Issues on beam dynamics in SuperKEKB

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With contributions from

KEK: T. Ishibashi et al.

Cornell: D. Sagan

SLAC: Y. Cai

SuperKEKB optics meeting, Sep. 17, 2014

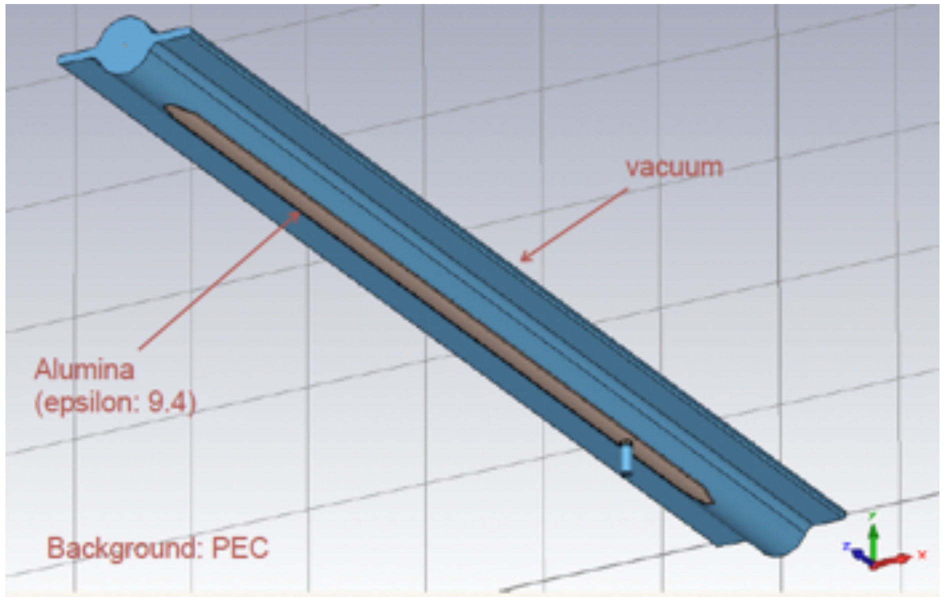
Outline

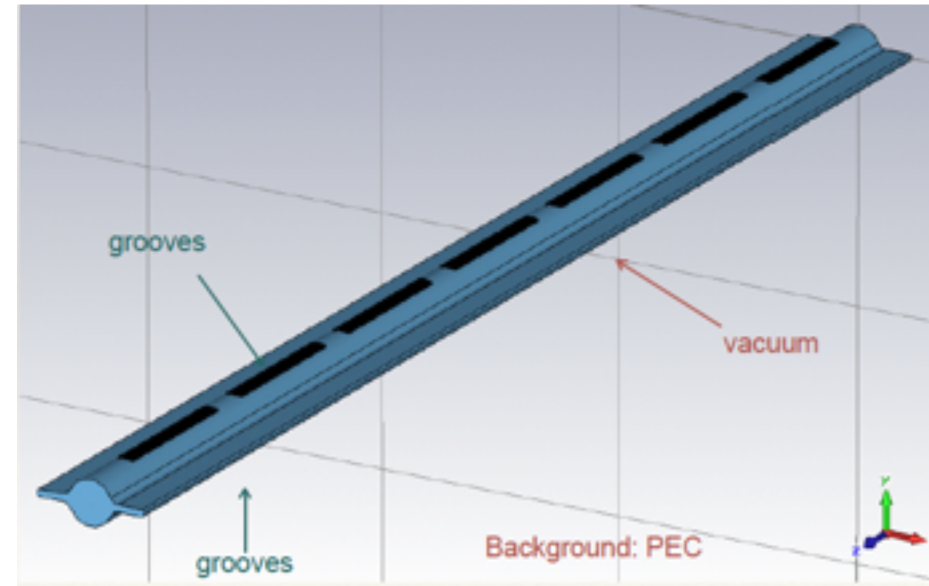
- **Updated results of MWI simulations**
  - **Impedance model with clearing electrodes, grooved surfaces**
  - **Paper published in proceedings of IPAC'14**
- **Hard-edge model for dipole fringe field**
  - **Dipole fringe map is the most complicated among fringe maps**
- **Benchmark of SAD and Bmad**
  - **Twiss functions, Transfer matrices, COD, etc.**
- **Future work with Bmad and SAD**
  - **Tracking simulations, lattice analysis, etc.**

1. MWI: Impedance calculations: LER

Clearing electrode

Grooved surfaces





From T. Ishibashi

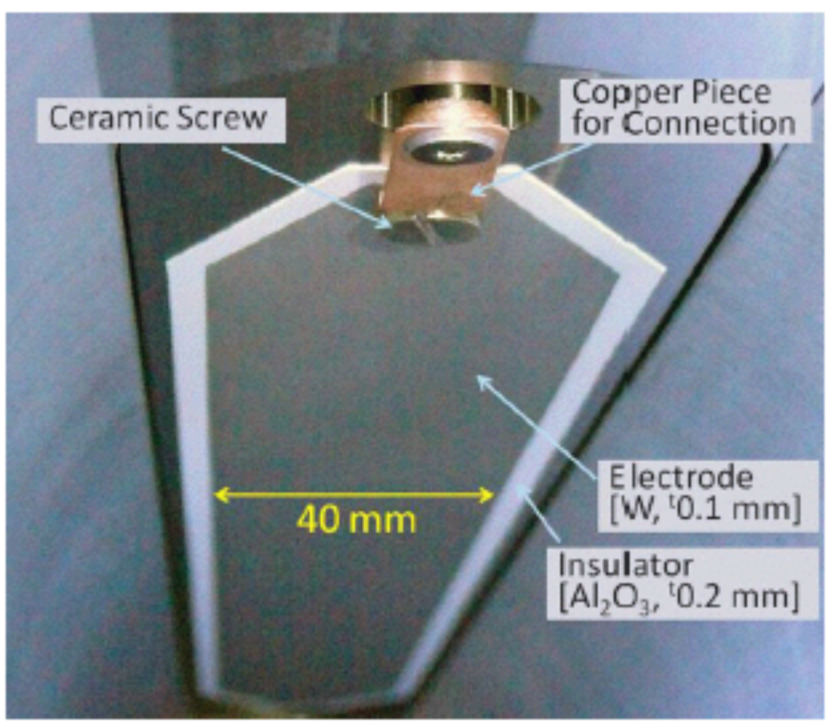


Fig. 2. Clearing electrode installed in test chamber. The electrode and the feed-through are connected by small piece of copper.

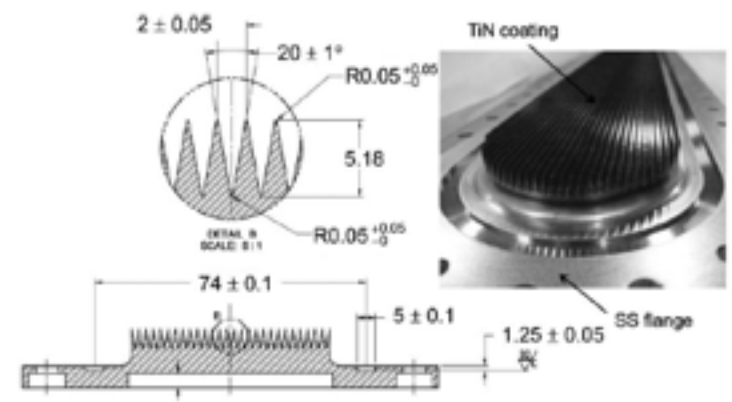


Fig. 1. Insertion with TiN-coated groove surface.

Tested in KEKB

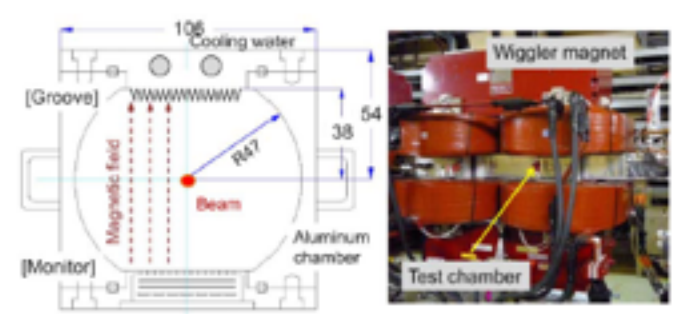


Fig. 2. Cross-section of the test chamber and the experimental setup in a wiggler magnet section in the KEKB positron ring.

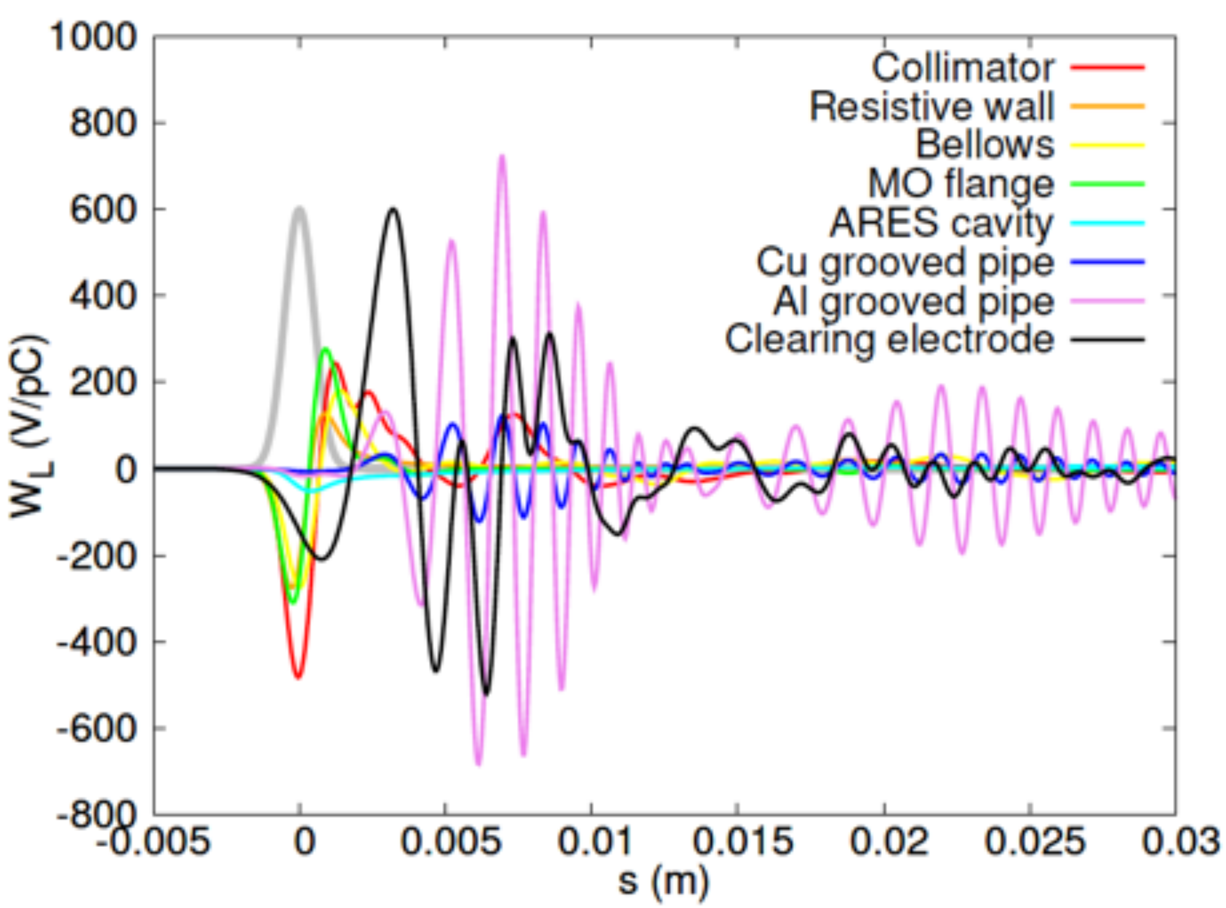
Ref. Y. Suetsugu et al., NIMA 598 (2009)

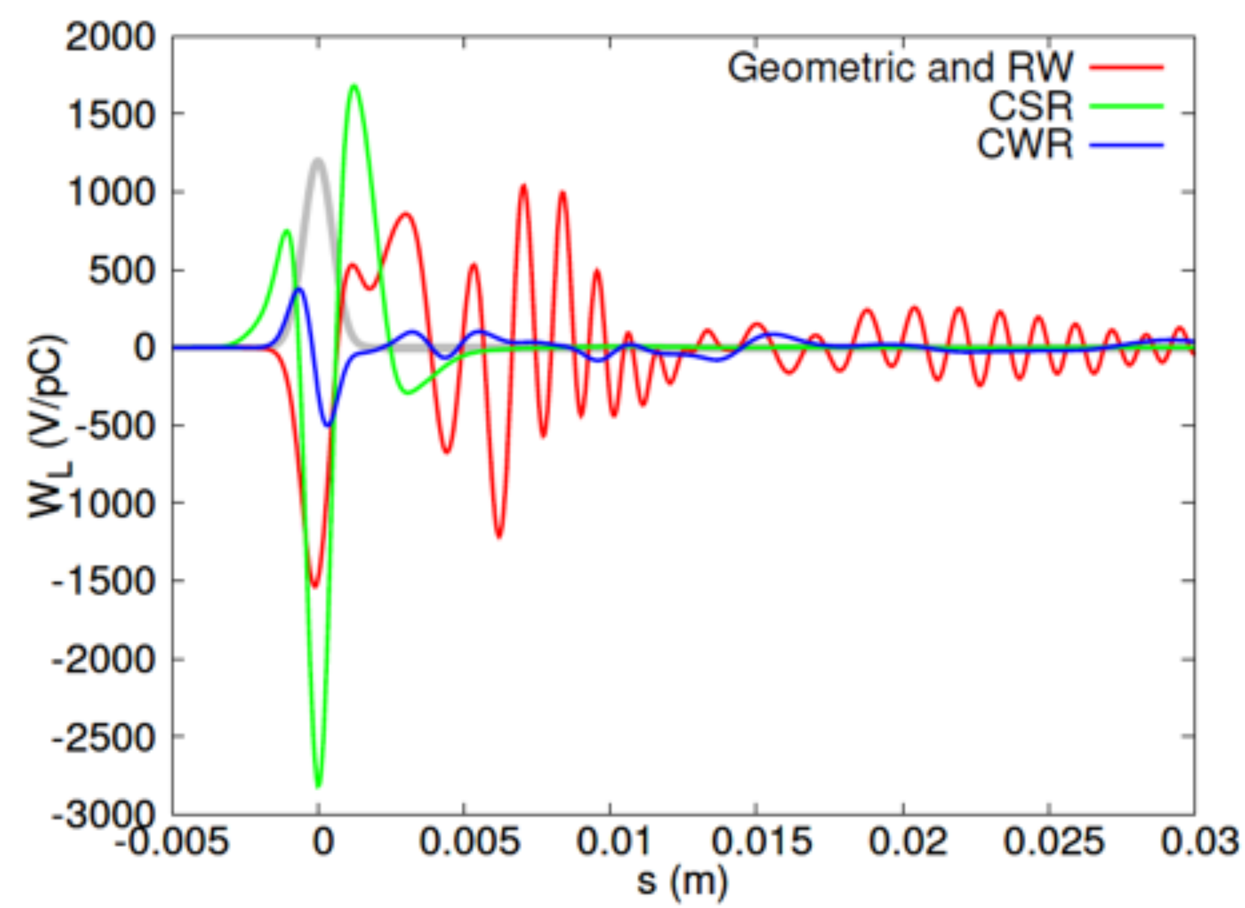
Ref. Y. Suetsugu et al., NIMA 604 (2009)

1. MWI: Impedance calculations: LER

➤ Pseudo-Green wake function

- σ_z=0.5mm
- Pumping ports and SR masks are negligible sources because of antechamber
- CSR and CWR (Wiggler radiation): CSRZ code with rectangular chamber

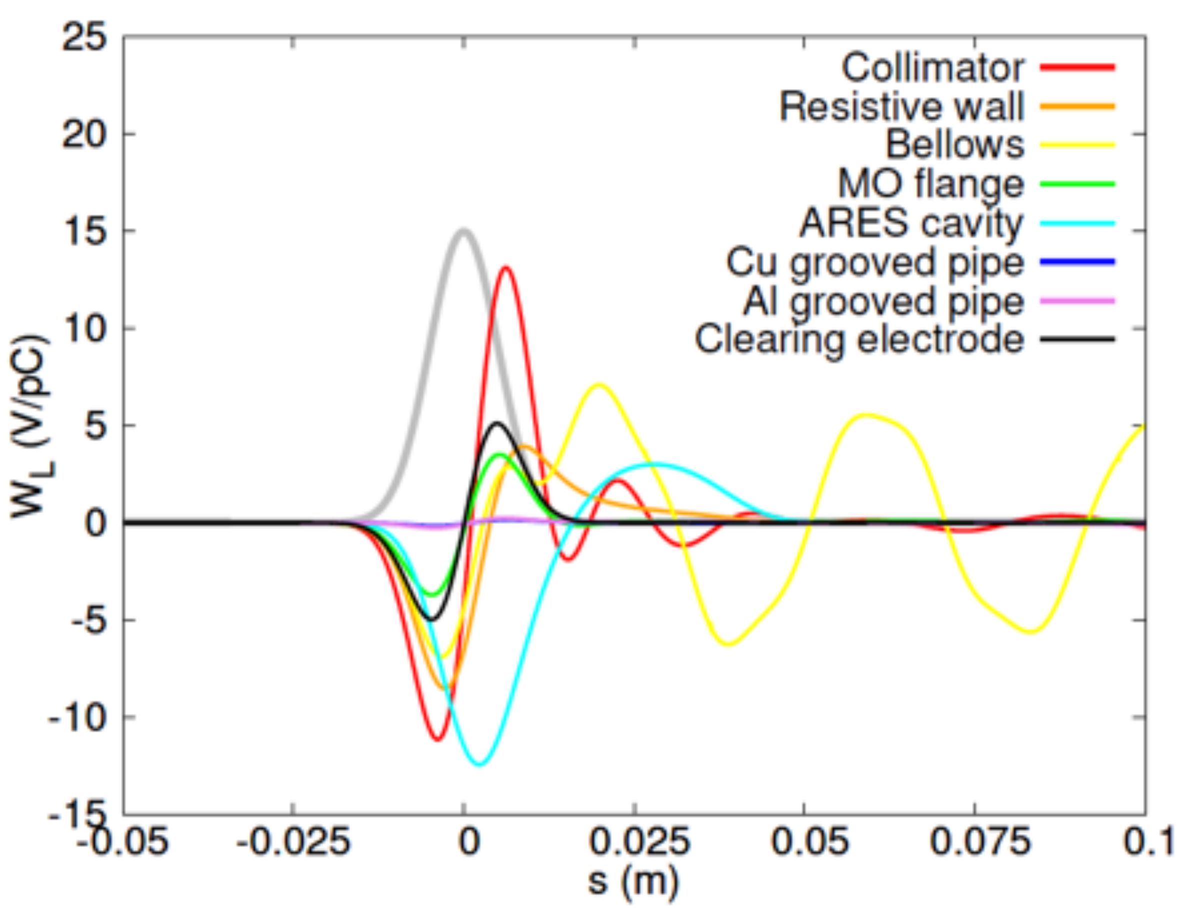


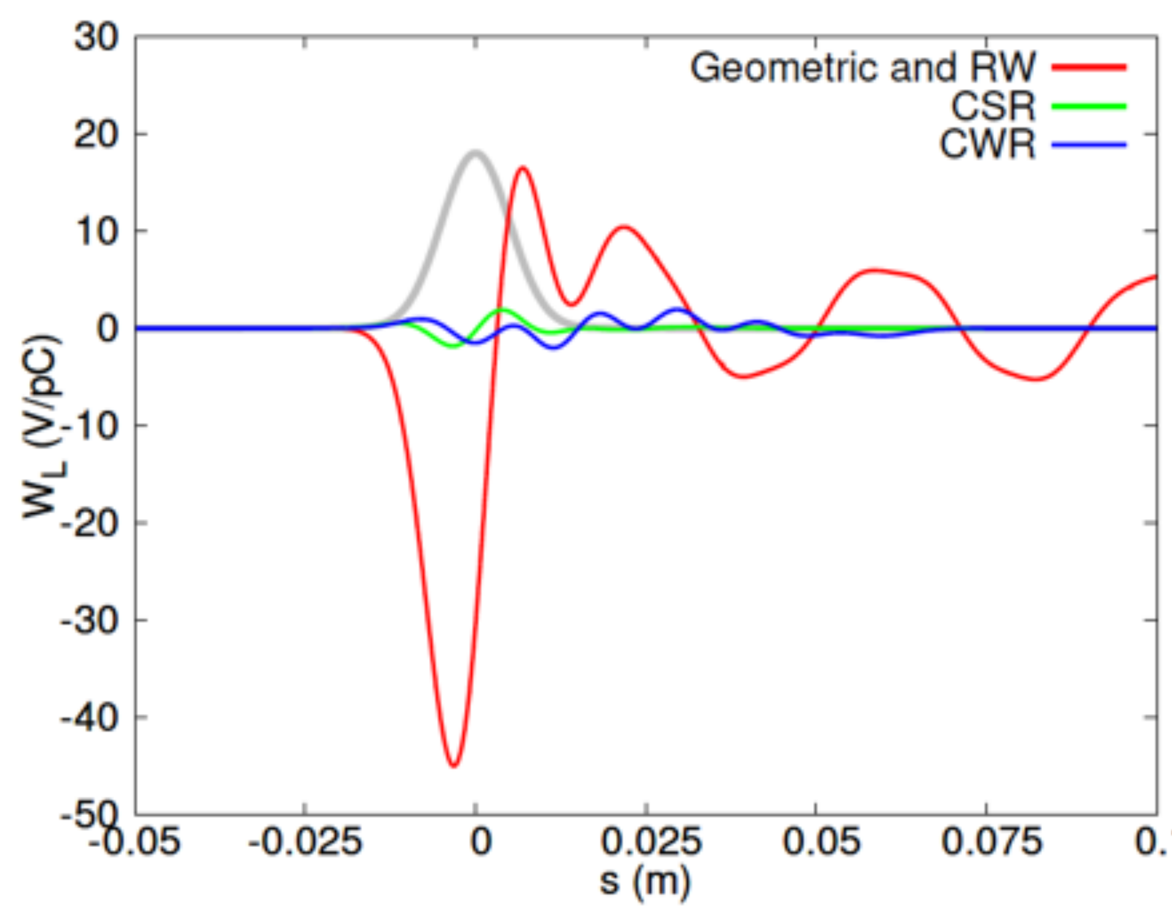


1. MWI: Impedance calculations: LER

➤ **Wake potential with nominal bunch length**

- σ_z=5mm
- Main sources: Collimators, Resistive wall, ARES cavity, Bellows, MO flanges, Clearing electrodes
- CSR and CWR are not strong if no microbunching happens





1. MWI: Impedance budget

➤ **Impedance budget with σ_z=5/4.9mm:**

- **Loss factors, resistance and inductance are calculated at nominal bunch lengths**
- **Bellows, flanges and pumping ports contribute more impedance in HER than in LER**

Table 2: Key parameters of SuperKEKB main rings for MWI simulations.

Parameter	LER	HER
Circumference (m)	3016.25	3016.25
Beam energy (GeV)	4	7.007
Bunch population (10^{10})	9.04	6.53
Nominal bunch length (mm)	5	4.9
Synchrotron tune	0.0244	0.028
Long. damping time (ms)	21.6	29.0
Energy spread (10^{-4})	8.1	6.37

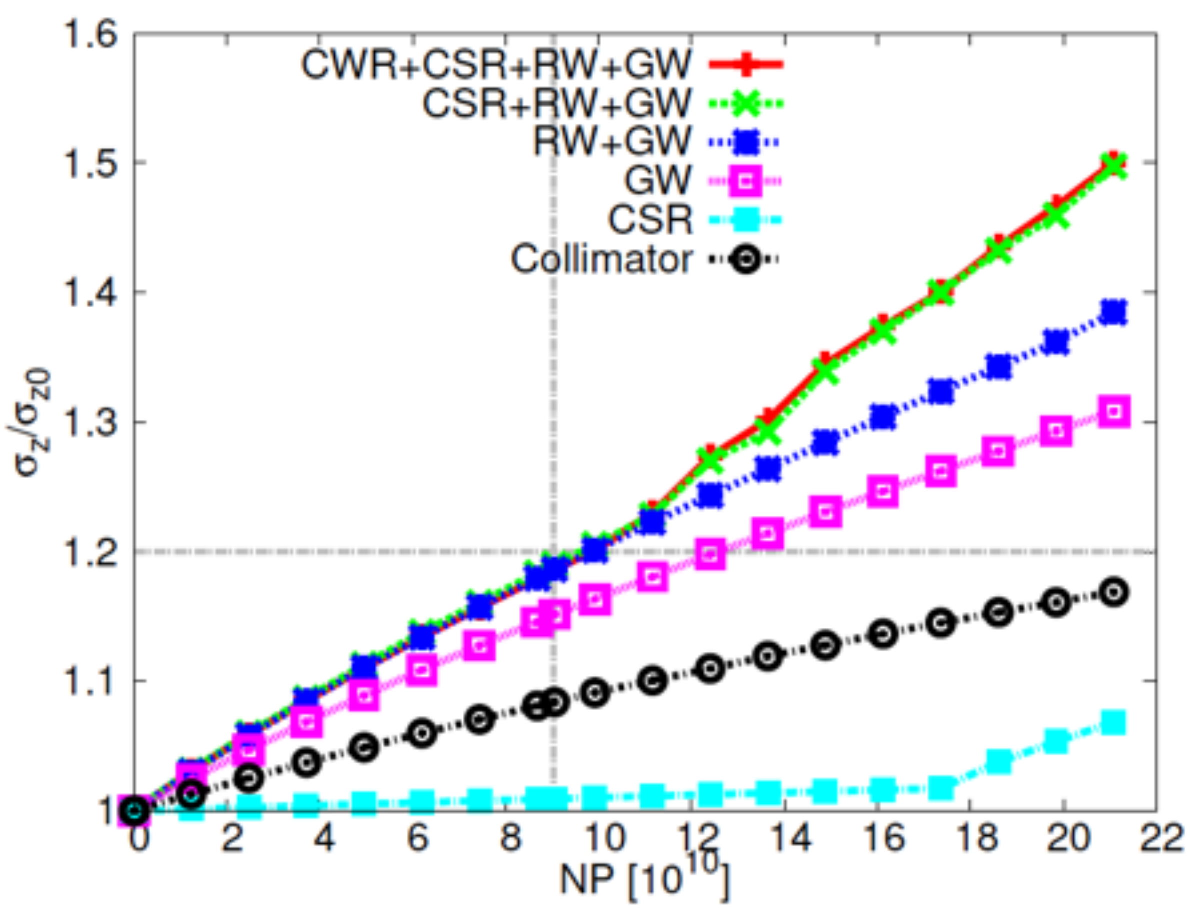
Component	LER			HER		
	$k_{\|\|}$	R	L	$k_{\|\|}$	R	L
ARES cavity	8.9	524	-	3.3	190	-
SC cavity	-	-	-	7.8	454	-
Collimator	1.1	62.4	13.0	5.3	309	10.8
Res. wall	3.9	231	5.7	5.9	340	8.2
Bellows	2.7	159	5.1	4.6	265	16.0
Flange	0.2	13.7	4.1	0.6	34.1	19.3
Pump. port	0.0	0.0	0.0	0.6	34.1	6.6
SR mask	0.0	0.0	0.0	0.4	21.4	0.7
IR duct	0.0	2.2	0.5	0.0	2.2	0.5
BPM	0.1	8.2	0.6	0.0	0.0	0.0
FB kicker	0.4	26.3	0.0	0.5	26.2	0.0
FB BPM	0.0	1.1	0.0	0.0	1.1	0.0
Long. kicker	1.8	105	1.2	-	-	-
Groove pipe	0.1	3.8	0.5	-	-	-
Electrode	0.0	0.7	5.7	-	-	-
Total	19.2	1137	36.4	29.0	1677	62.1

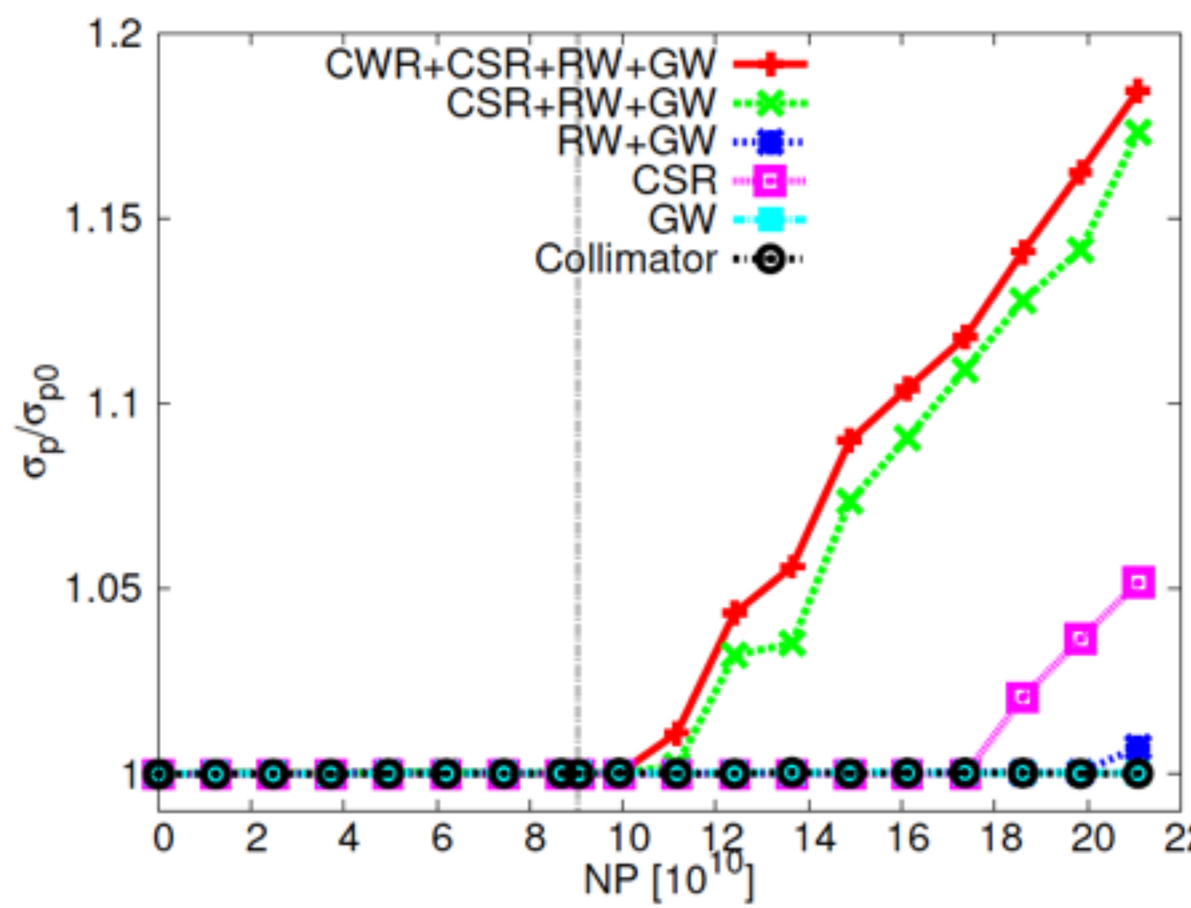
Ref. D. Zhou et al., IPAC14, TUPRI021

1. MWI: LER

➤ **Simulations with input of Pseudo-Green wake:**

- **Use Warnock-Cai's VFP solver**
- **Collimators are important sources in bunch lengthening**
- **Simulated $\sigma_z \approx 5.9$mm @Design bunch current**
- **Simulated MWI threshold is around $NP_{th}=1.05E11$**
- **Interplay between CSR and conventional wakes?**

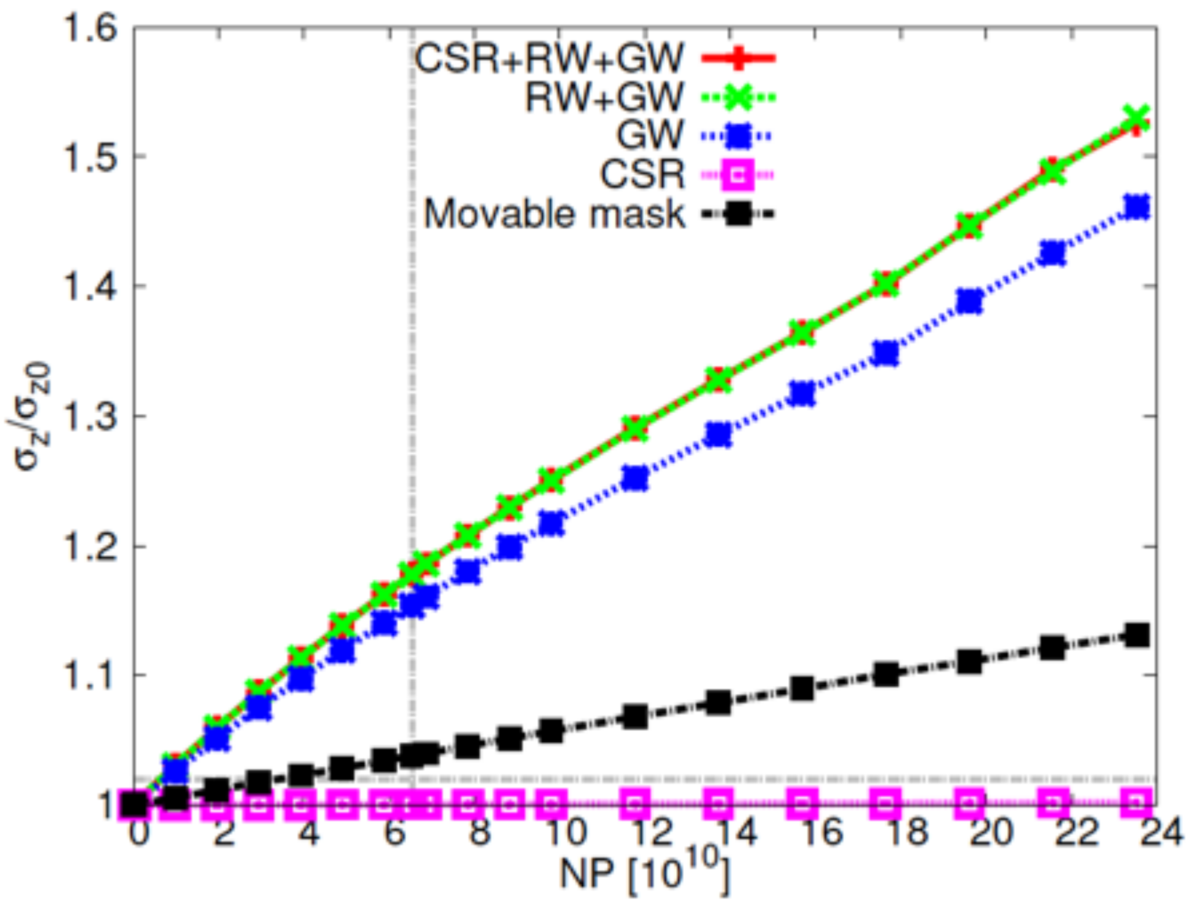


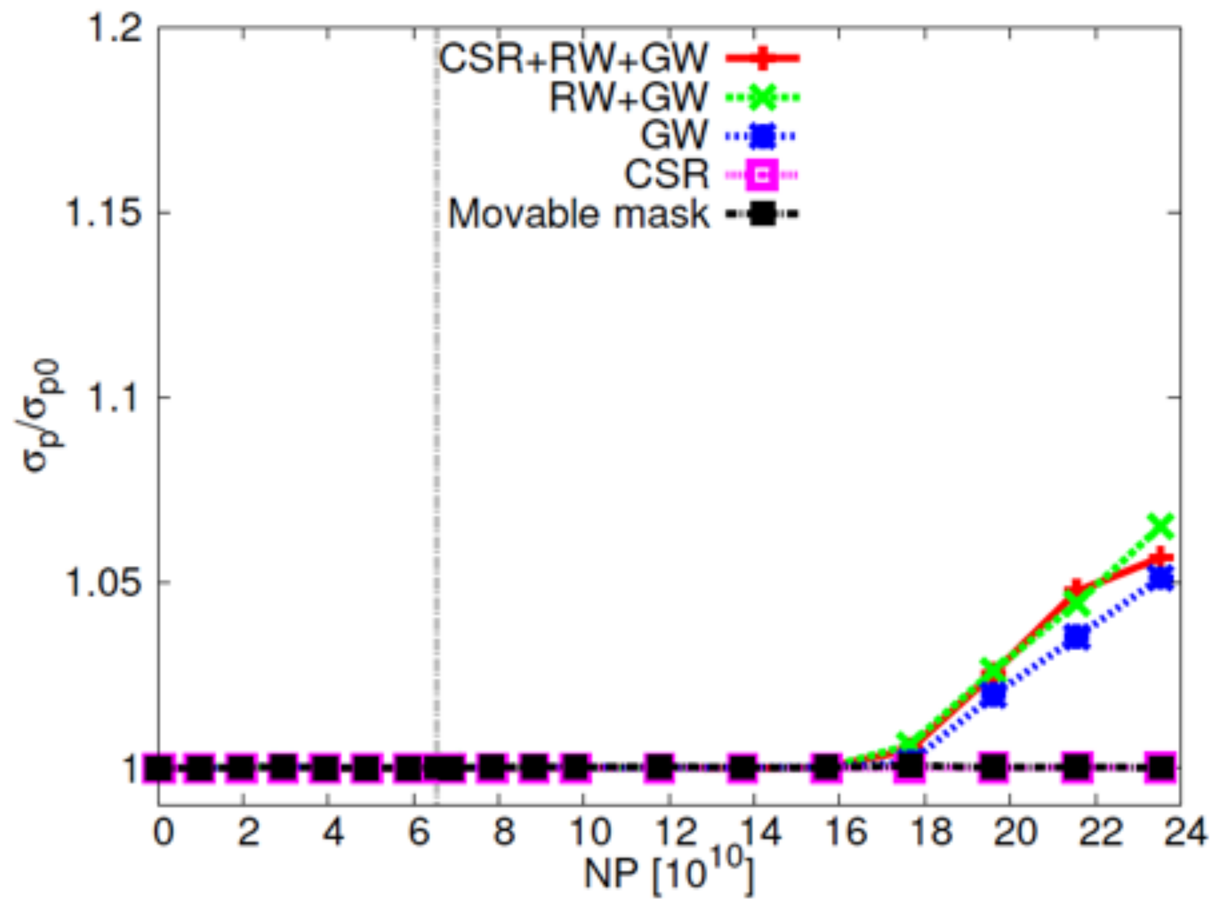


1. MWI: HER

➤ **Simulations with input of Pseudo-Green wake:**

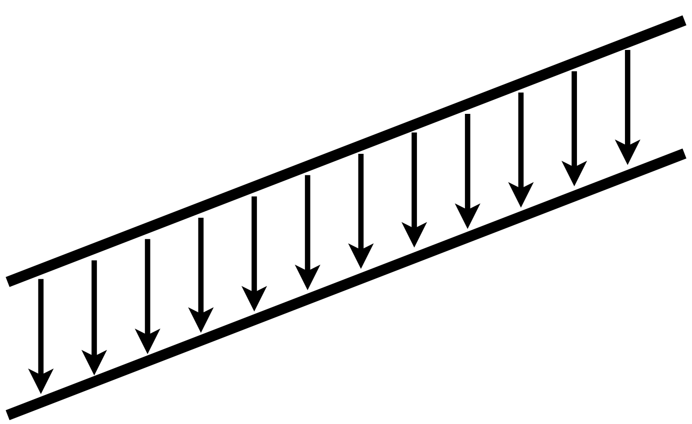
- **Use Warnock-Cai's VFP solver**
- **Simulated $\sigma_z \approx 5.8$mm @Design bunch current**
- **Simulated MWI threshold is around NP_{th}=1.7E11**
- **Y. Cai's comment: CSR should not be important in SuperKEKB (consider shielding and long bunch).**



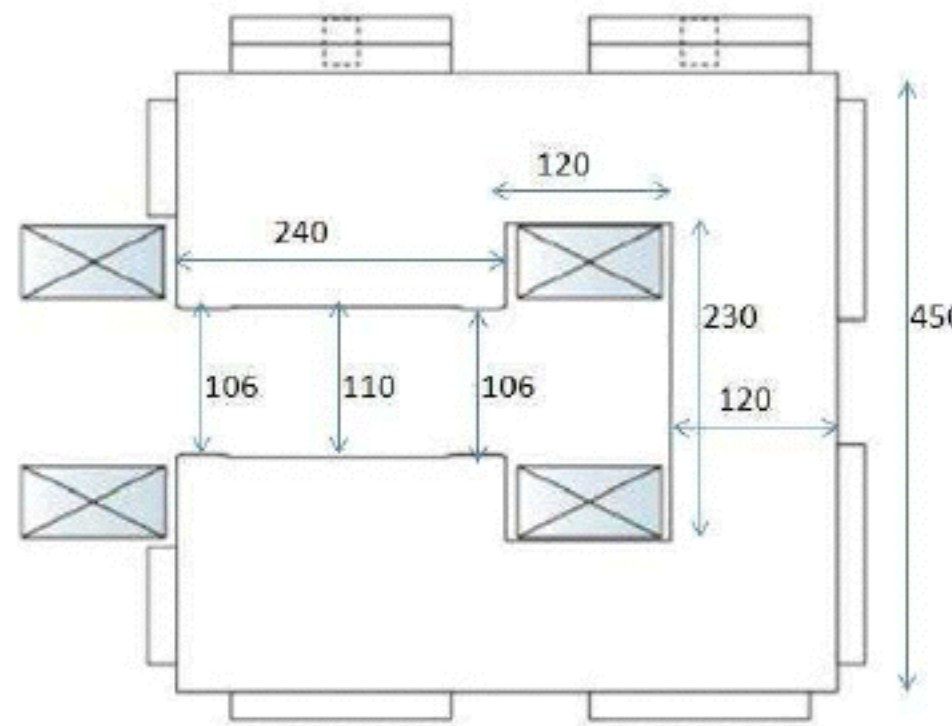


2. Dipole fringe

- ➤ **Question raised from debugging SAD code**
- ➤ **Two models found for hard-edge fringe**
  - **E. Forest: popular theory**
  - **Y. Cai: Ambiguous but likely close to reality (?)**



Infinitely wide magnet



Realistic case
(From SuperKEKB TDR)

2. Dipole fringe

➤ **Maxwellian solution for hard-edge dipole field**

- **G. Lee-Whiting et al. => E. Forest et al.**
- **S. Caspi et al. => M. Bassetti et al. => Y. Cai et al.**

$$A_s = -xB(s) = -xB_0\theta(s).$$

$$\vec{A} = (A_x, 0, A_s)$$

$$\nabla \times \nabla \times \vec{A} = 0$$

$$A_x = B_0 \sum_{n=1}^{\infty} \frac{(-1)^n \theta^{(2n-1)}(s)}{(2n)!} y^{2n}$$

$$A_y = 0$$

$$A_x = \frac{1}{2}(x^2 - y^2) \sum_{p=0}^{\infty} \frac{1}{2+p} G_{1,2p+1}(s)(x^2 + y^2)^p,$$

$$A_y = xy \sum_{p=0}^{\infty} \frac{1}{2+p} G_{1,2p+1}(s)(x^2 + y^2)^p,$$

$$A_s = -x \sum_{p=0}^{\infty} G_{1,2p}(s)(x^2 + y^2)^p.$$

$$G_{n,2p}(s) = (-1)^p \frac{n!}{4^p (n+p)! p!} \frac{d^{2p} G_{n,0}(s)}{ds^{2p}},$$

$$G_{n,2p+1}(s) = \frac{dG_{n,2p}(s)}{ds},$$

$$A_y \neq 0$$

2. Dipole fringe

➤ **Open question: which model is better?**

- **M. Masuzawa et al. are to help check the theory …**

$$H = -(1+\delta) + \frac{1}{2(1+\delta)}(p_x^2 + p_y^2) - \left[a_s + \frac{1}{1+\delta}(p_x a_x + p_y a_y)\right]$$

$$a_{x,y,s} = \frac{e}{cp_0} A_{x,y,s}$$

$$f = -V_1 = -\frac{1}{2\rho(1+\delta)} p_x y^2$$

Implemented in SAD:

$$x_2 = x_1 - \frac{1}{\rho(1+\delta)} y_1^2,$$

$$p_{y2} = p_{y1} + \frac{1}{\rho(1+\delta)} y p_{x1},$$

$$z_2 = z_1 + \frac{y_1^2}{2\rho(1+\delta)^2} p_{x2}.$$

$$f = \frac{1}{8\rho(1+\delta)}(-p_x x^2 + 2p_y xy - 3p_x y^2)$$

$$x_2 = x_1 - \frac{1}{8\rho(1+\delta)}(x_1^2 + 3y_1^2),$$

$$y_2 = y_1 + \frac{1}{4\rho(1+\delta)} x_1 y_1,$$

$$p_{x2} = \frac{1}{d}\left[p_{x1} - \frac{1}{4\rho(1+\delta)}(y_1 p_{y1} - x_1 p_{x1})\right],$$

$$p_{y2} = \frac{1}{d}\left[p_{y1} - \frac{1}{4\rho(1+\delta)}(x_1 p_{y1} - 3y_1 p_{x1})\right],$$

$$z_2 = z_1 + \frac{x_1^2 + 3y_1^2}{8\rho(1+\delta)^2} p_{x2} - \frac{x_1 y_1}{4\rho(1+\delta)^2} p_{y2},$$

$$d = 1 + \frac{3y_1^2 - x_1^2}{16\rho^2(1+\delta)^2}.$$

3. Benchmark SAD and Bmad: sher_5764

➤ Parameters at IP with δ=0

- **In general, now Bmad agree well with SAD**

Bmad:

βx=0.02498209m, αx=-4.959E-5, νx=45.5299896,
Dx=-4.E-8m, D'x=-8.16E-6,
βy=2.941E-4m, αy=-6.791E-5, νy=43.56852721,
Dy=-4.55E-9, D'y=-2.4E-7,

SAD:

βx=0.025m, αx=-1.34E-12, νx=45.53,
Dx=-1.03E-13m, D'x=-3.11E-13,
βy=3.E-4m, αy=-3.545E-13, νy=43.57,
Dy=2.963E-15, D'y=-1.616E-12,

3. Benchmark SAD and Bmad: sher_5764

➤ **Parameters at IP with δ=0.002**

- **In general, now Bmad agree well with SAD**

Bmad:

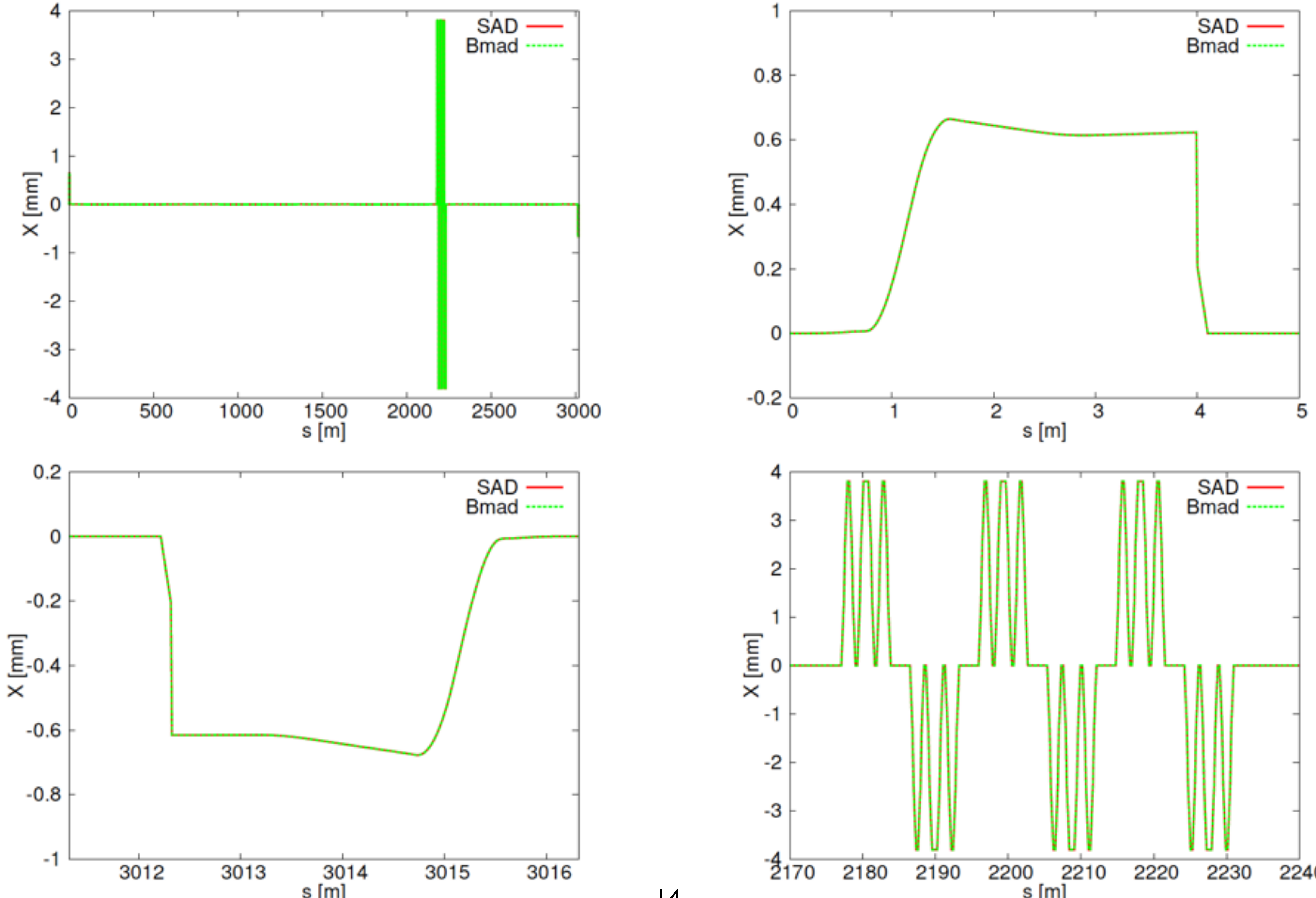
β_x=0.32635028E-01m, α_x=0.65882408E-01, ν_x=45.536646,
D_x=-0.47815350E-03m, D'_x=-0.11870747E-01,
β_y=0.31470442E-03m, α_y=0.13545109E-01, ν_y=43.577108,
D_y=0.64778741E-06, D'_y=0.23488780E-02,

SAD:

β_x=.032642757m, α_x=.0658513493, ν_x=45.536688655,
D_x=-.0004781727, D'_x=-.01190317,
β_y=.00032006m, α_y=.01341448, ν_y=43.57852356,
D_y=6.27523687e-07, D'_y=.0022601526,

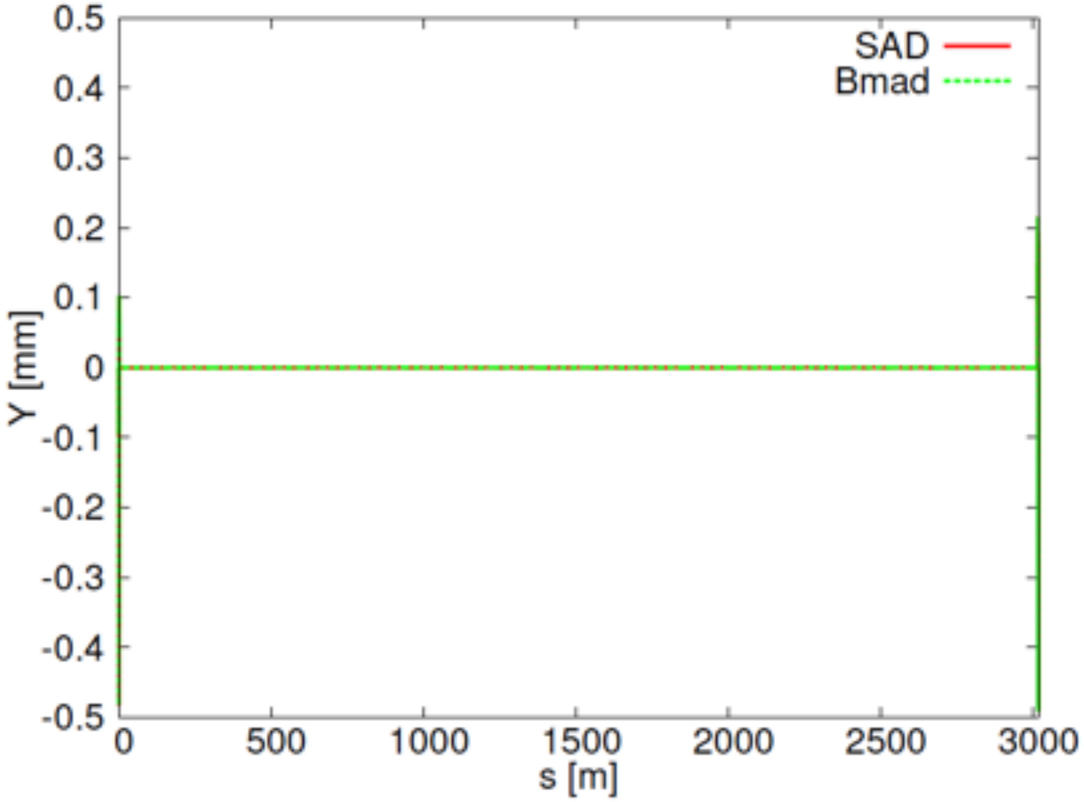
3. Benchmark SAD and Bmad: sher_5764

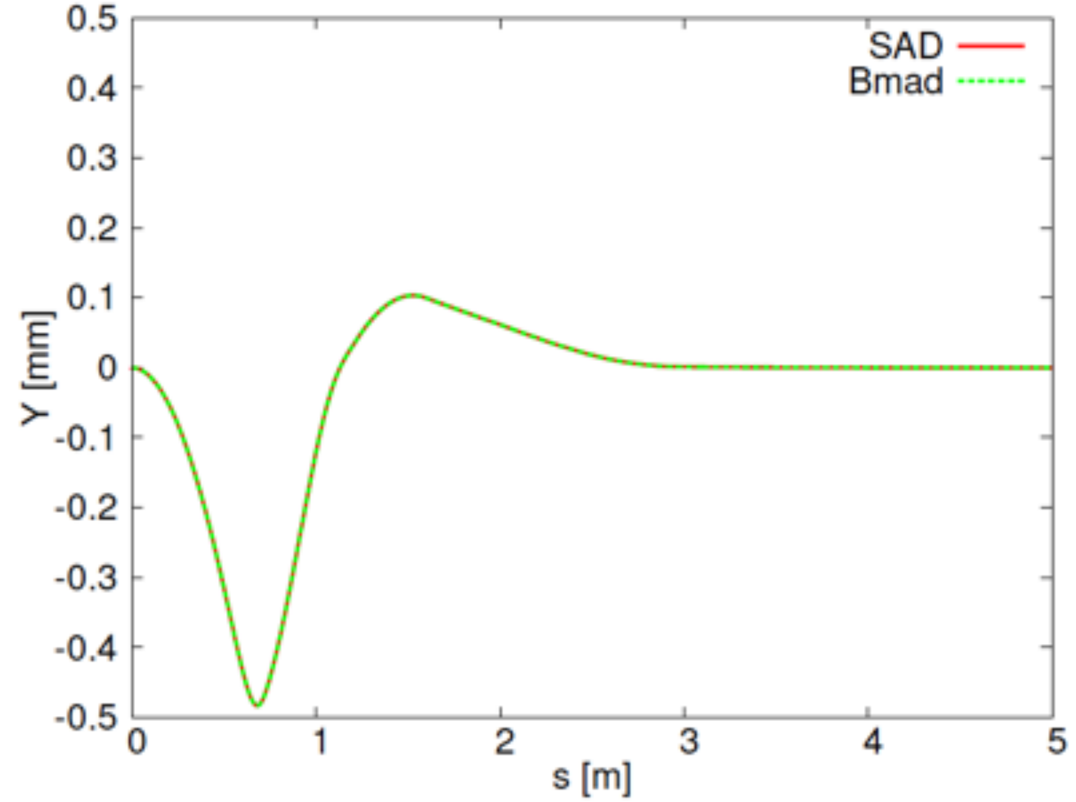
➤ **COD in X with δ=0**

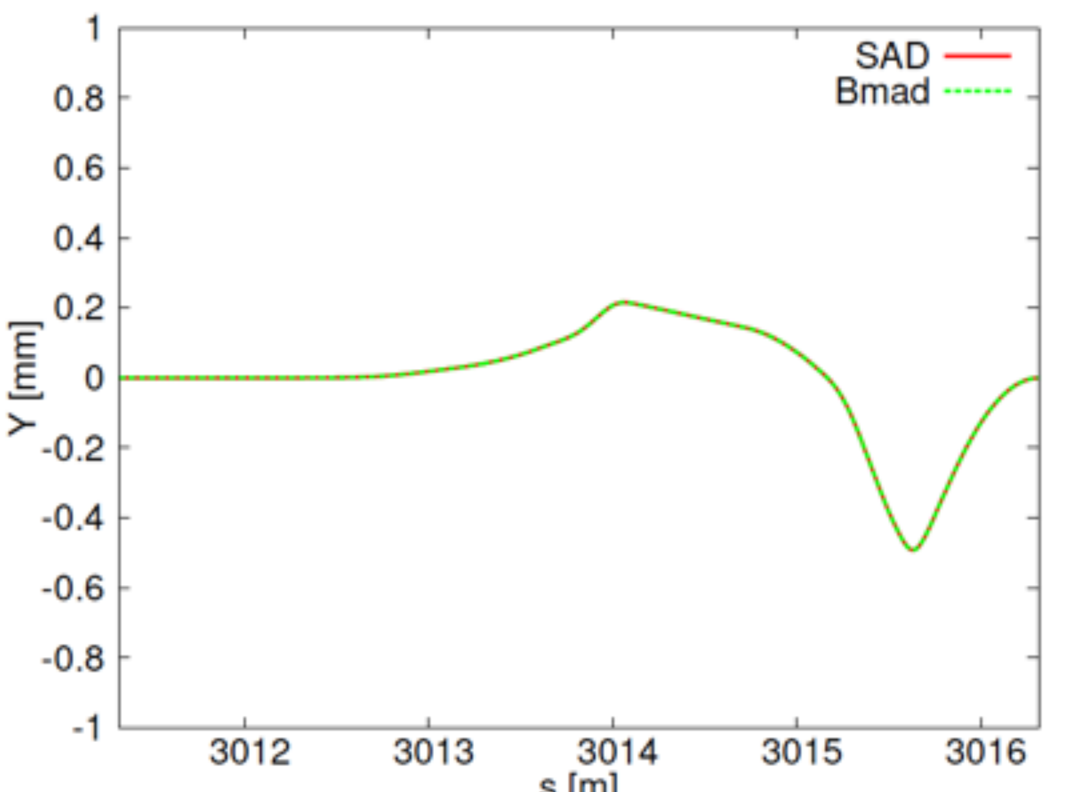


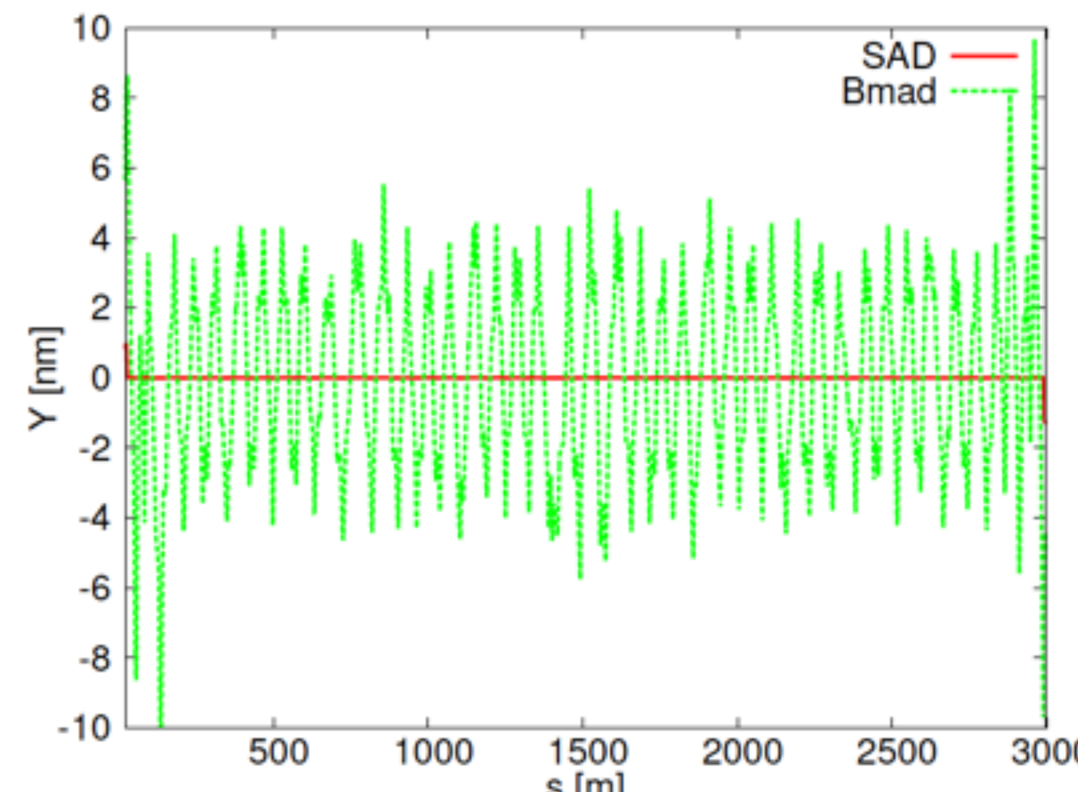
3. Benchmark SAD and Bmad: sher_5764

➤ COD in Y with δ=0



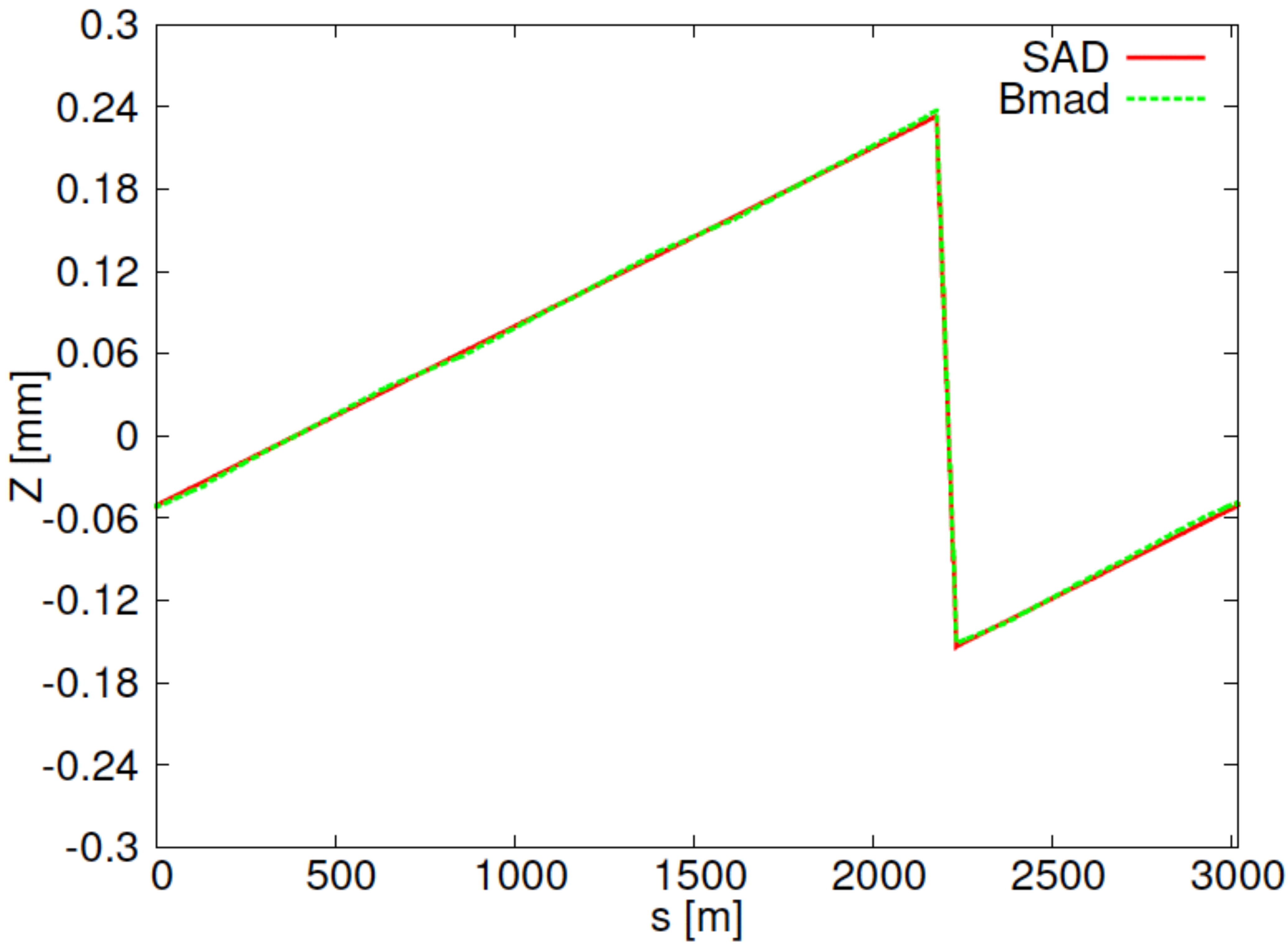






3. Benchmark SAD and Bmad: sher_5764

➤ **COD in Z with δ=0**



4. Future work with Bmad and SAD

➤ D. Sagan's seminar (Sep. 19, 13:30PM -) for more details

➤ To-Do list considered for SuperKEKB

- Bmad-to-SAD translator
- Implement higher-order fringe maps in Bmad tracking
- Particle tracking using Bmad including beam-beam, space-charge, luminosity calculation, etc.
- PTC analysis of design lattices (with help from E. Forest)
- … …

➤ Any other requests are welcome!