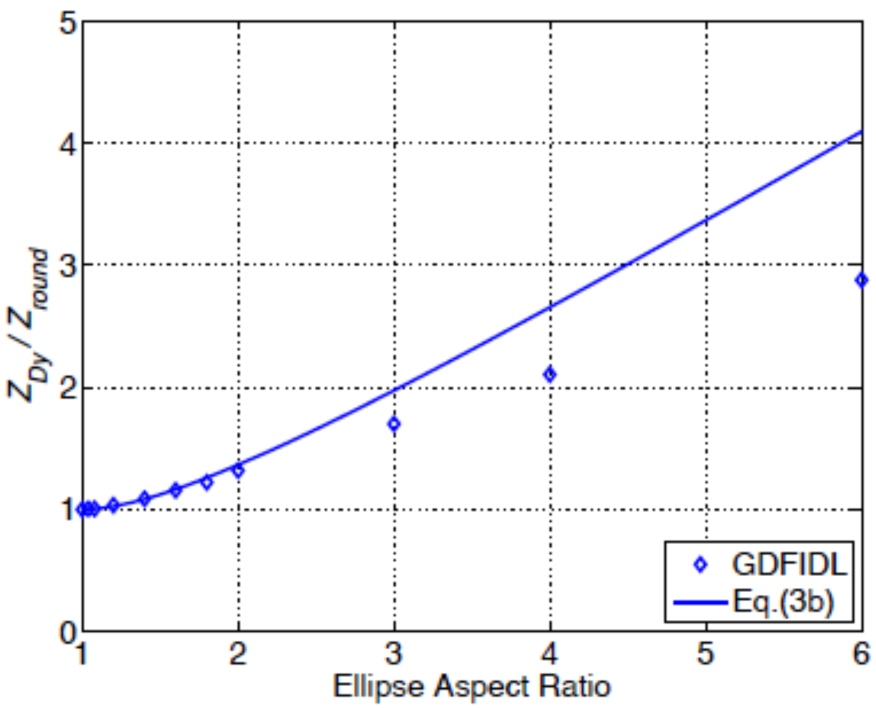


Figure 2: Dipolar vertical impedance.

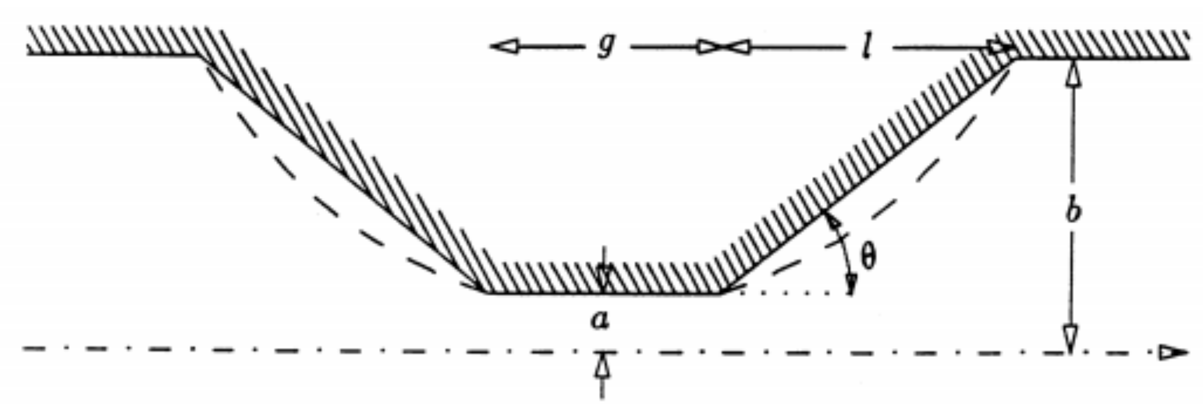
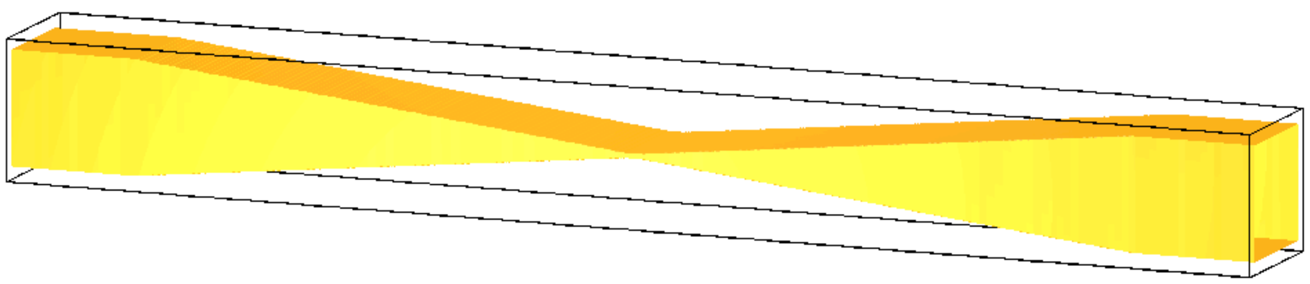
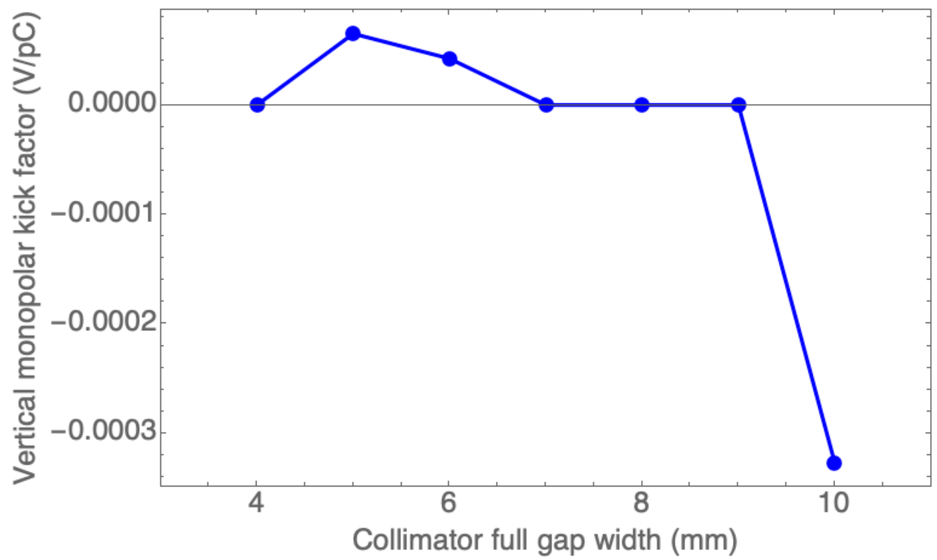


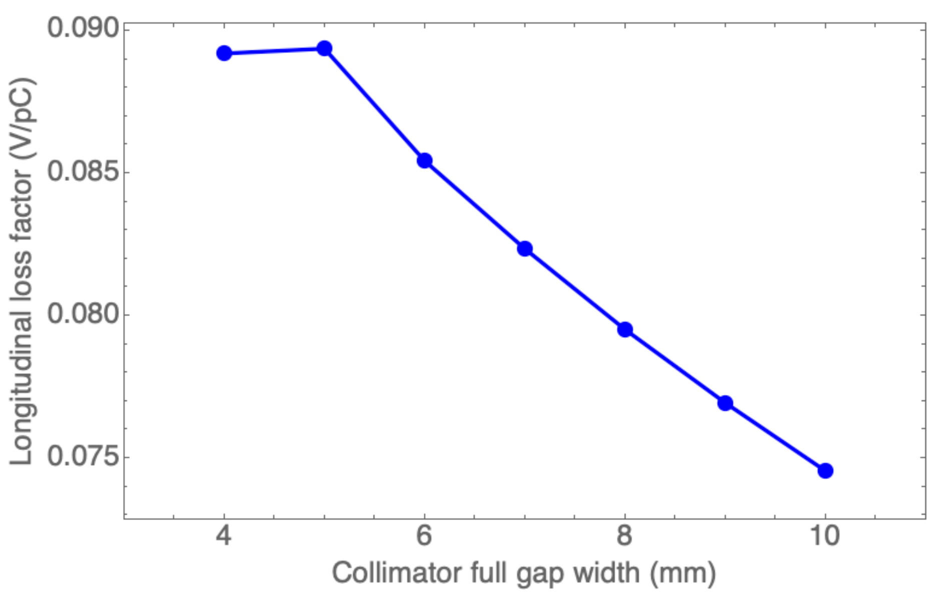
Fig.2. Linearly and exponentially tapered scrapers.

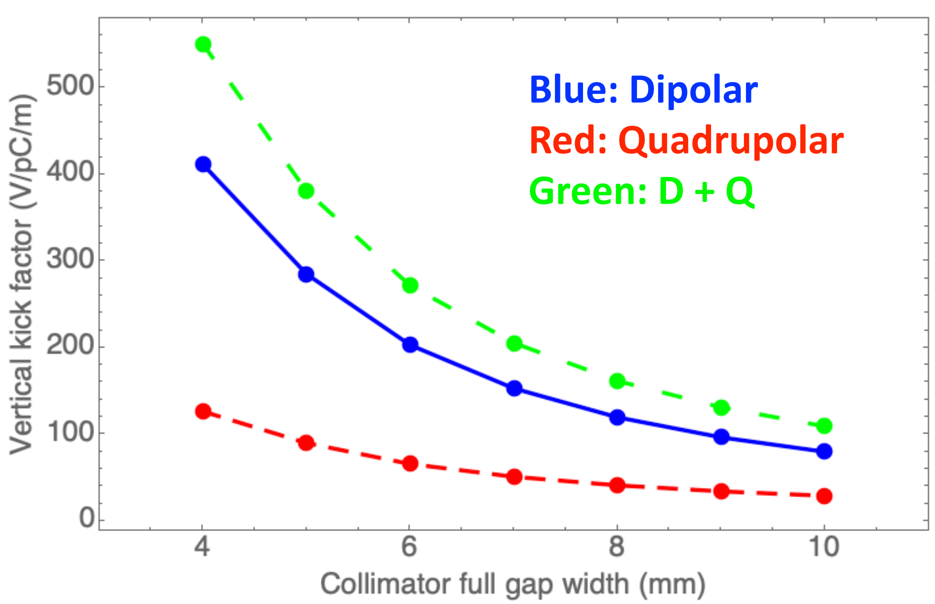
4. KEKB-type collimator

➤ **PEP-II collimator is used in SuperKEKB**
- Relatively large vertical dipolar kick factor
- Relatively small longitudinal kick factor
- Zero vertical monopolar kick factor (symmetry)





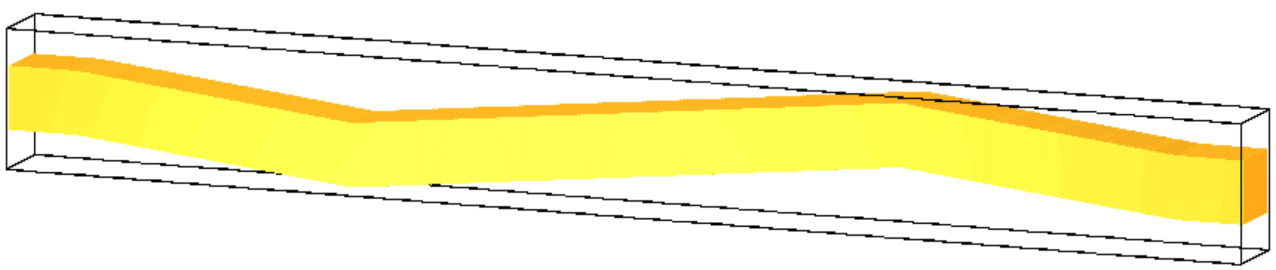


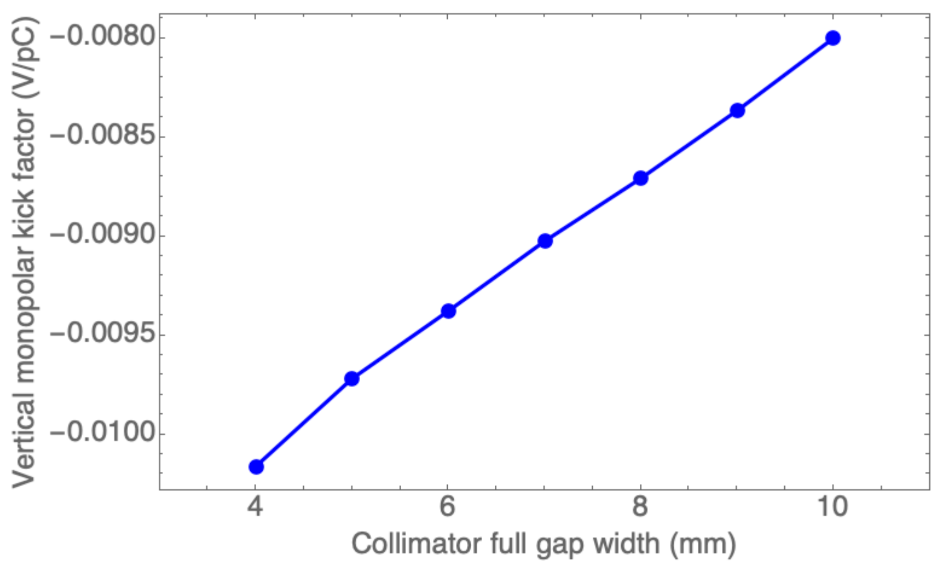


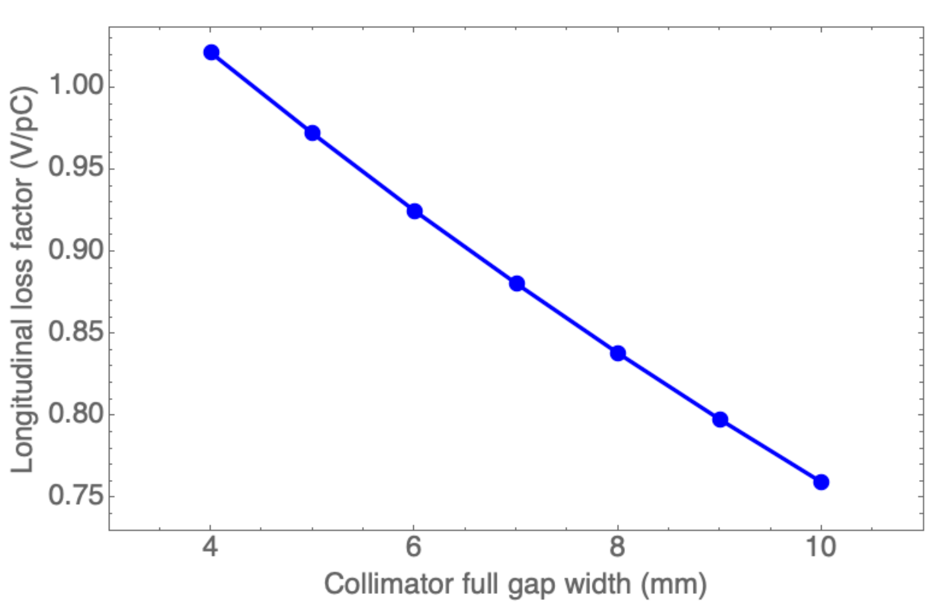
4. KEKB-type collimator

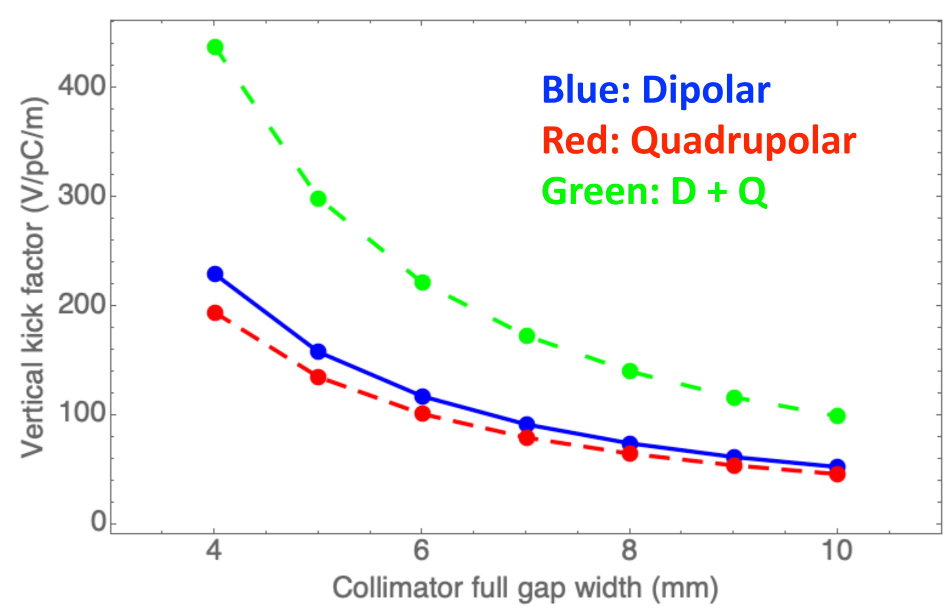
➤ **The KEKB-type collimator can be used to to reduce TMCI threshold**

- **Relatively smaller vertical dipolar kick factor?**
- **Relatively large longitudinal kick factor**
- **Non-zero vertical monopolar kick factor (non-symmetry) (KEKB used Pi-phase difference between two collimators to cancel monopolar wake kicks)**





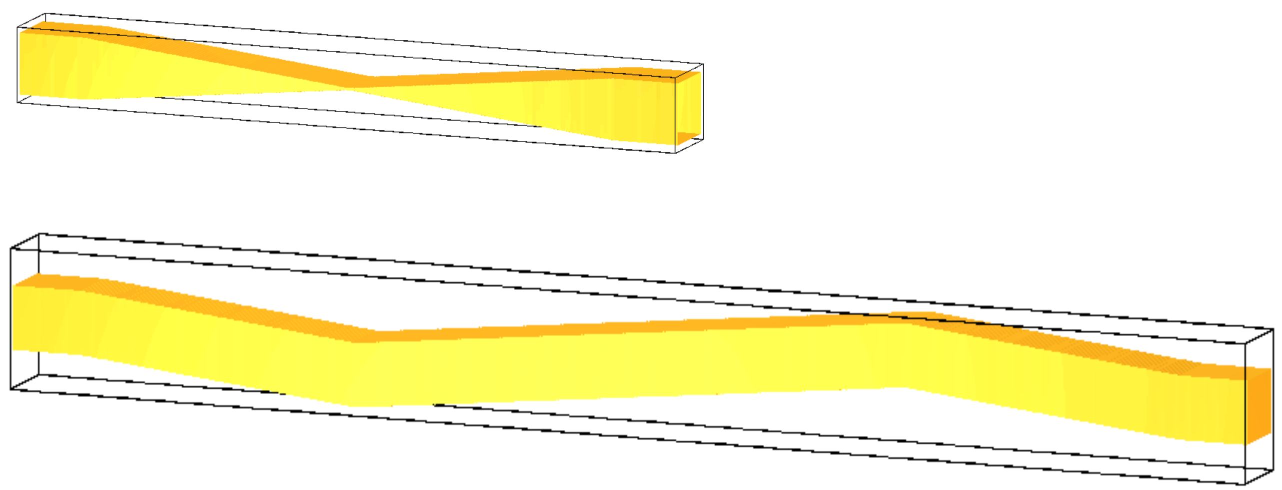


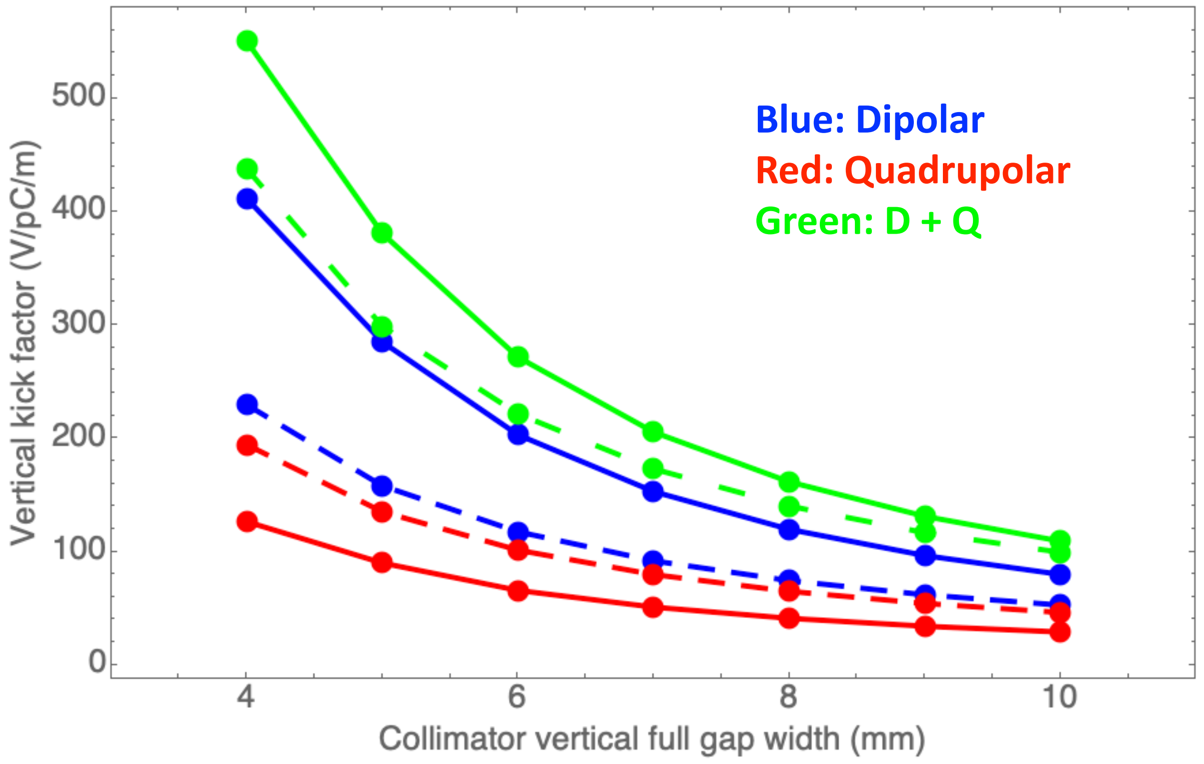


4. KEKB-type collimator

➤ Compare KEKB-type and PEP-II-type collimators

- Assume same length for tapers: 2 tapers for PEP-II type, and 4 tapers for KEKB-type (not a fair comparison?)





Solid lines: KEKB-type
Dashed lines: PEP-II type

5. Summary

➤ On geometry optimization of collimators

- Round collimator is theoretically good for reducing dipolar wakes, but practically (likely) not possible.
- The KEKB-type collimators might be useful for reducing vertical dipolar kick factor (to reduce TMCI threshold)
- Possible methods to improve the current SuperKEKB collimators (PEP-II type)
  * Add horizontal tapers to vertical collimators (close to round collimator)
  * Use exponential tapers instead of linear tapers

6. References

[1] S. Heights, A. Wagner, B. Zotter, “Generalized Impedance and Wakes in Asymmetric Structures”, SLAC/AP110, Jan. 1998.
[2] G. Stupakov and D. Zhou, “Transverse wakefields due to asymmetric protrusions into a vacuum chamber”, Nucl. Instrum. Meth. A 764 (2014) 378–382.
[3] S. Sakanaka, T. Mitsuhashi, and T.Obina, “Observation of transverse quadrupolar tune shifts in the Photon Factory storage ringrogate”, Phys. Rev. ST Accel. Beams 8, 042801 (2005).
[4] K. Shibata, “Small impedance structure”, SuperKEKB collimator meeting, Mar. 11, 2021, https://kds.kek.jp/event/37378/.