Impedance model for SuperKEKB LER

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Acknowledgements

W. Bruns, M. Migliorati, and SuperKEKB team

SuperKEKB TMCI workgroup meeting, Nov. 09, 2021, KEK

Introduction

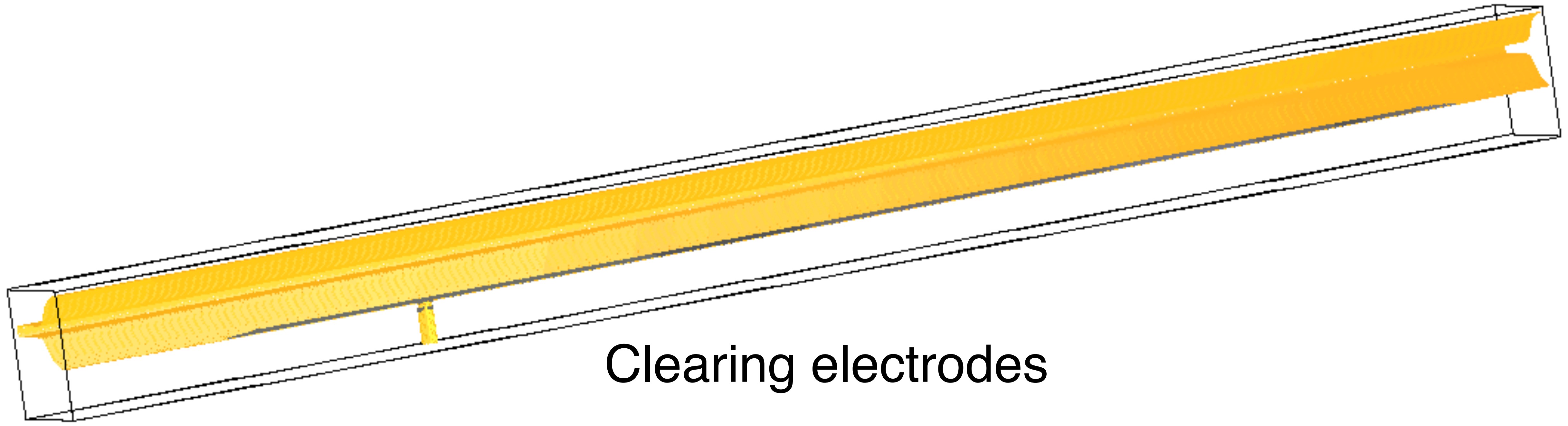
- The longitudinal pseudo-Green's function impedance model was constructed in the design stage of SuperKEKB (see my talk at the first TMCI group meeting [1])
- To understand the TMCI problem at SuperKEKB LER, wake calculations were done in 2021 with emphasis on the transverse wakes (separation of dipolar and quadrupolar parts).
  - GdfidL version: 200723.
  - Driving Gaussian bunch σ_z=0.5 mm.
  - Mesh sizes: dx=dy=0.2 mm, dz=0.1 mm (limited by available computing resources).
  - Use standard "-fdtd" method.
- The impedance model for both longitudinal and transverse planes was then constructed.

- The numerical errors in GdfidL calculations with the above conditions were well understood (thanks to A. Blednykh, W. Bruns, I. Zagorodnov et al.) (see my talk on benchmark at this meeting).
- More careful wake calculations are under preparation.

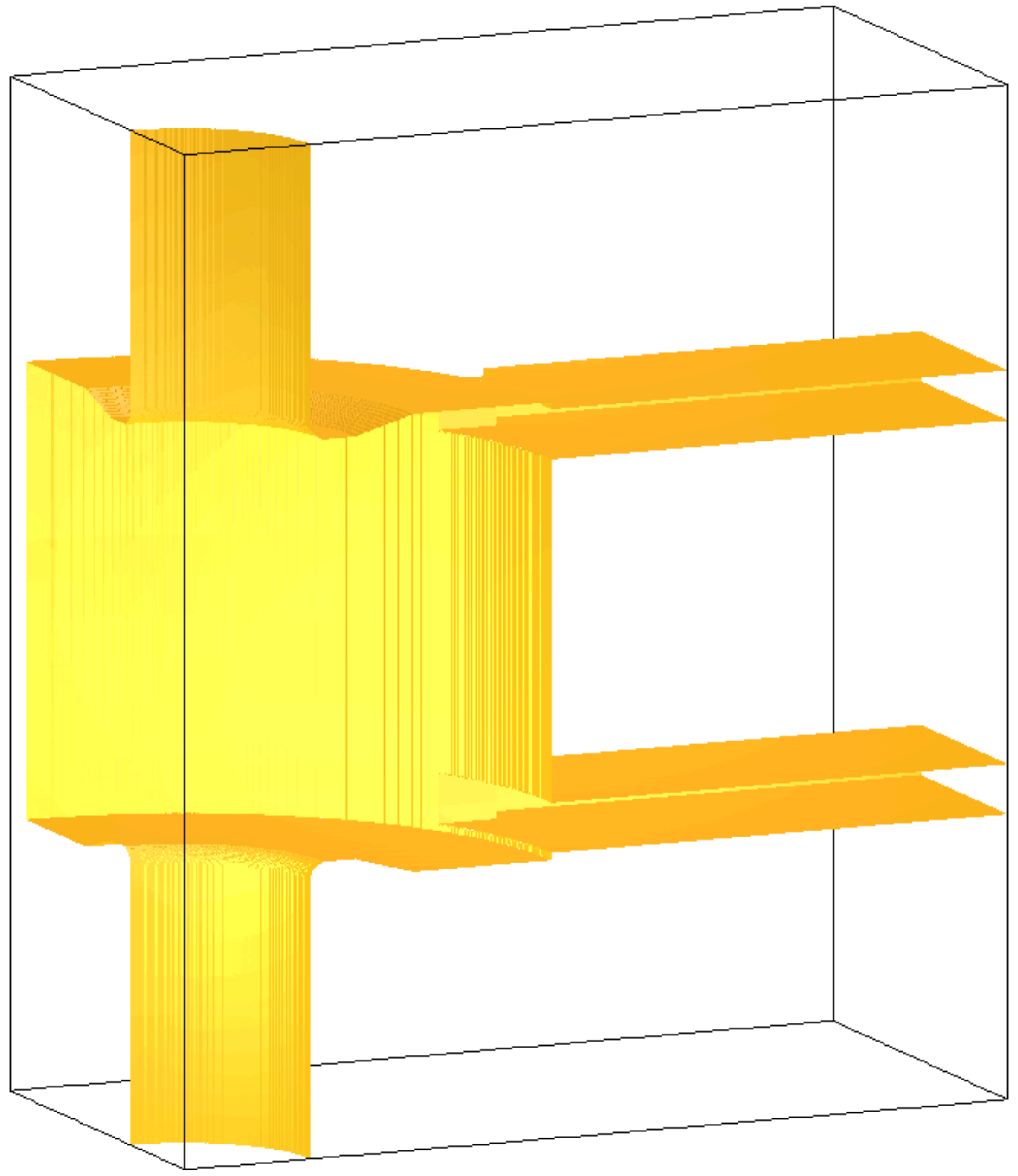
[1] D. Zhou, Talk presented at the first SuperKEKB TMCI group meeting, KEK, Aug. 27, 2021(https://kds.kek.jp/event/39138/).

Introduction

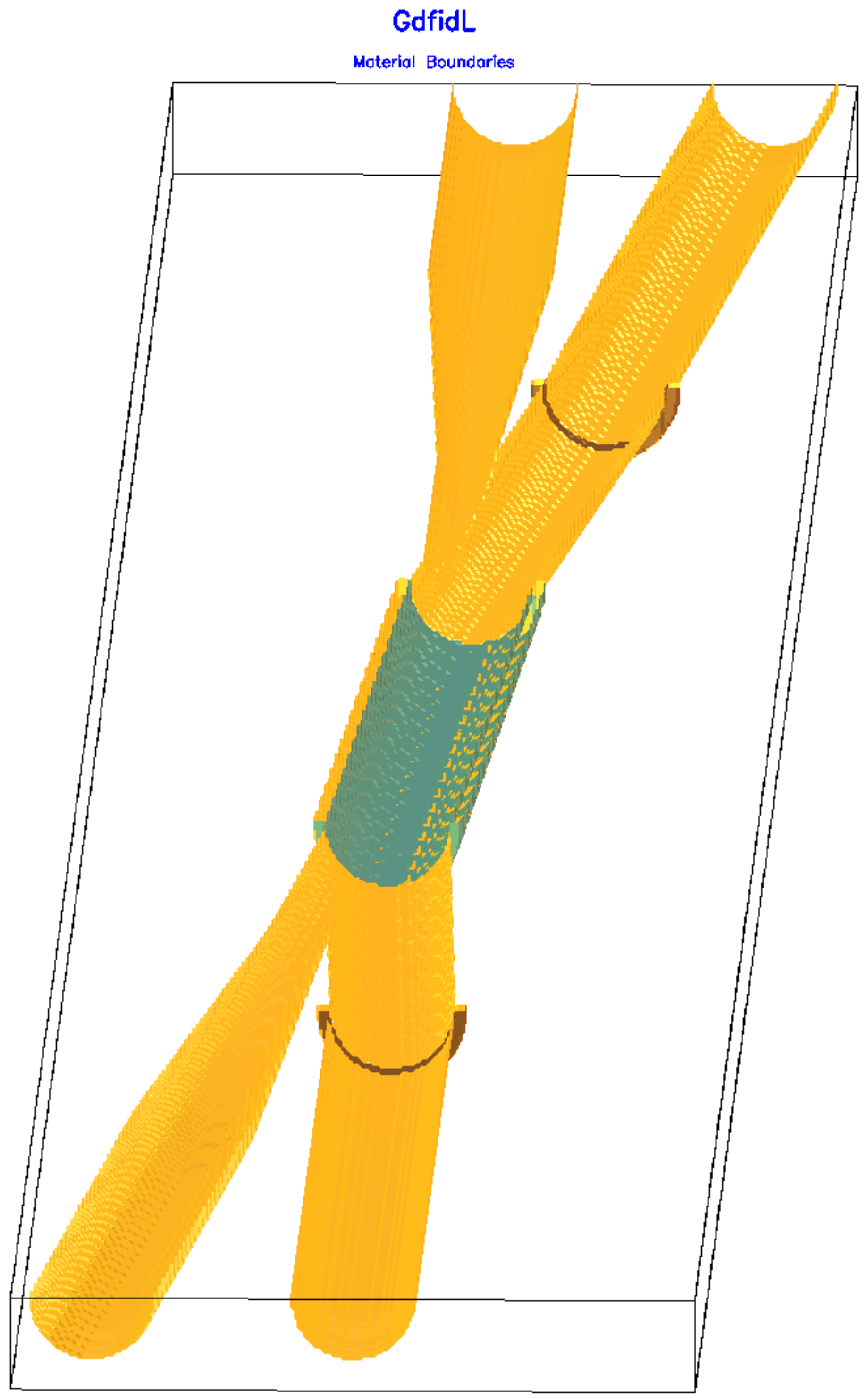
- Some components



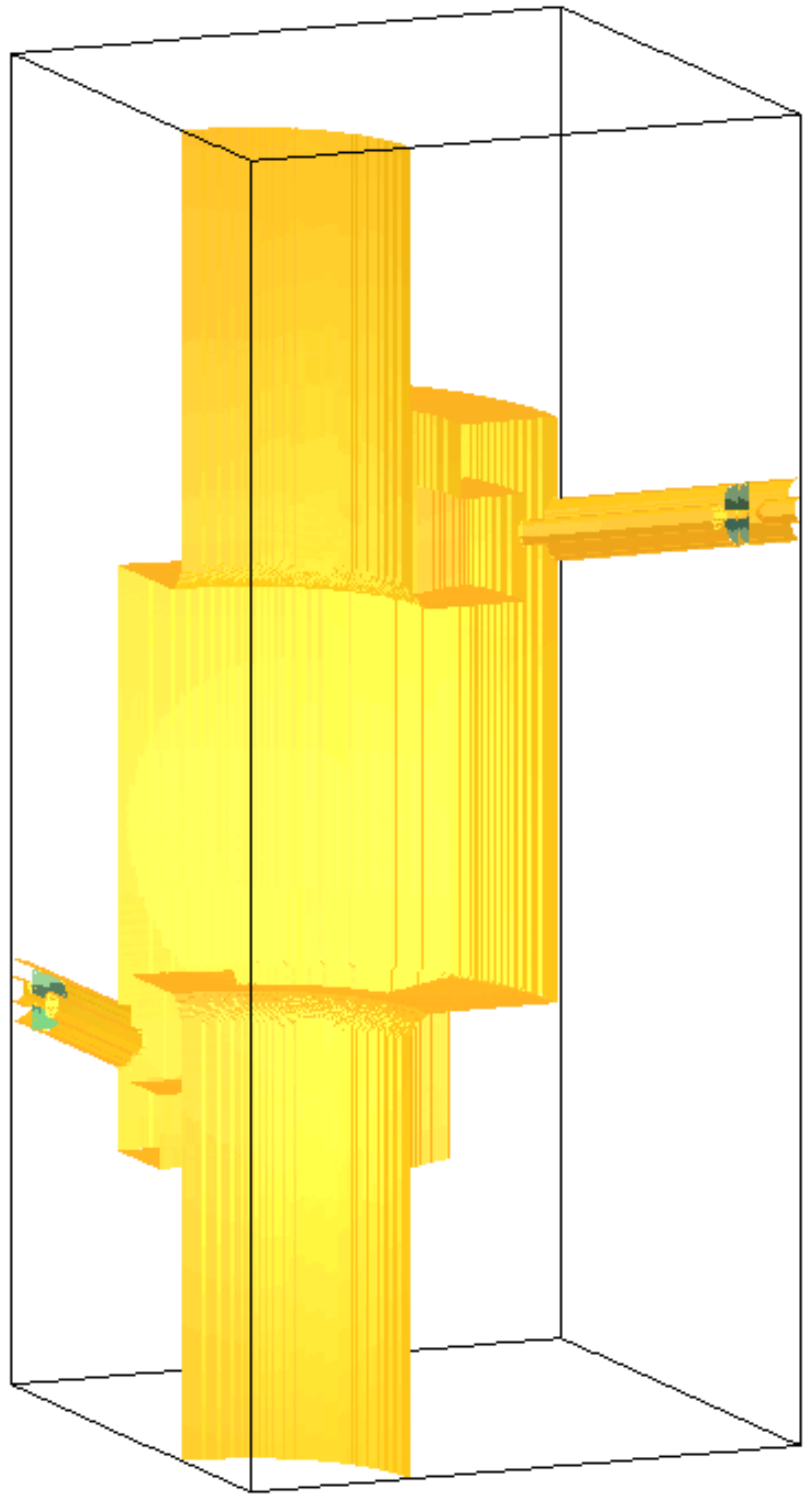
Clearing electrodes



ARES RF cavity



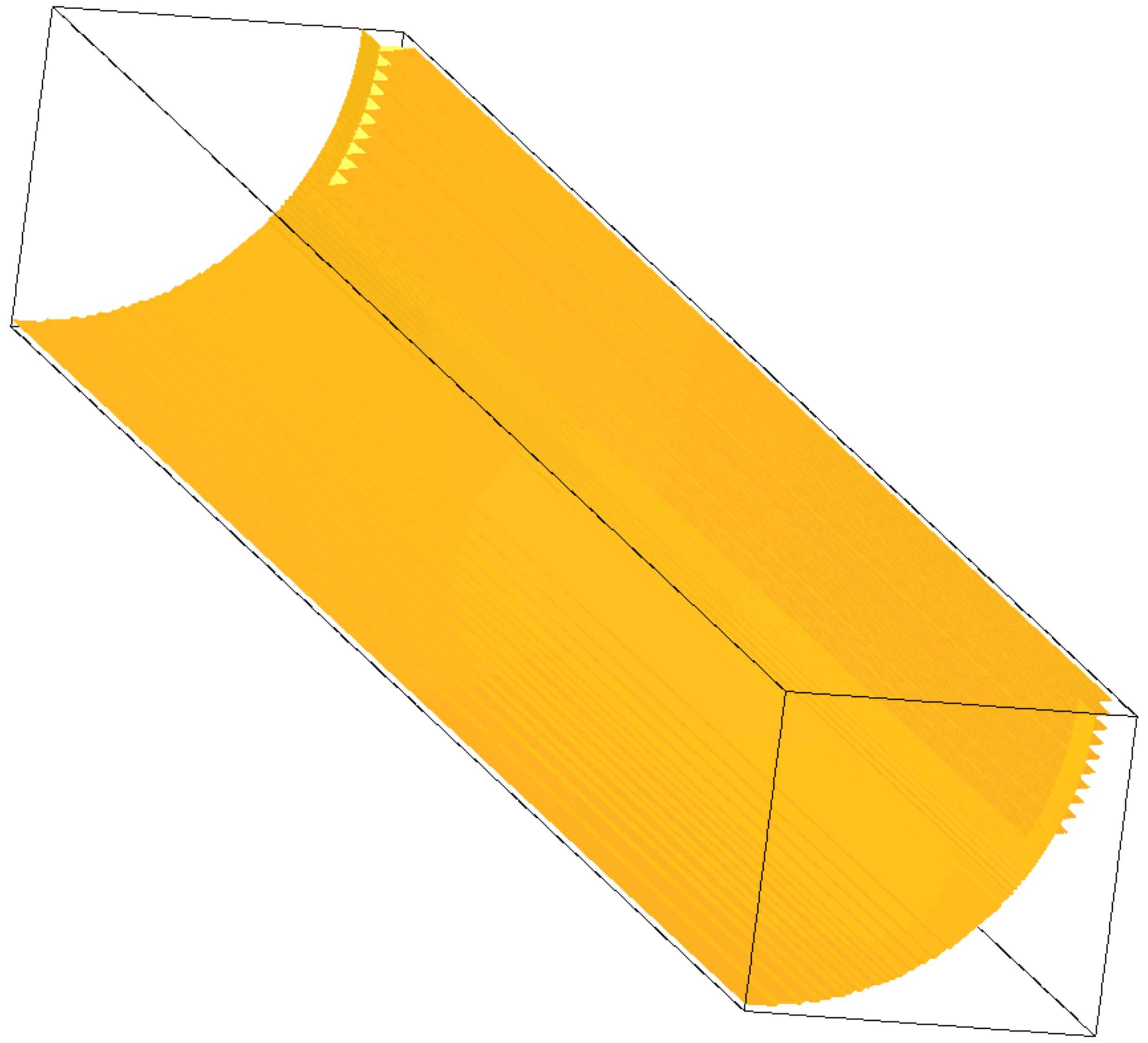
IR duct



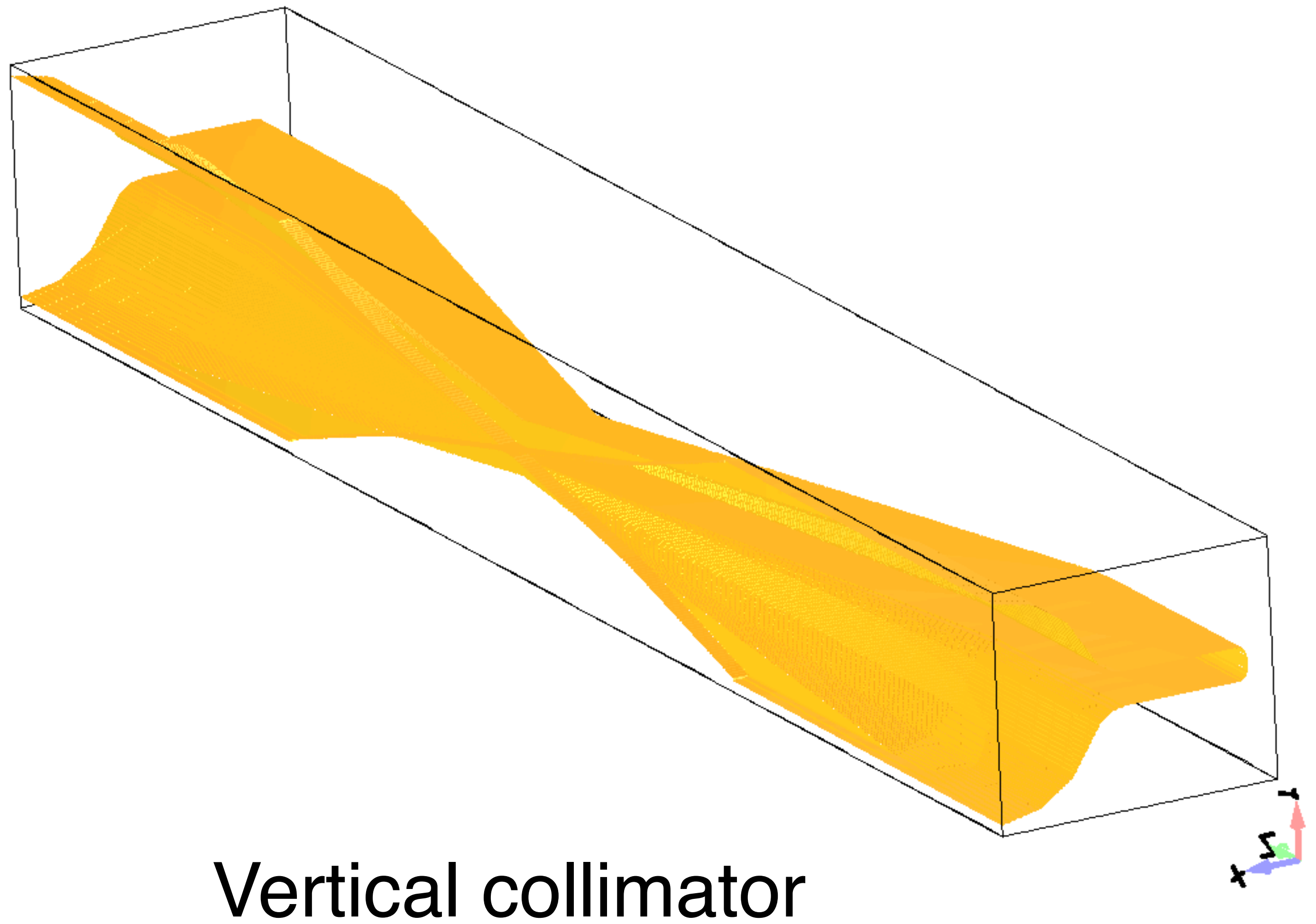
Long. FB kicker

Introduction

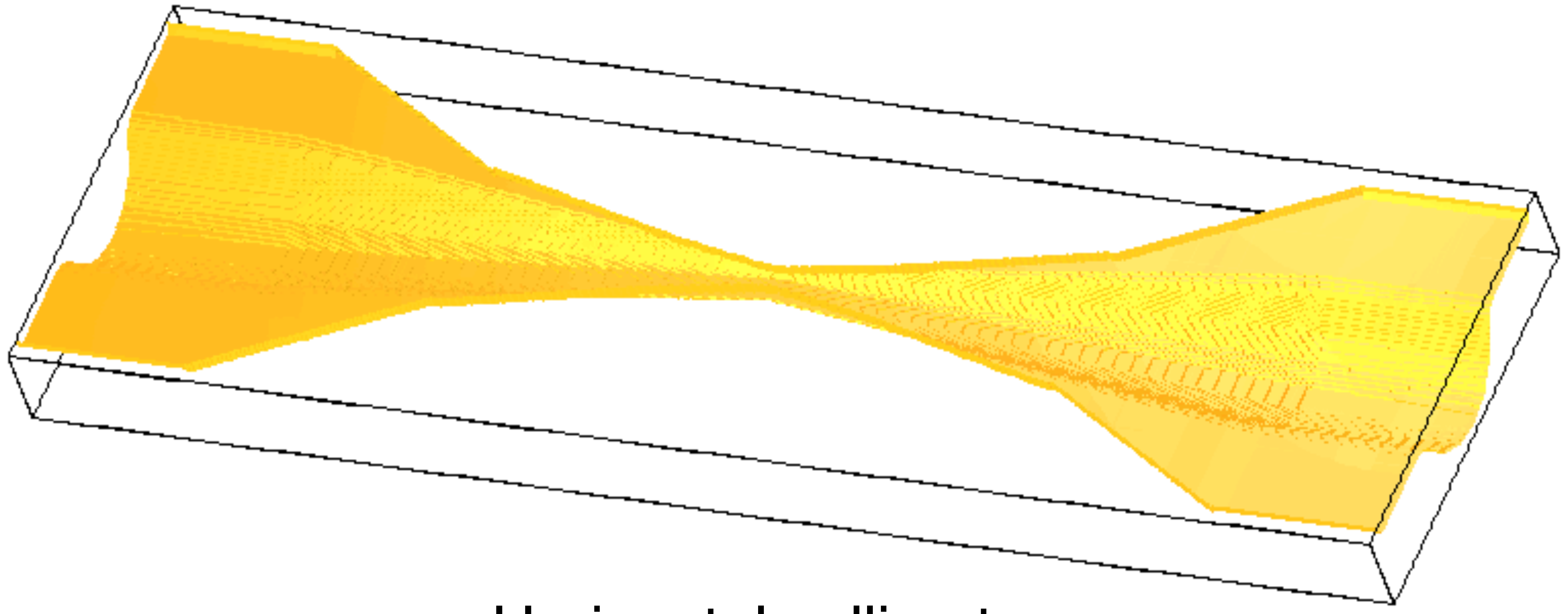
- Some components



Grooved beam pipe



Vertical collimator



Horizontal collimator

Longitudinal impedance model of SuperKEKB LER

- Use data of design stage.
- Assume collimator settings on Jun. 30, 2021.
- The table is for σ_z=5 mm.
- Ref.[2] for details.

	Number of items	Total loss factor (V/pC)	Total Resistance (Ohm)	Total inductance (nH)
ARES	22	8.9	524	0
Comb bellows	1047	2.7	159	5.1
MO flange	2000	0.2	13.7	4.1
Pumping port (m)	2200/0.4	0	0	0
SR mask	1000	0	0	0
IR duct	1	0.04	0	0.5
BPM	445	0.1	8.2	0.6
Transverse FB kicker	2	0.4	26	0
Transverse FB BPM	12	0.02	1.0	0.02
Longitudinal FB kicker	2	1.8	105	0
Grooved beam pipe (m)	520/0.4	0.1	5.7	0.9
Tapers	25	0.01	0.7	0.1
Clearing electrode (m)	150/0.8	0.04	2.2	2.3
Collimators	-	1.4	82	18.2
Resistive wall	-	3.9	230	5.7
Total	-	19.6	1157	37.6

[2] D. Zhou et al., Impedance calculation and simulation of microwave instability for the main rings of SuperKEKB, in Proceedings of IPAC'14, Dresden, Germany..

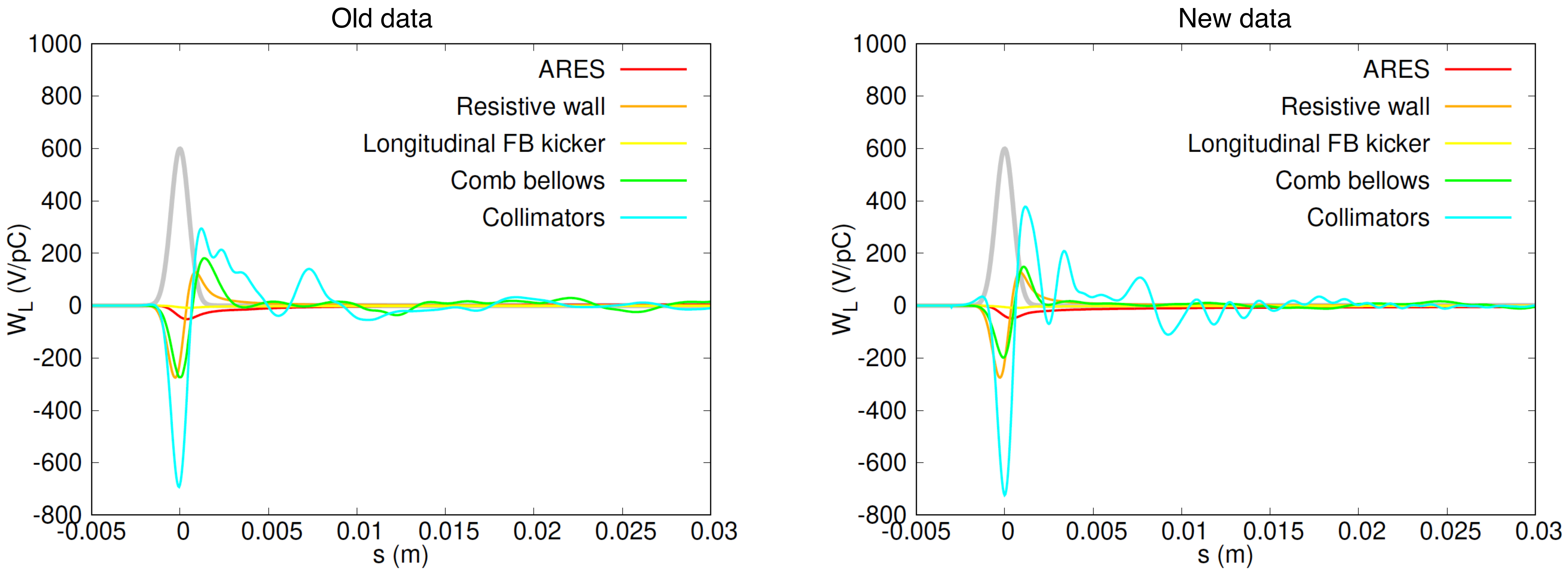
Longitudinal impedance model of SuperKEKB LER

- Use data of 2021.
- Assume collimator settings on Jun. 30, 2021.
- The table is for σ_z=5 mm.

	Number of items	Total loss factor (V/pC)	Total Resistance (Ohm)	Total inductance (nH)
ARES	22	10.2	601	0
Comb bellows	1047	1.4	83	4.7
MO flange	2000	0.01	0.5	1.1
Pumping port (m)	2200/0.4	0	0	0
SR mask	1000	0	0	0
IR duct	1	0.002	0.1	0.6
BPM	445	0.1	8.5	0.6
Transverse FB kicker	2	0.4	26	0
Transverse FB BPM	12	0.02	1.0	0.03
Longitudinal FB kicker	2	1.8	105	0
Grooved beam pipe (m)	520/0.4	0.1	6.3	0.9
Tapers	25	0.01	0.4	0.06
Clearing electrode (m)	150/0.8	0.1	4	11
Collimators	-	0.7	44	13.4
Resistive wall	-	3.9	230	5.7
Total	-	18.8	1112	37.6

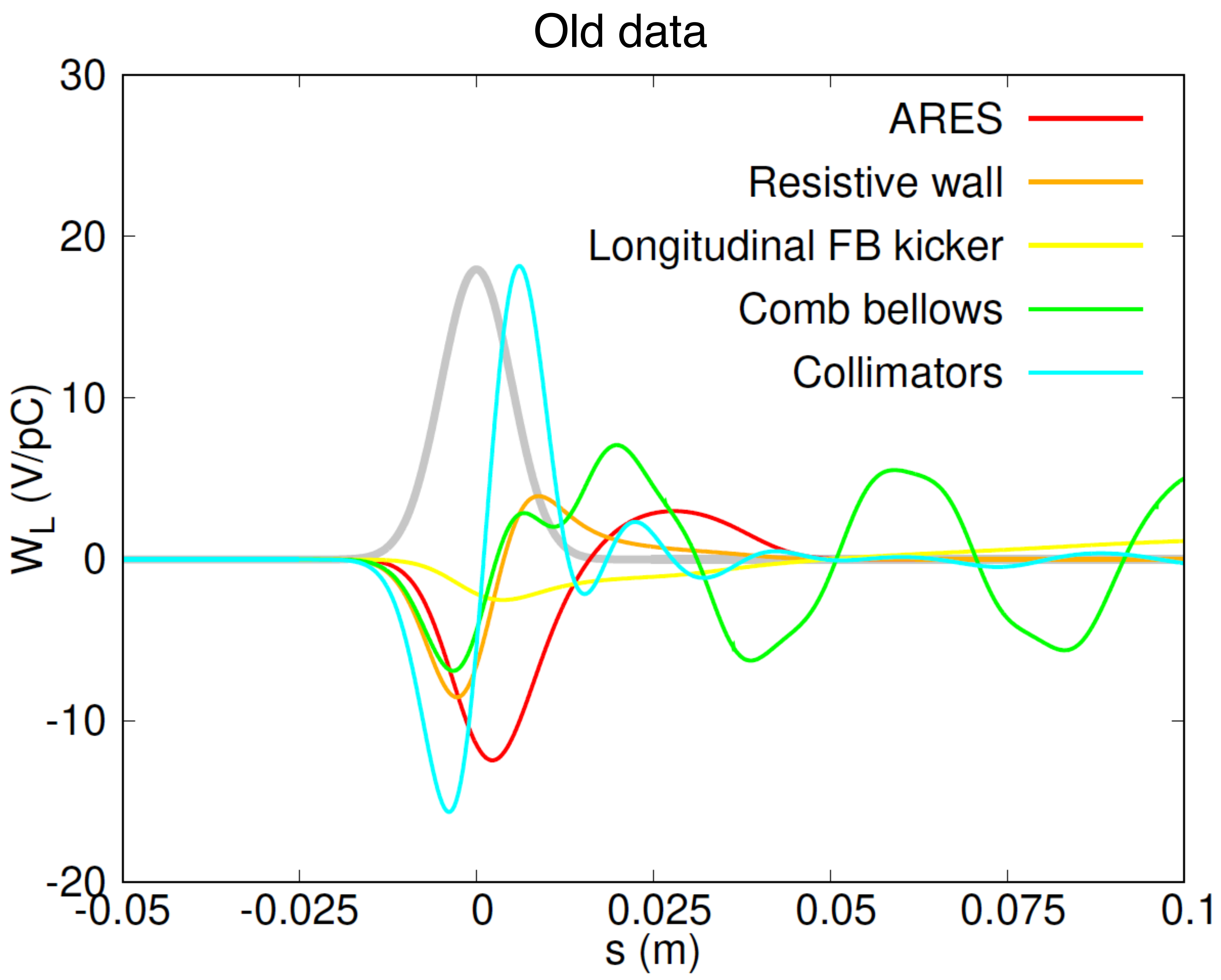
Longitudinal impedance model of SuperKEKB LER

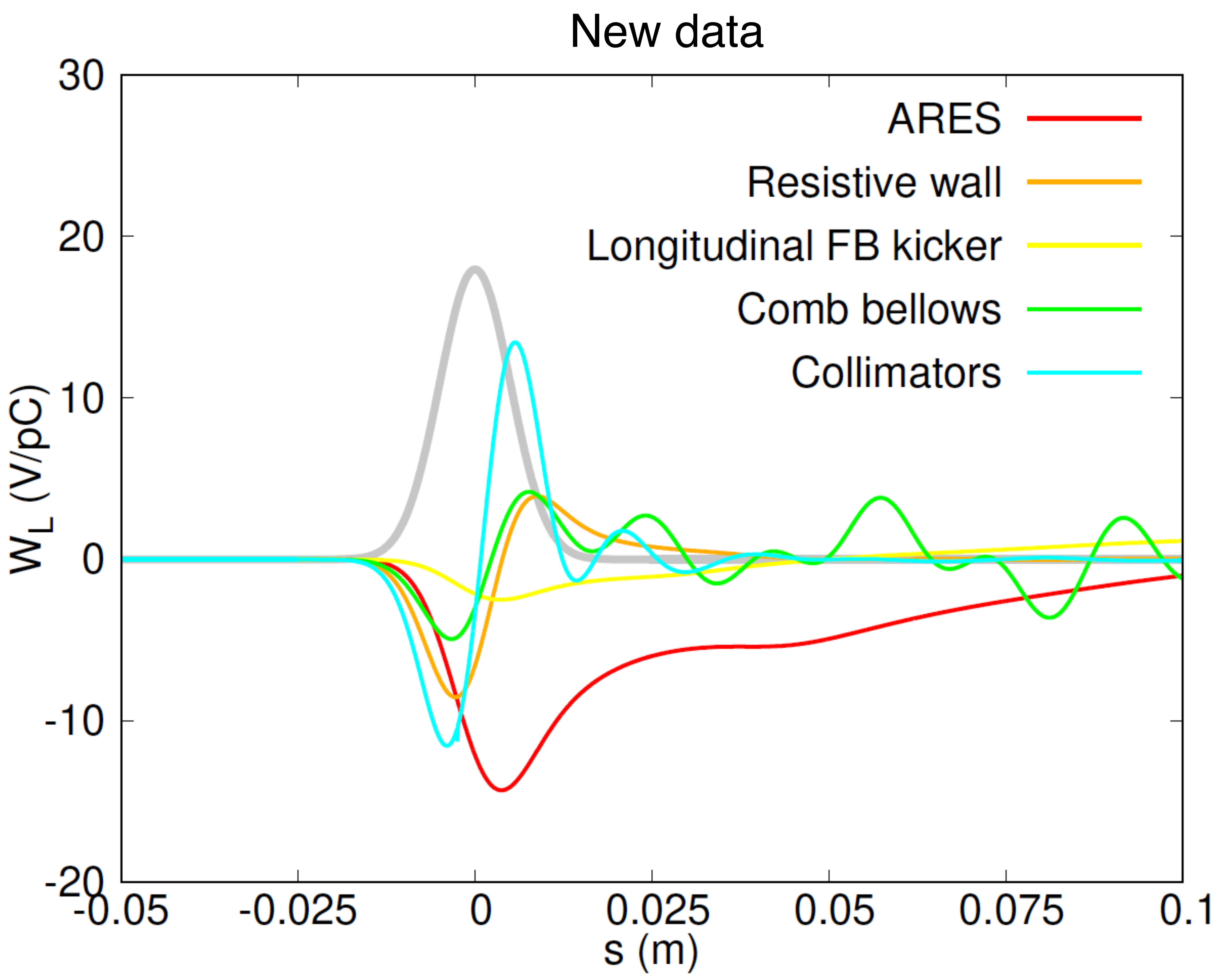
- Comparison of old and new model: Pseudo-Green's function wakes for σ_z=0.5 mm.
  - Top-5 sources: ARES, RW, Long. FB kickers, Comb bellows, Collimators.



Longitudinal impedance model of SuperKEKB LER

- Comparison of old and new model: Long-bunch wakes for σ_z=5 mm.
  - Top-5 sources: ARES, RW, Long. FB kickers, Comb bellows, Collimators.

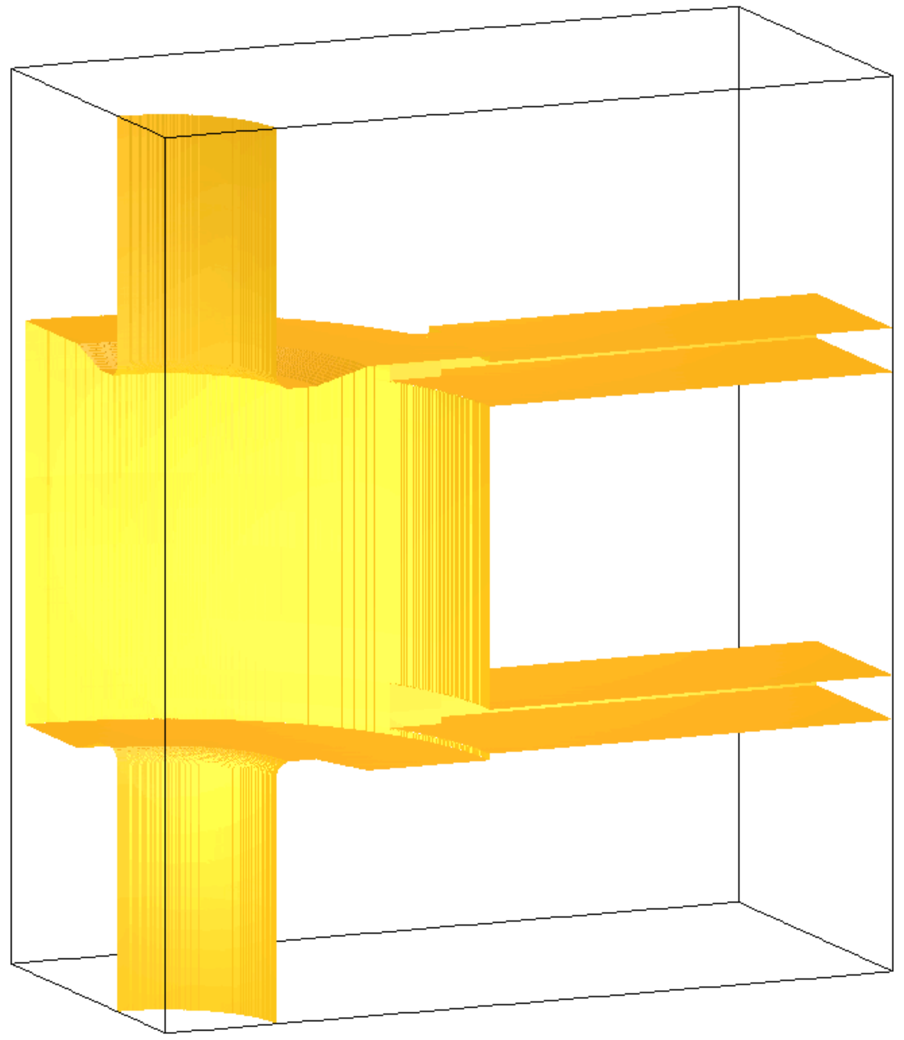




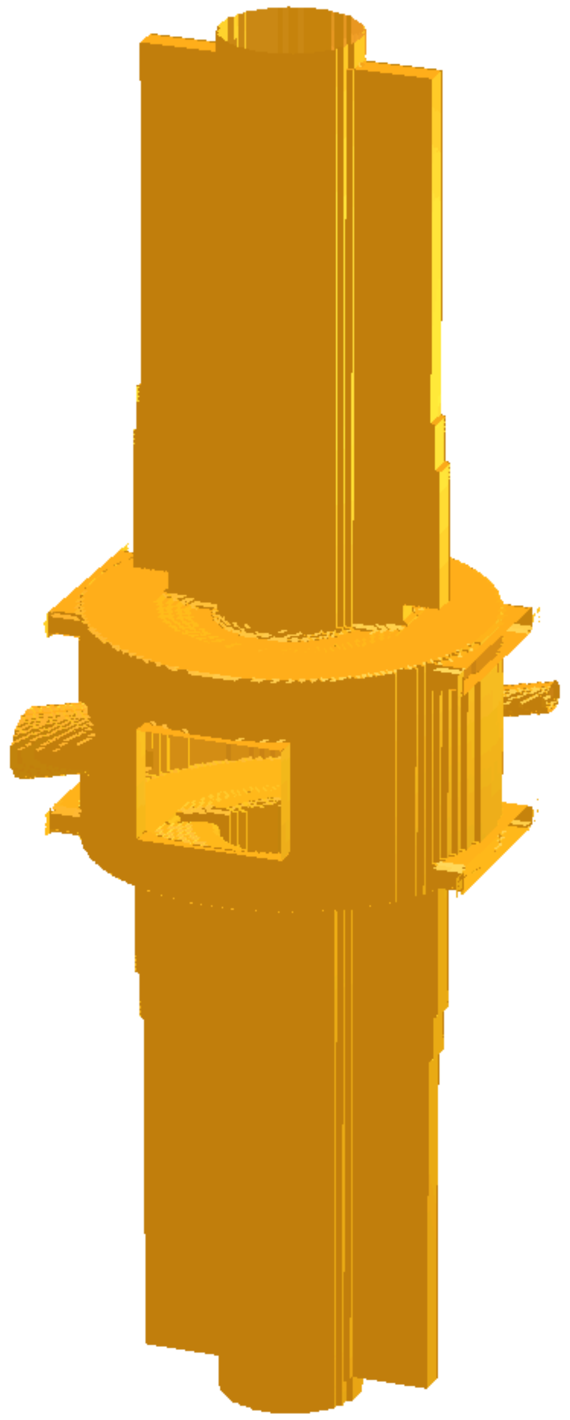
Longitudinal impedance model of SuperKEKB LER

- Comparison of old and new model: Pseudo-Green's function wakes for σ_z=5 mm.
  - New model for bellows is better: Cavity structure shielded by RF fingers.
  - Old model for RF cavity is better: Realistic structure modeled.

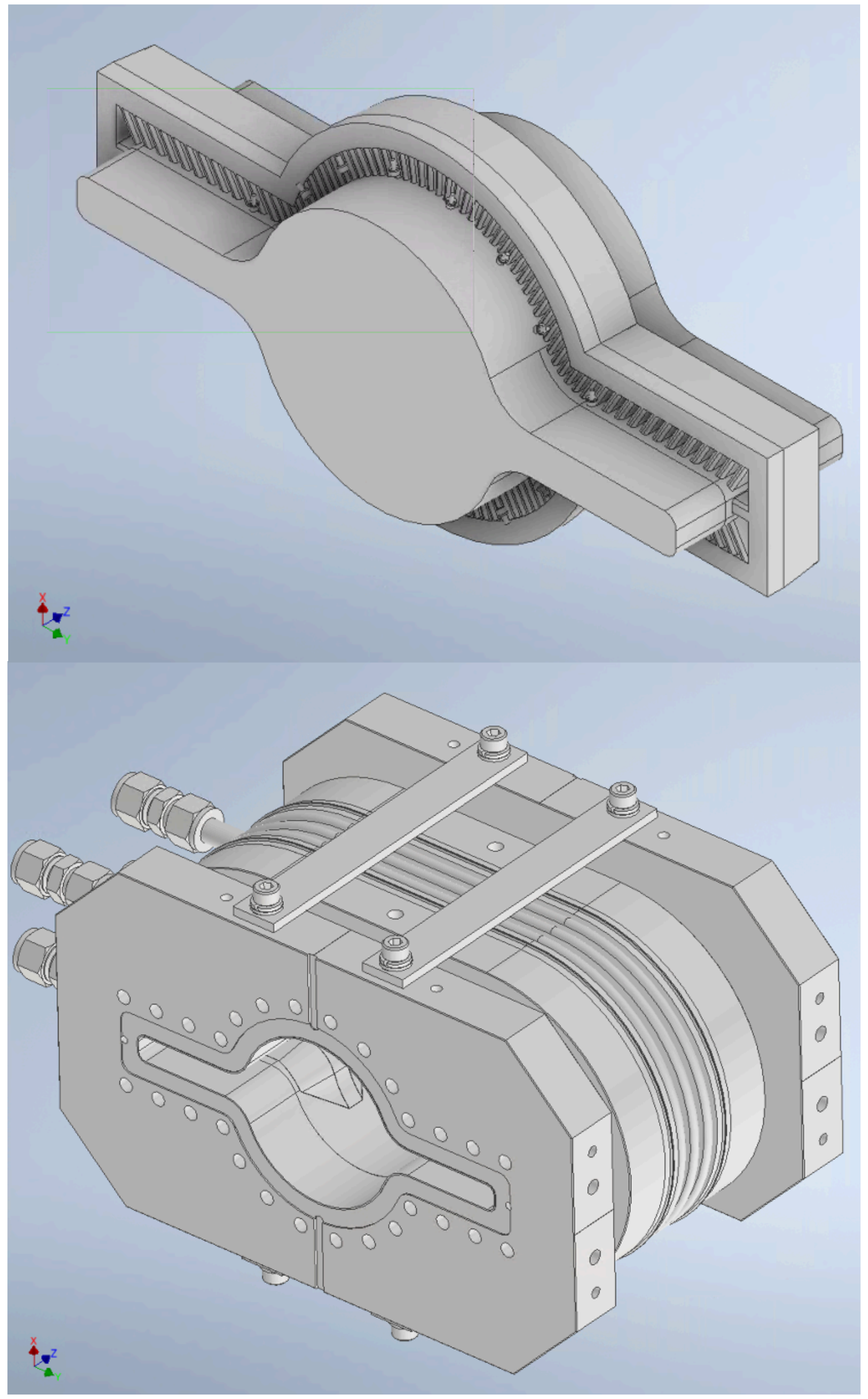
New model



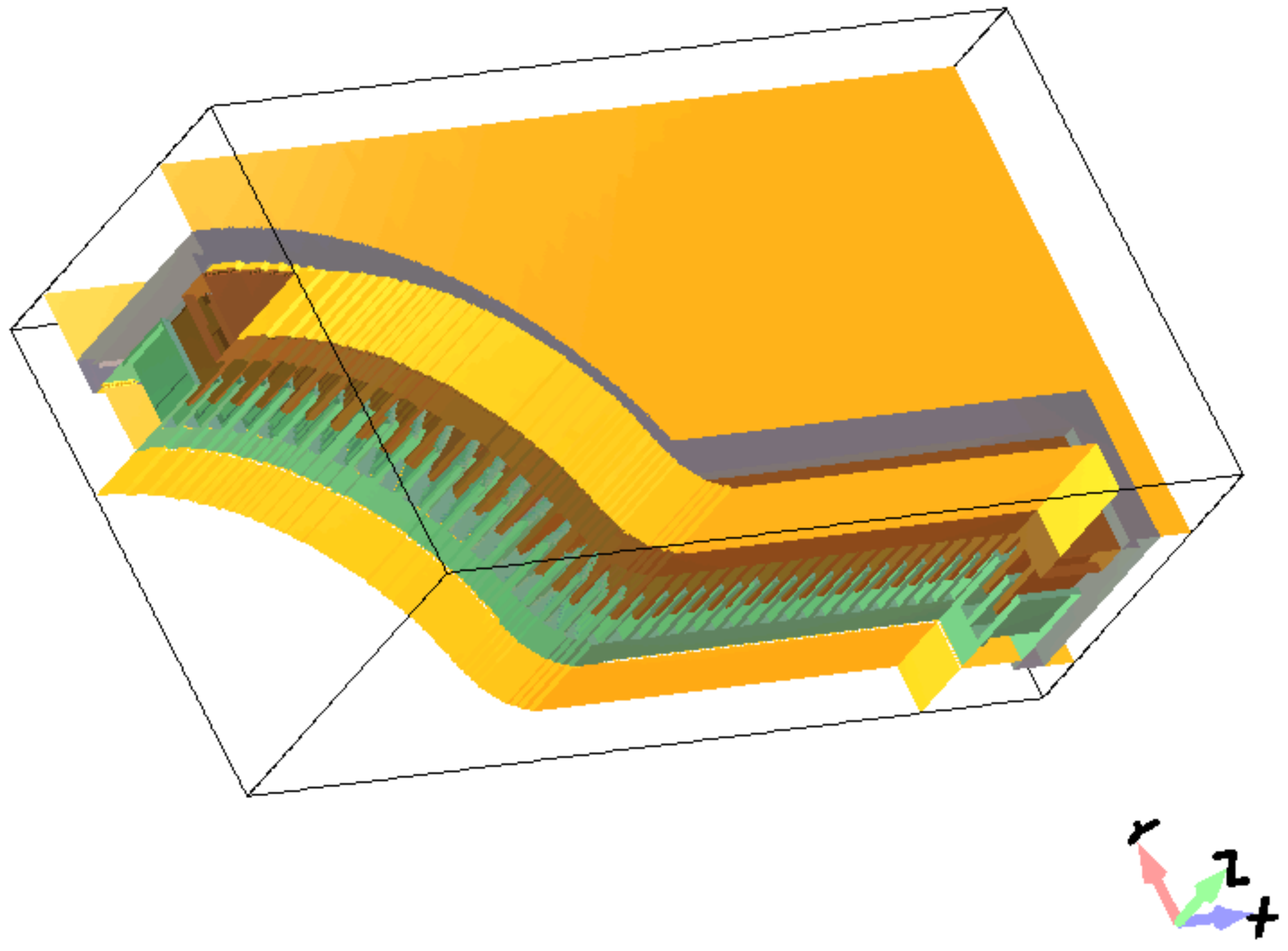
Old model



Comb bellows

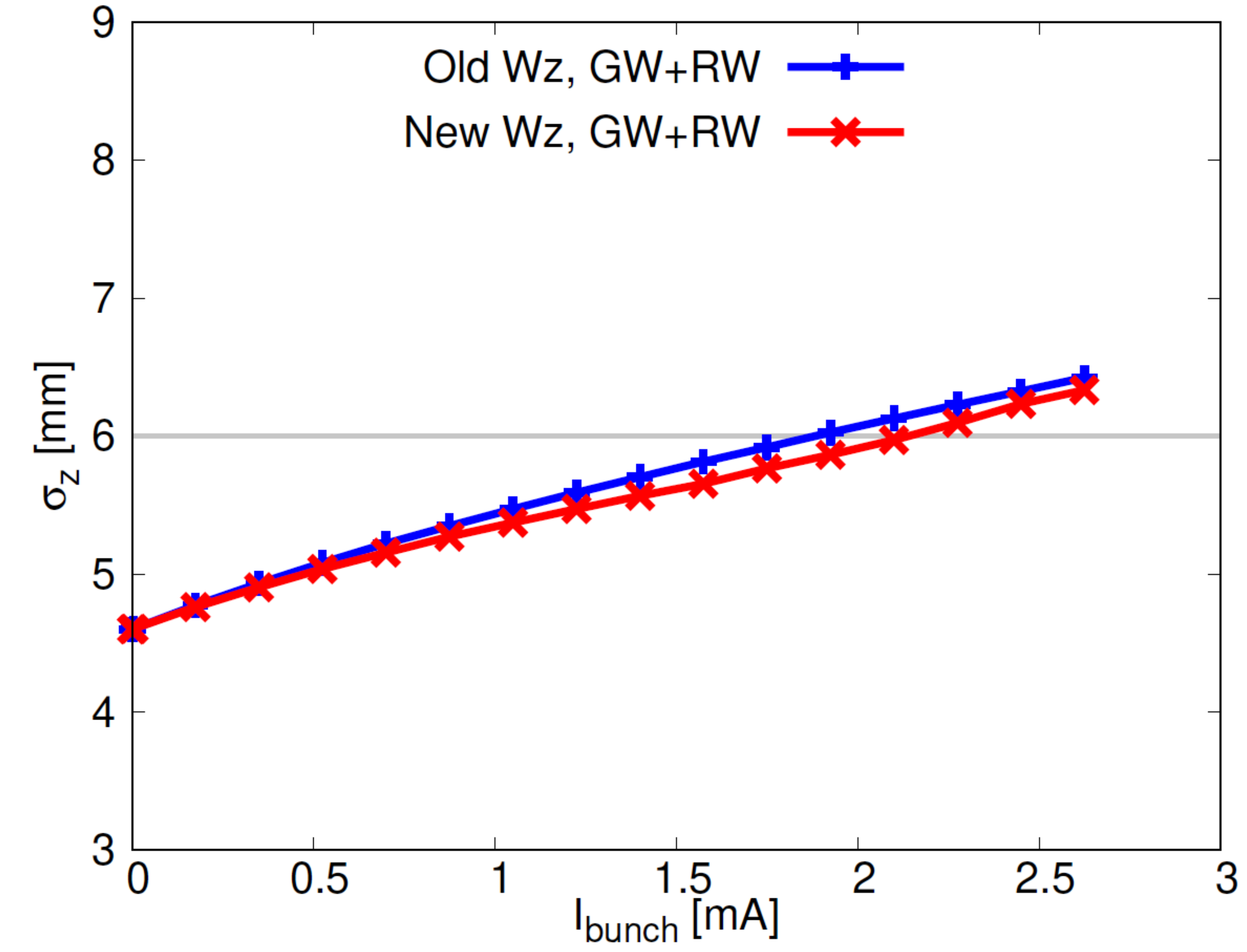


Comb bellows
(Old GdfidL model)

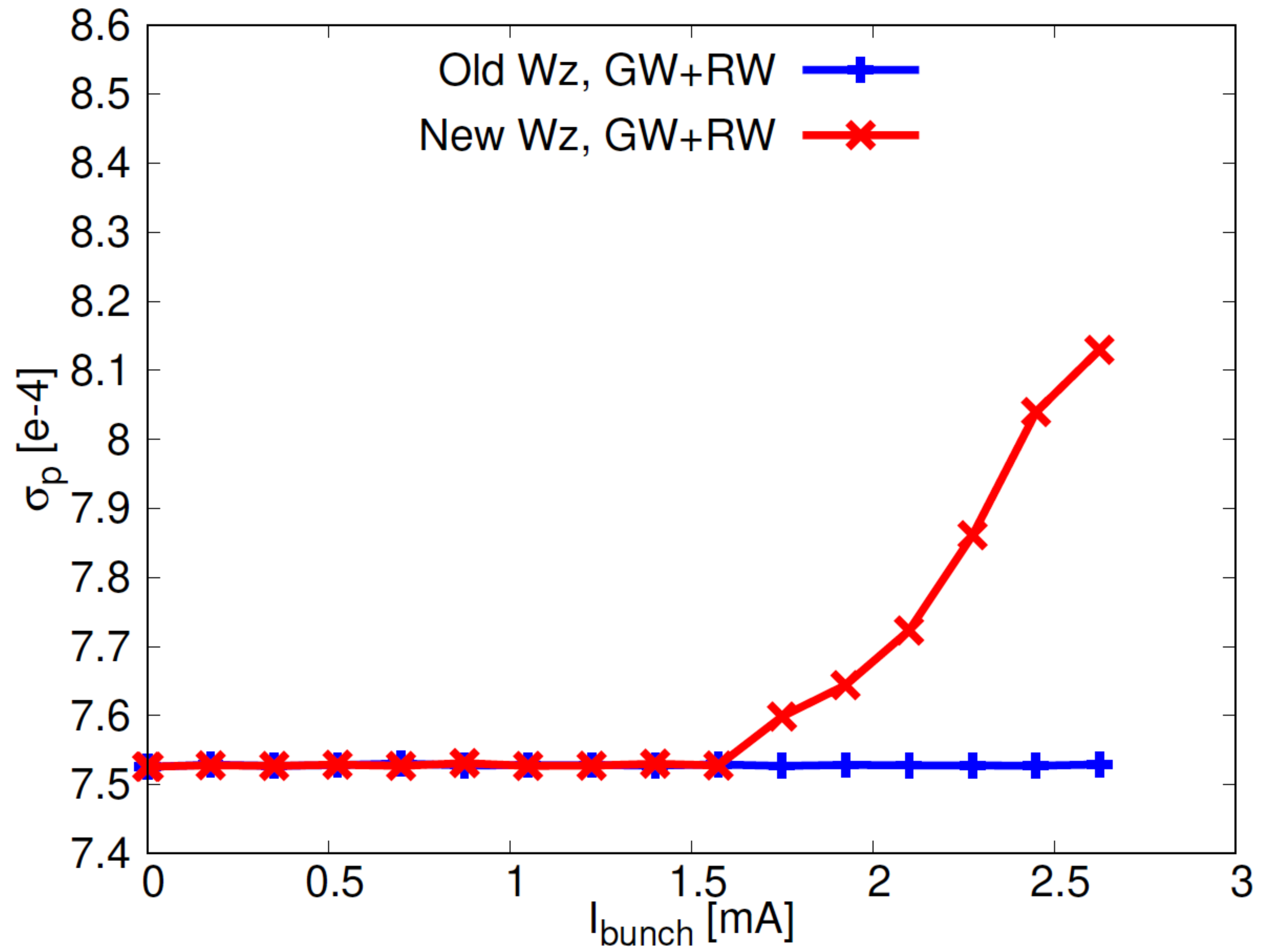


Simulation of bunch lengthening and microwave instability by Vlasov solver

- Use beam parameters of Jun. 30, 2021 ($\beta_y^* = 1$ mm).
- Compare old and new longitudinal impedance model.
- New model gives lower MWI threshold (to be understood)
  - Possible sources: More resistive wakes of ARES cavities, high-frequency noise in impedance model.

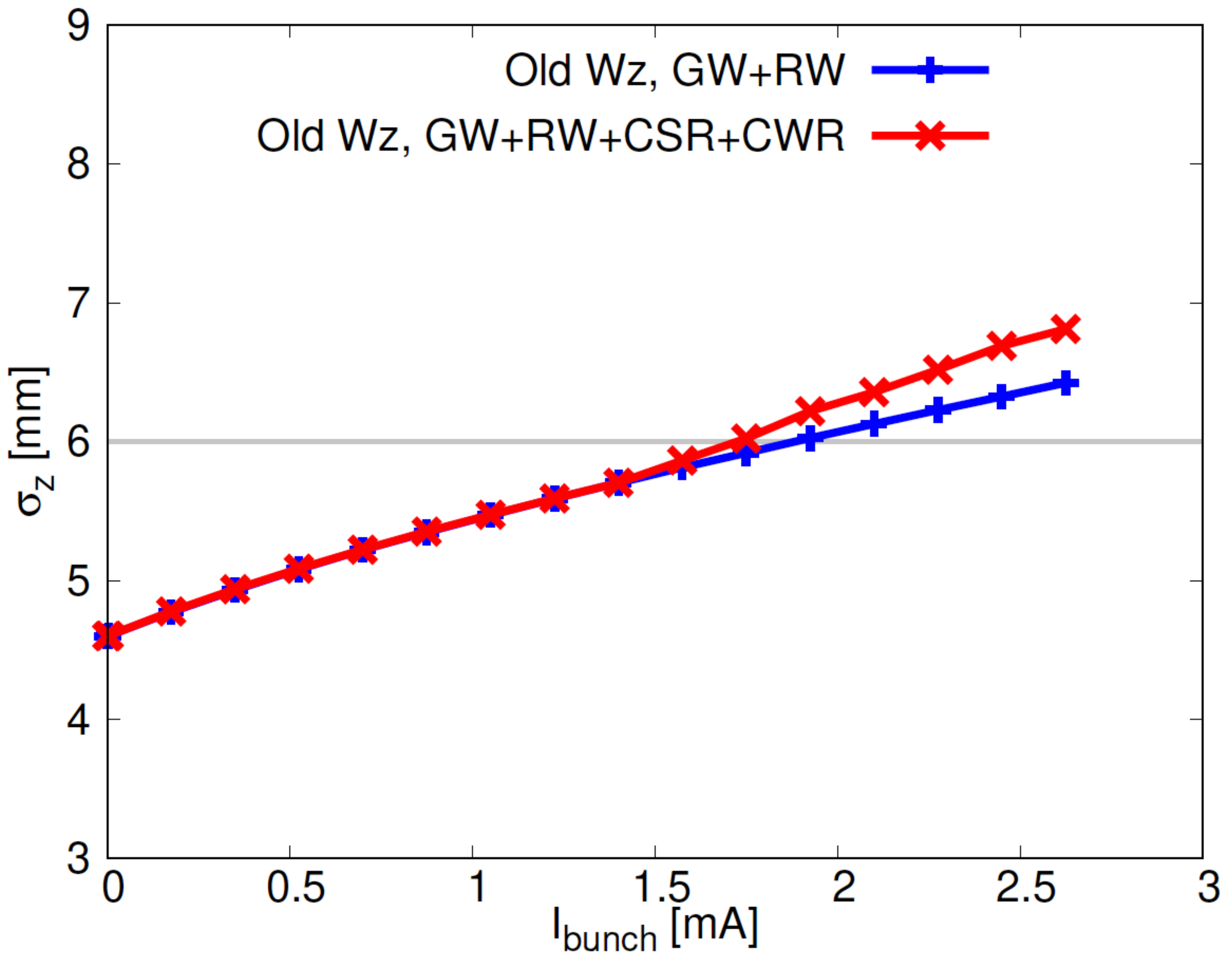


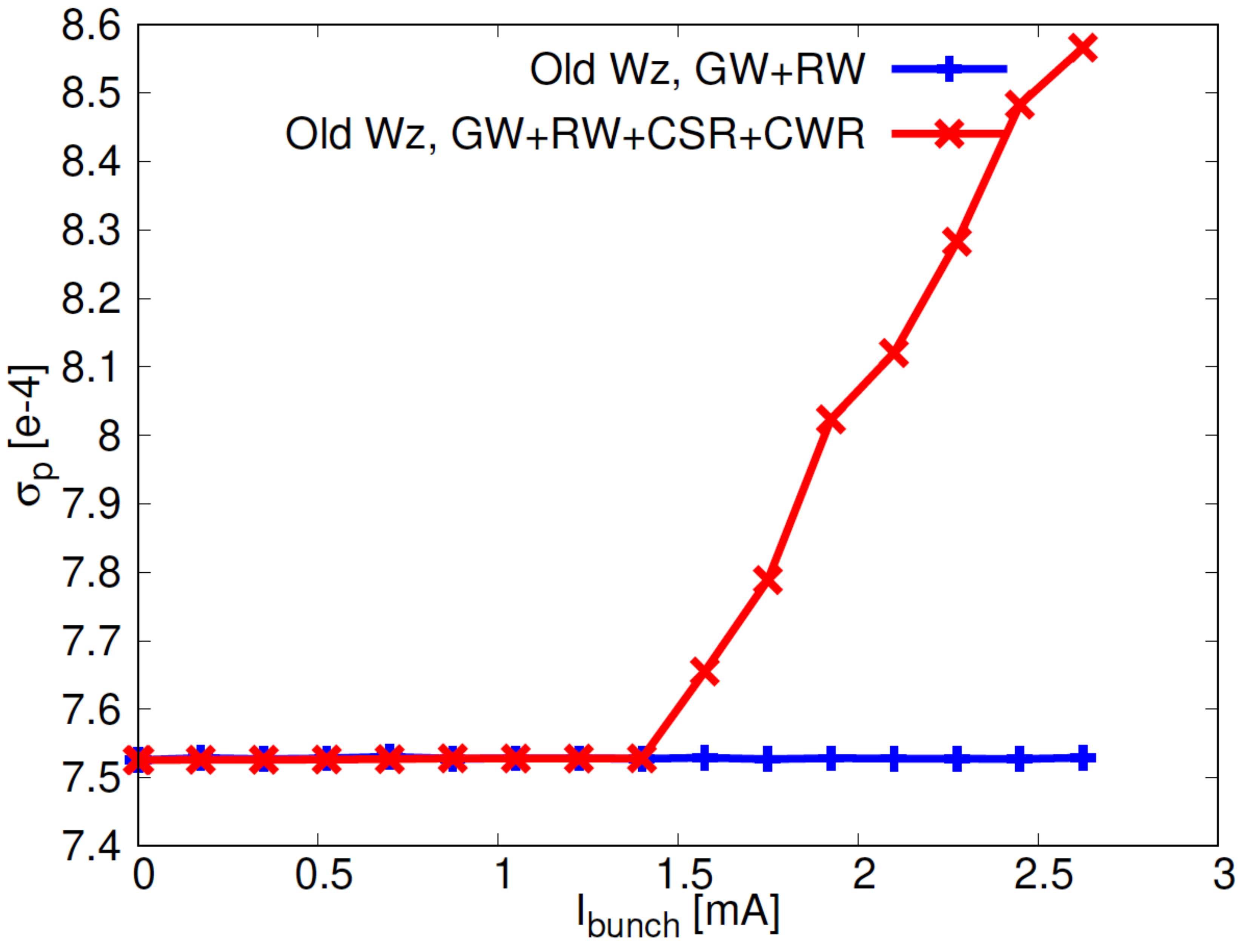
	Values
RF voltage (MV)	9.12
Beam energy (GeV)	4
Natural bunch length (mm)	4.6
Momentum compaction factor (E-4)	2.9690
Longitudinal damping time (ms)	22.84954
Energy spread (E-4)	7.52596
Energy loss per turn (MeV)	1.7621609
Synchrotron tune	0.0232639



Simulation of bunch lengthening and microwave instability by Vlasov solver

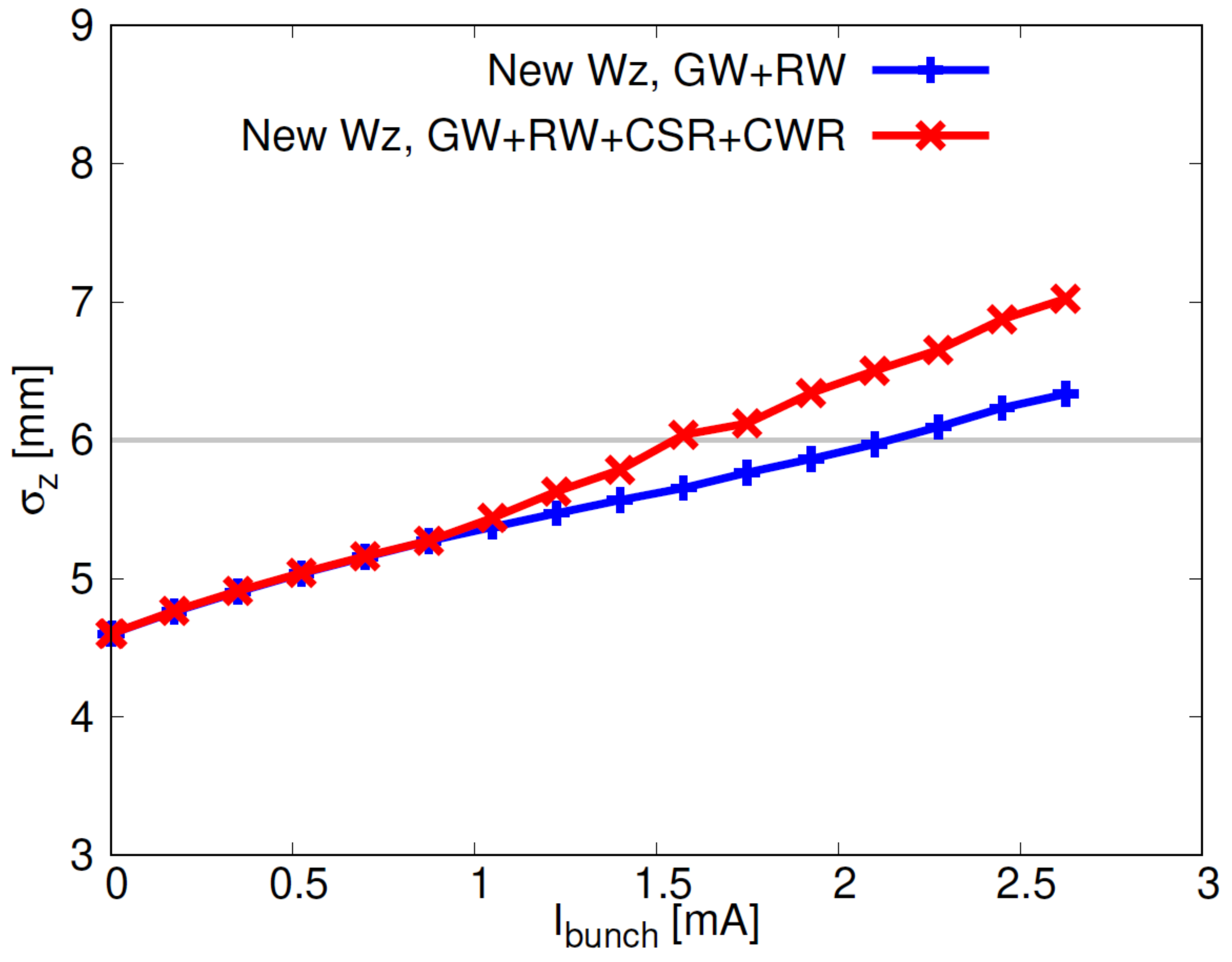
- Use beam parameters of Jun. 30, 2021.
- Using old impedance model with inclusion of CSR and CWR.
- CSR remarkably reduces MWI threshold. This was known [2].

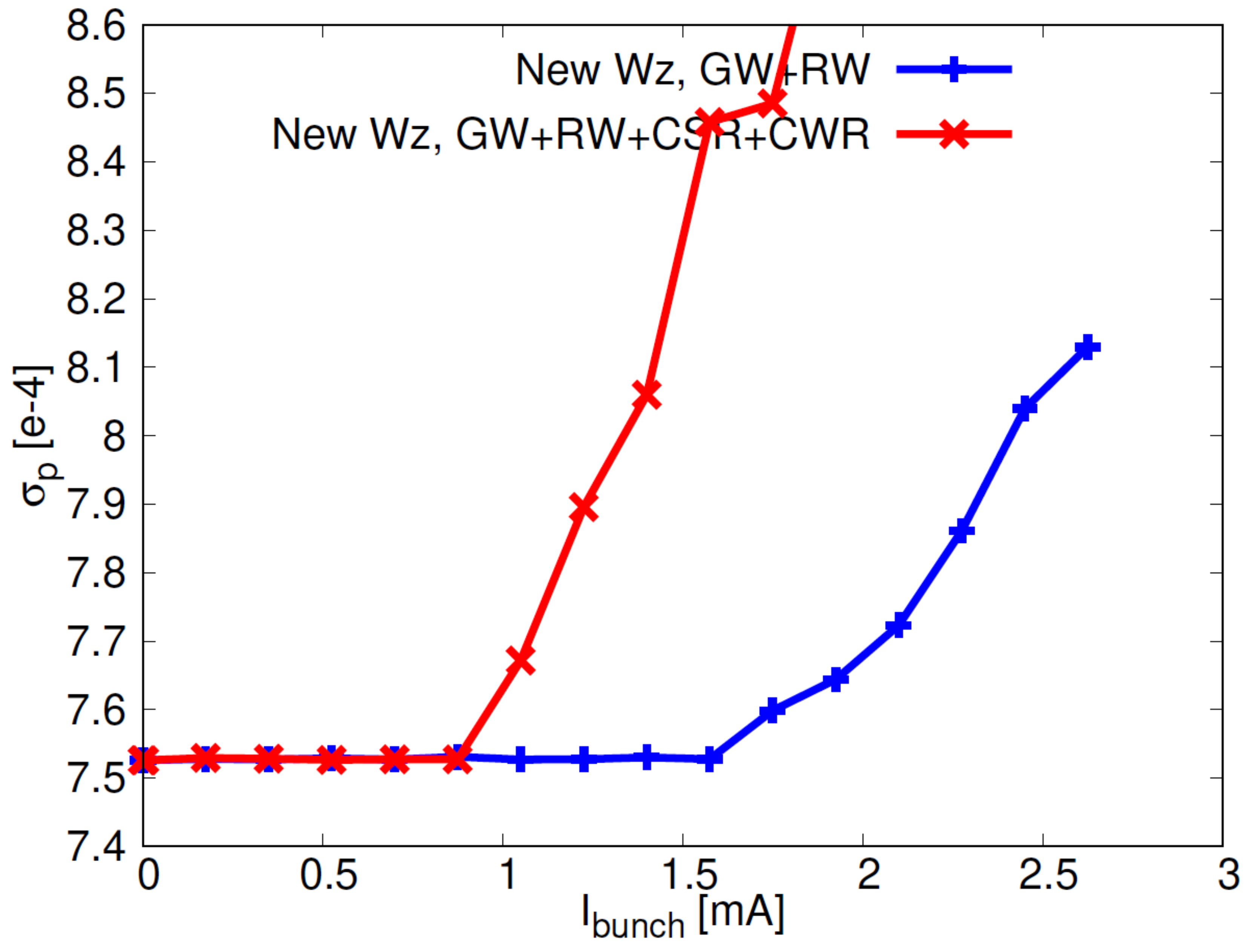




Simulation of bunch lengthening and microwave instability by Vlasov solver

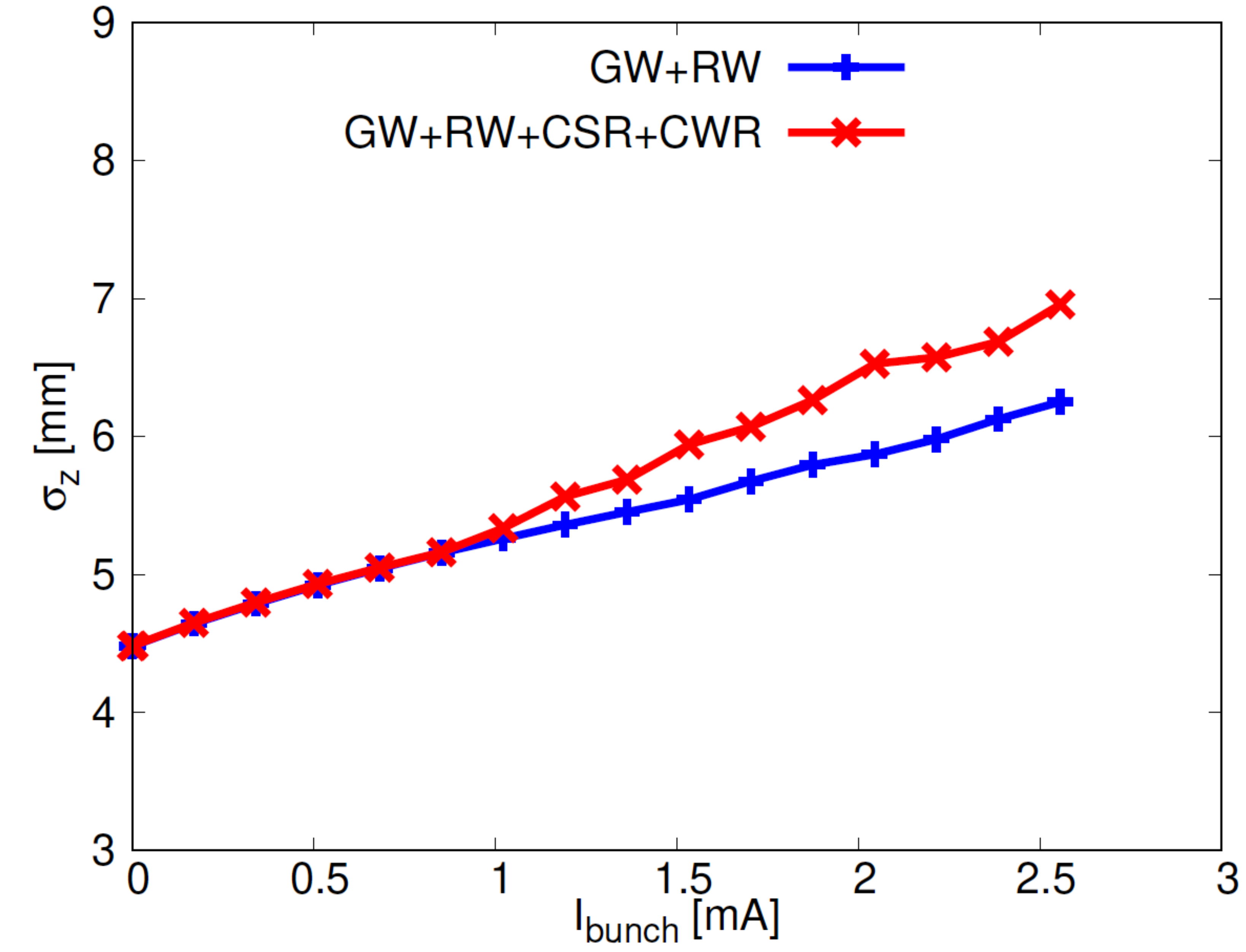
- Use beam parameters of Jun. 30, 2021.
- Using new impedance model with inclusion of CSR and CWR.
- The results with GW+RW are very consistent with M. Migliorati's using PyHEADTAIL (See Mauro's talk at this meeting).
  - Linear fitting of Vlasov results gives $\sigma_z\ (\mathrm{mm}) = 4.66 + 0.64 I_b\ (\mathrm{mA})$.
  - MWI threshold also similar.



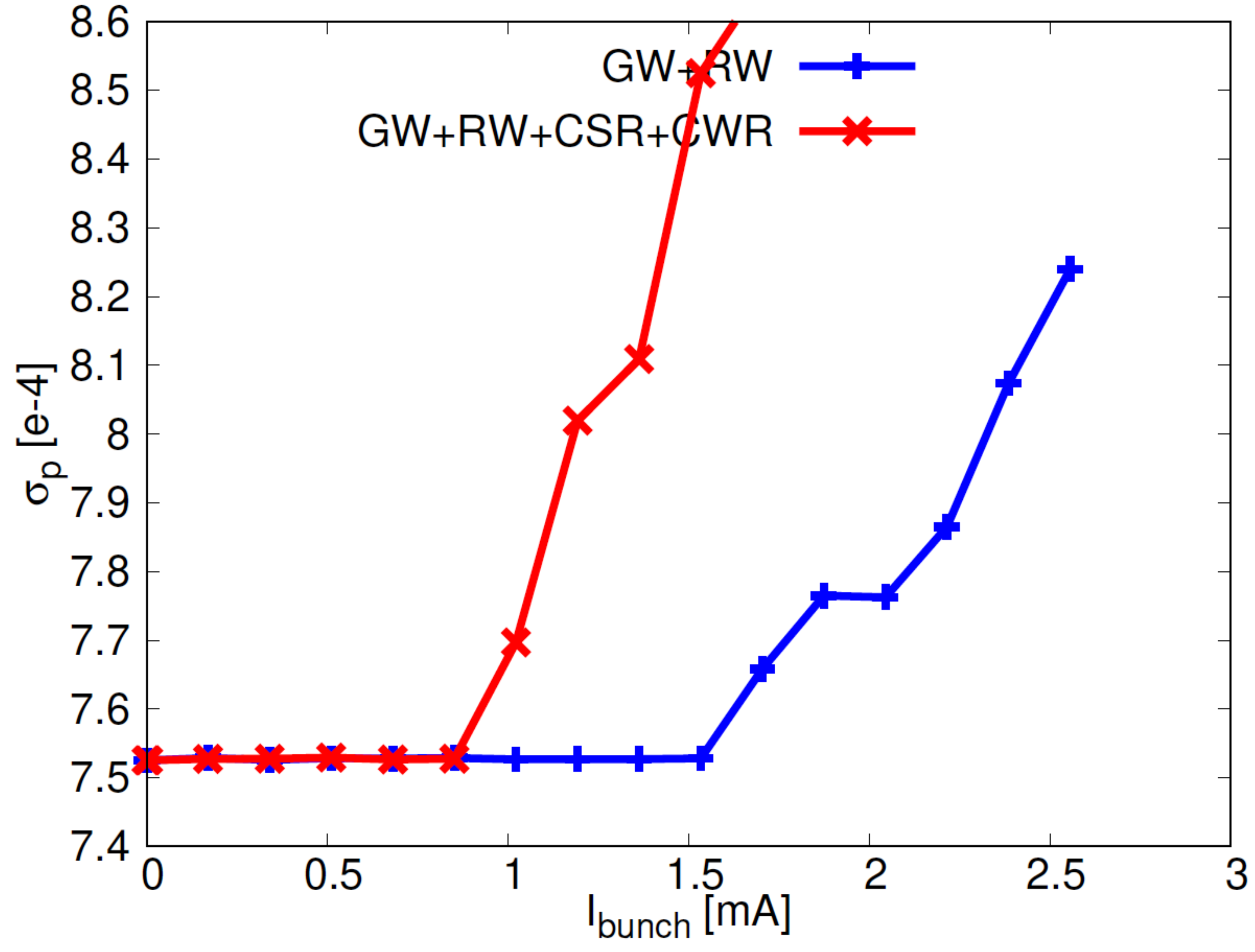


Simulation of bunch lengthening and microwave instability by Vlasov solver

- Use beam parameters of Oct. 26, 2021 (during TMCI machine study with $\beta_y^* = 8$ mm).
- See T. Ishibashi's talk at this meeting about TMCI study.



	Values
RF voltage (MV)	9.12
Beam energy (GeV)	4
Natural bunch length (mm)	4.48
Momentum compaction factor (E-4)	2.8158
Longitudinal damping time (ms)	22.84953
Energy spread (E-4)	7.52536
Energy loss per turn (MeV)	1.7621609
Synchrotron tune	0.022656



Vertical impedance model of SuperKEKB LER

- Use data of 2021.
- Assume collimator settings on Jun. 30, 2021.
- The table is for σ_z=5 mm.

	Number of items	Average β_y (m)	$\beta_y * \kappa_{yD}$ (V/pC)	$\beta_y * \kappa_{yQ}$ (V/pC)
ARES	22	17.7	-420	0
Comb bellows	1047	19.1	-867	182
MO flange	2000	19.1	-103	-3
Pumping port (m)	2200/0.4	19.1	0	0
SR mask	1000	19.1	0	0
IR duct	1	20.8	-661	170
BPM	445	28.0	-89	5
Transverse FB kicker	2	7.8	-40	0
Transverse FB BPM	12	19.4	-9	0
Longitudinal FB kicker	2	20.2	-155	0
Grooved beam pipe (m)	520/0.4	19.0	-196	-187
Tapers	25	19.1	0	10
Clearing electrode (m)	150/0.8	15.7	-1464	-1240
Resistive wall	-	19.1	-1111	-
Total	-	-	-5116	-1062

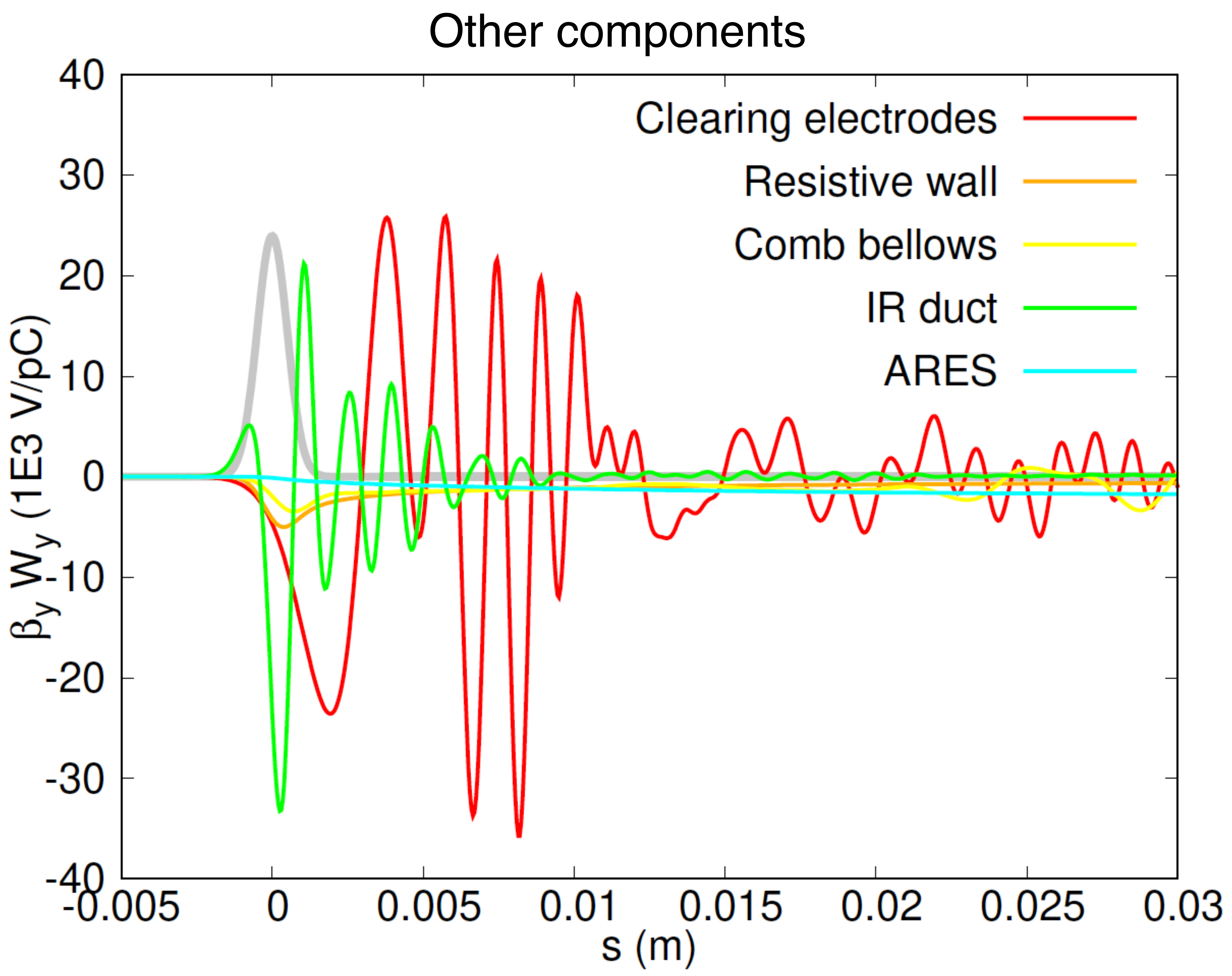
Vertical impedance model of SuperKEKB LER

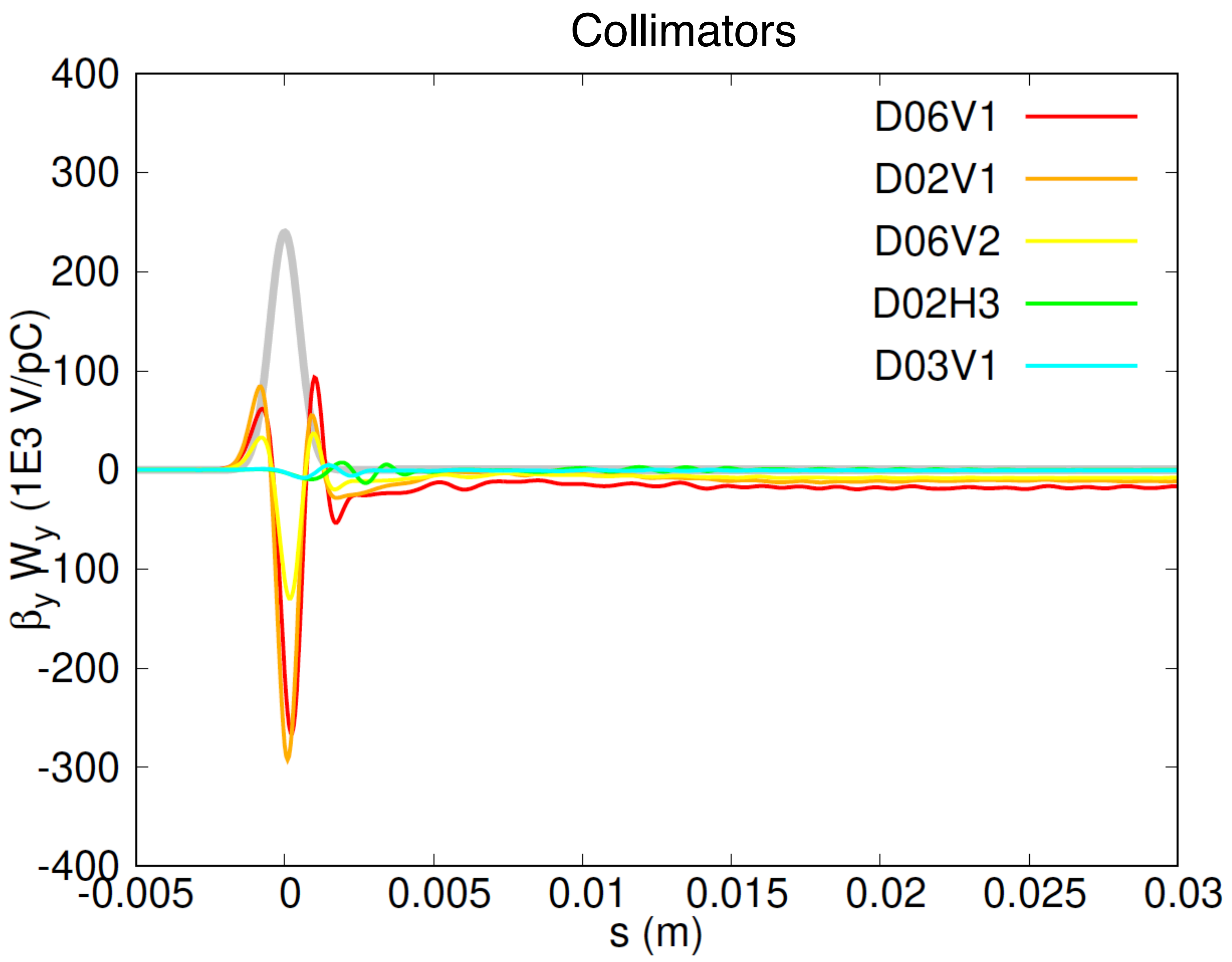
- Use data of 2021.
- Assume collimator settings on Jun. 30, 2021.
- The table is for σ_z=5 mm.

	Half gap (mm)	Average β_y (m)	$\beta_y * \kappa_{yD}$ (V/pC)	$\beta_y * \kappa_{yQ}$ (V/pC)
D06H1	9	5.6	-82	76
D06H3	8.69	5.6	-85	86
D06V1	2.86	67.3	-13696	-6190
D06V2	2.27	20.6	-6137	-2658
D03H1	12	3.0	-44	10
D03V1	8	17.0	-608	-398
D02H1	7.98	24.7	-404	493
D02H2	10	13.2	-191	125
D02V1	1.225	13.9	-11025	-3523
D02H3	13	55.4	-817	55
D02H4	8.03	13.3	-217	262
Total	-	-	-33305	-11662

Vertical impedance model of SuperKEKB LER

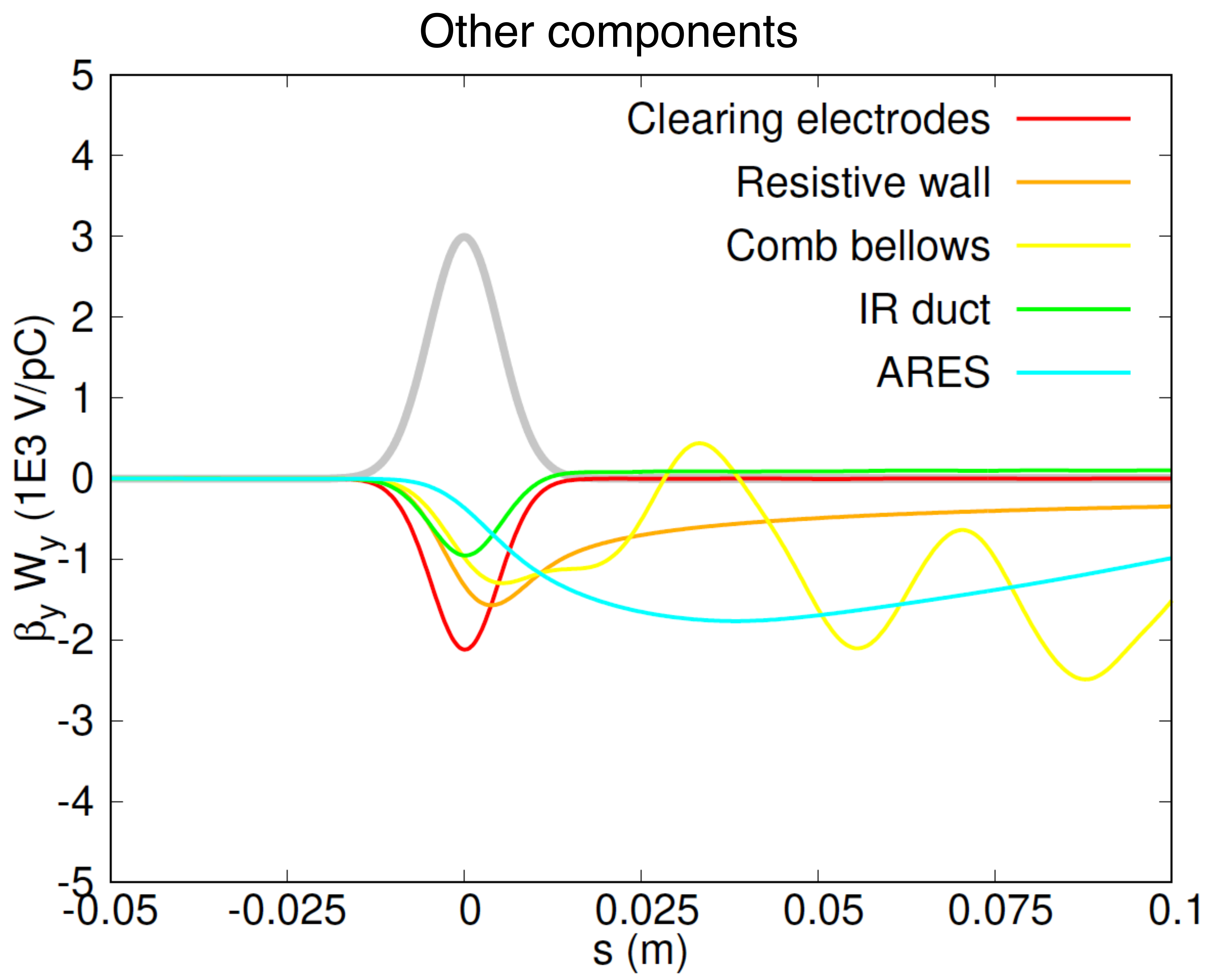
- Plots of Pseudo-Green's function wakes for σ_z=0.5 mm.
- Assume collimator settings on Jun. 30, 2021.

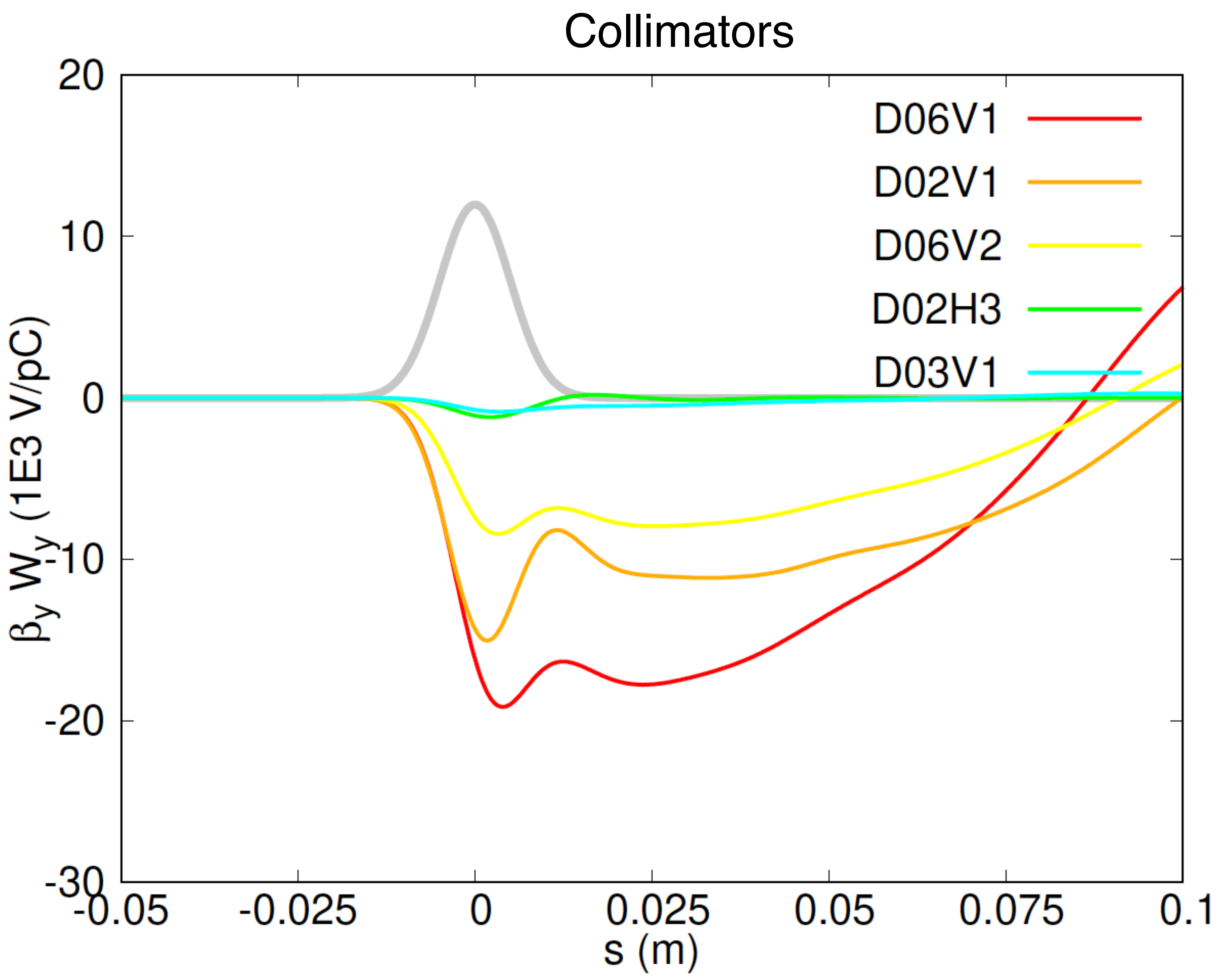




Vertical impedance model of SuperKEKB LER

- Long-bunch wakes for σ_z=5 mm.
- Assume collimator settings on Jun. 30, 2021.





Horizontal impedance model of SuperKEKB LER

- Use data of 2021.
- Assume collimator settings on Jun. 30, 2021.
- The table is for σ_z=5 mm.

	Number of items	Average β_x (m)	$\beta_x*\kappa_{xD}$ (V/pC)	$\beta_x*\kappa_{xQ}$ (V/pC)
ARES	22	17.2	-408	0
Comb bellows	1047	15.8	-442	-77
MO flange	2000	15.8	-82	2
Pumping port (m)	2200/0.4	15.8	-2	0
SR mask	1000	15.8	0	0
IR duct	1	0.34	-14	-4
BPM	445	18.9	-64	-4
Transverse FB kicker	2	18.9	-31	-69
Transverse FB BPM	12	23.9	-12	0
Longitudinal FB kicker	2	35.5	-273	0
Grooved beam pipe (m)	520/0.4	11	-547	42
Tapers	25	15.8	-9	-9
Clearing electrode (m)	150/0.8	15.6	-174	1285
Resistive wall	-	15.8	-924	-
Total	-	-	-2982	1167

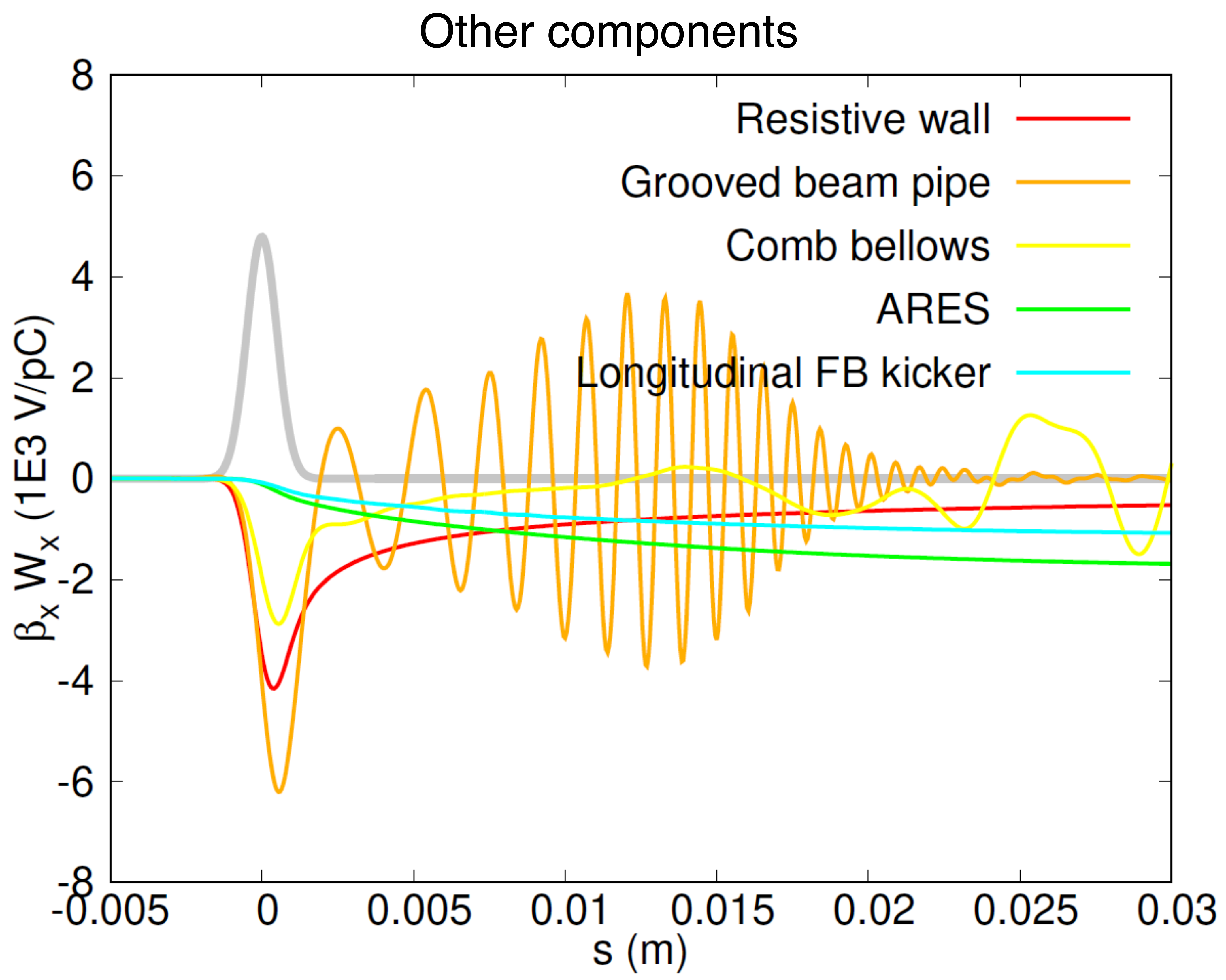
Horizontal impedance model of SuperKEKB LER

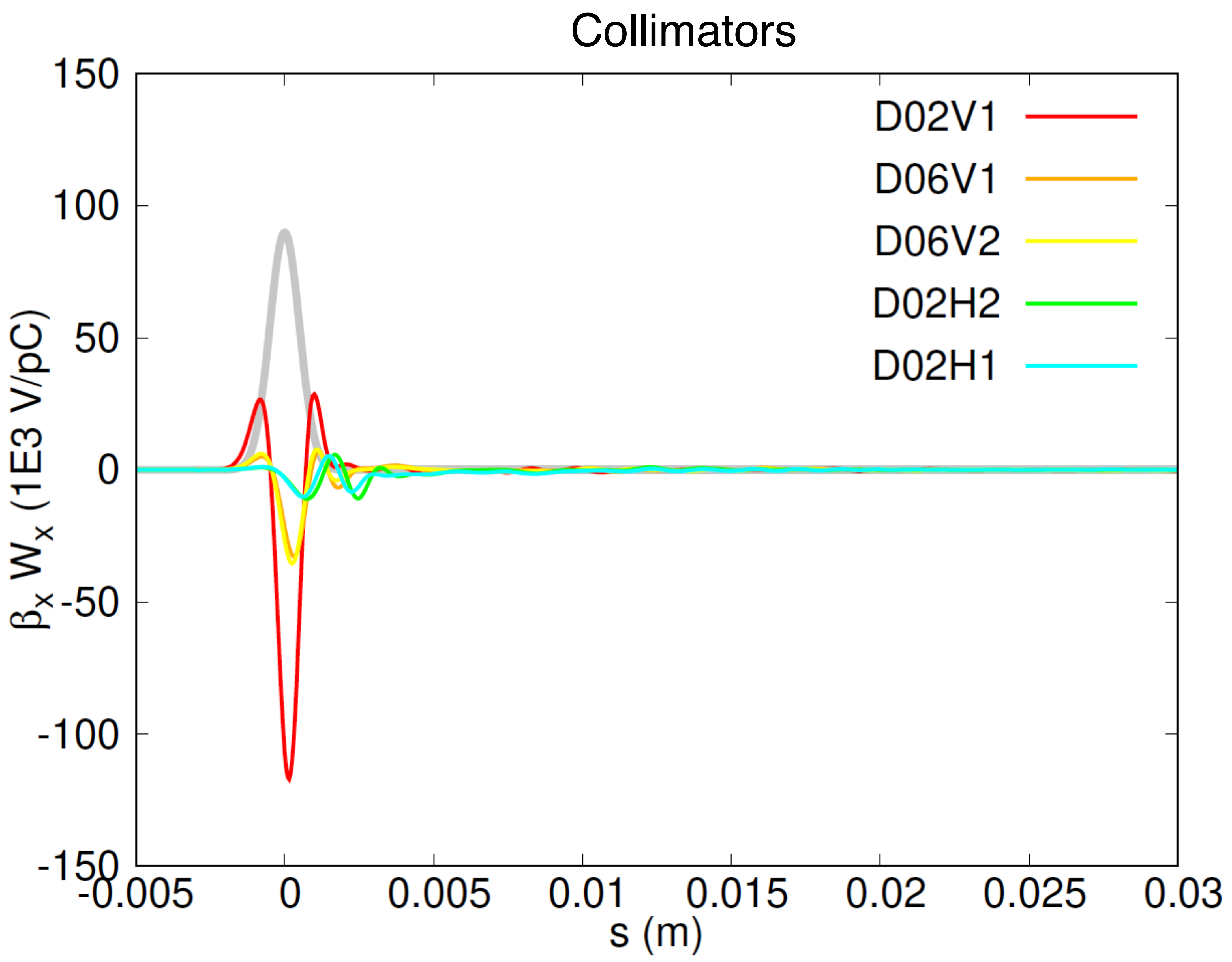
- Use data of 2021.
- Assume collimator settings on Jun. 30, 2021.
- The table is for σ_z=5 mm.

	Half gap (mm)	Average β_x (m)	$\beta_x * \kappa_{xD}$ (V/pC)	$\beta_x * \kappa_{xQ}$ (V/pC)
D06H1	9	24.2	-786	-335
D06H3	8.69	24.2	-882	-382
D06V1	2.86	14.6	-1201	1249
D06V2	2.27	10	-1134	1147
D03H1	12	29	-485	-95
D03V1	8	10.4	-157	241
D02H1	7.98	20.8	-947	-421
D02H2	10	36.5	-949	-353
D02V1	1.225	10.9	-2734	2738
D02H3	13	50.8	-703	-53
D02H4	8.03	20.4	-916	-407
Total	-	-	-10893	3329

Horizontal impedance model of SuperKEKB LER

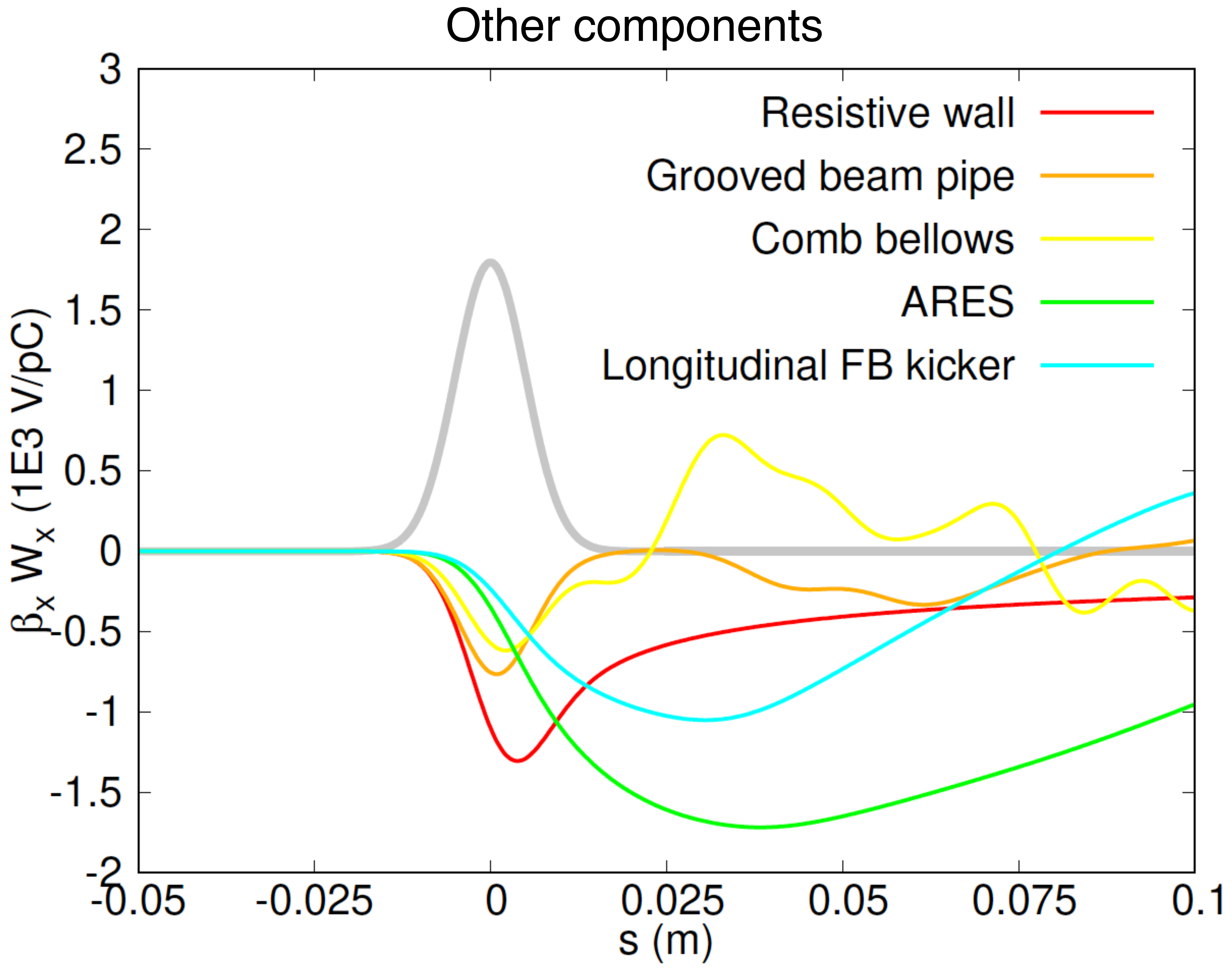
- Plots of Pseudo-Green's function wakes for σ_z=0.5 mm.
- Assume collimator settings on Jun. 30, 2021.

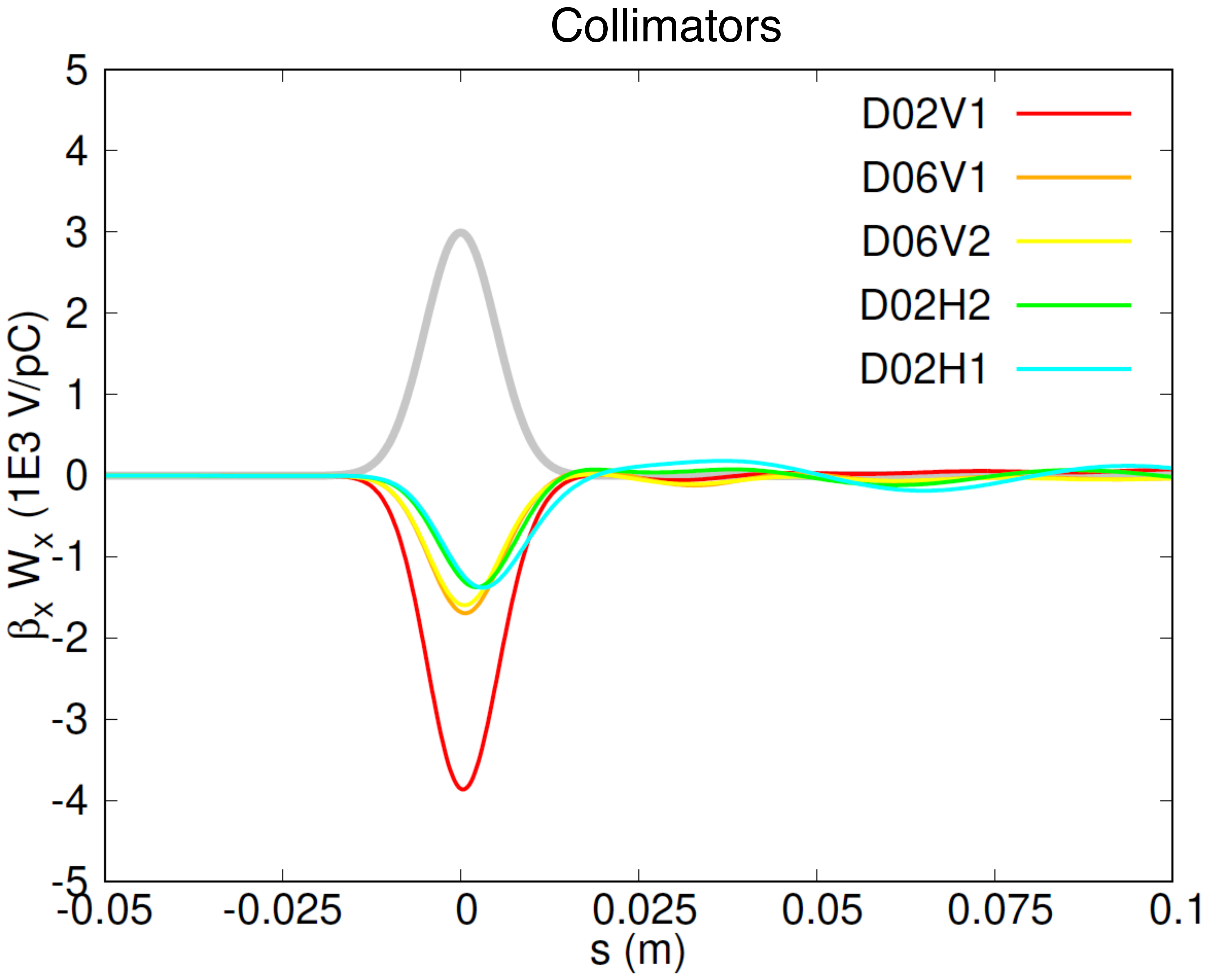




Horizontal impedance model of SuperKEKB LER

- Long-bunch wakes for σ_z=5 mm.
- Assume collimator settings on Jun. 30, 2021.





Betatron tune shift

- Use data of 2021.
- Assume collimator settings on Jun. 30, 2021.
- Use beam parameters and lattice on Jun. 30, 2021.
- Unit: /mA

$$\text{dvdI}[\beta x\_] := \frac{\beta x * 10^{12} * 10^{-3}}{4\pi * (\text{c0}/\text{Cir}) * (\text{Ep} * 10^{9})};$$

	Ver. Dipolar Collimators	Vert. Dipolar. Others	Vert. Quad Collimators	Hor. Quad. Others	Total
σ_z=5 mm	-0.00666651	-0.00102394	-0.0023343	-0.000212568	-0.0102373
σ_z=6 mm	-0.00606247	-0.000917733	-0.00195026	-0.000170975	-0.00910144

	Hor. Dipolar Collimators	Hor. Dipolar. Others	Hor. Quad Collimators	Hor. Quad. Others	Total
σ_z=5 mm	-0.00218038	-0.000596873	0.000666322	0.000233627	-0.0018773
σ_z=6 mm	-0.00184463	-0.000548731	0.000561459	0.00018929	-0.00164261

Summary

- Longitudinal impedance model
  - The new model gives similar loss factor, resistance and inductance as the old model.
  - But Vlasov simulations with the new model show lower MWI threshold. The reason is to be understood
- Vertical impedance model
  - Vertical collimators dominates the dipolar and quadrupolar wakes.
  - Numerical noises in small-gap collimators is a problem to be solved.
- Horizontal impedance model