ISSUES ON THE UPGRADE

FEB 9, 2009

K. Oide @ 14th KEKB-ARC

1. Coherent Synchrotron Radiation Revisited

2. Travel Waist Scheme / IR Design / Crab Crossing

3. Construction & Running Costs

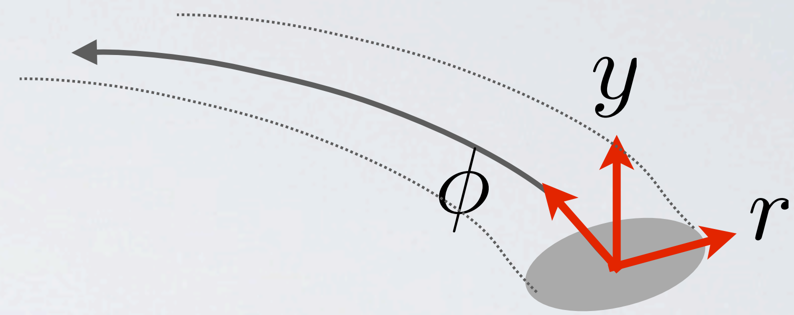
4. Italian Option

CSR REVISITED

- Coherent Synchrotron Radiation (CSR) in SuperKEKB has been studied by T. Agoh since 2004 as reported at KEKB ARC.
- An independent estimation was done in 2008, which takes realistic shape of the beam pipe and other impedances into account.
- Confirmed the results by Agoh.
- Heavy impact on the design parameters of SuperKEKB.

MAXWELL'S EQUATIONS

$$
\begin{aligned}
\frac{1}{r}\frac{\partial r E_\phi}{\partial r} - \frac{1}{r}\frac{\partial E_r}{\partial \phi} &= -\frac{\partial B_y}{\partial t} \\
\frac{1}{r}\frac{\partial E_y}{\partial \phi} - \frac{\partial E_\phi}{\partial y} &= -\frac{\partial B_r}{\partial t} \\
\frac{\partial E_r}{\partial y} - \frac{\partial E_y}{\partial r} &= -\frac{\partial B_\phi}{\partial t} \\
\frac{1}{r}\frac{\partial r B_\phi}{\partial r} - \frac{1}{r}\frac{\partial B_r}{\partial \phi} &= \mu_0 j_y + \frac{1}{c^2}\frac{\partial E_y}{\partial t} \\
\frac{1}{r}\frac{\partial B_y}{\partial \phi} - \frac{\partial B_\phi}{\partial y} &= \mu_0 j_r + \frac{1}{c^2}\frac{\partial E_r}{\partial t} \\
\frac{\partial B_r}{\partial y} - \frac{\partial B_y}{\partial r} &= \mu_0 j_\phi + \frac{1}{c^2}\frac{\partial E_\phi}{\partial t} \\
\frac{1}{r}\frac{\partial r E_r}{\partial r} + \frac{1}{r}\frac{\partial E_\phi}{\partial \phi} + \frac{\partial E_y}{\partial y} &= \frac{\rho}{\varepsilon_0}
\end{aligned}
$$



$$j_r = j_y = 0, \qquad j_\phi = \rho c$$

$$
\begin{aligned}
\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial r E_r}{\partial r} + \frac{1}{r^2}\frac{\partial^2 E_r}{\partial \phi^2} + \frac{\partial^2 E_r}{\partial y^2} - \frac{1}{c^2}\frac{\partial^2 E_r}{\partial t^2} - \frac{2}{r^2}\frac{\partial E_\phi}{\partial \phi} &= \frac{1}{\varepsilon_0}\frac{\partial \rho}{\partial r} \\
\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial r E_\phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2 E_\phi}{\partial \phi^2} + \frac{\partial^2 E_\phi}{\partial y^2} - \frac{1}{c^2}\frac{\partial^2 E_\phi}{\partial t^2} + \frac{2}{r^2}\frac{\partial E_r}{\partial \phi} &= \frac{1}{\varepsilon_0}\left(\frac{1}{r}\frac{\partial \rho}{\partial \phi} + \frac{1}{c}\frac{\partial \rho}{\partial t}\right)
\end{aligned}
$$

MAXWELL'S EQUATIONS

$$\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial r E_r}{\partial r} + \frac{1}{r^2}\frac{\partial^2 E_r}{\partial \phi^2} + \frac{\partial^2 E_r}{\partial y^2} - \frac{1}{c^2}\frac{\partial^2 E_r}{\partial t^2} - \frac{2}{r^2}\frac{\partial E_\phi}{\partial \phi} = \frac{1}{\varepsilon_0}\frac{\partial \rho}{\partial r}$$

$$\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial r E_\phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2 E_\phi}{\partial \phi^2} + \frac{\partial^2 E_\phi}{\partial y^2} - \frac{1}{c^2}\frac{\partial^2 E_\phi}{\partial t^2} + \frac{2}{r^2}\frac{\partial E_r}{\partial \phi} = \frac{1}{\varepsilon_0}\left(\frac{1}{r}\frac{\partial \rho}{\partial \phi} + \frac{1}{c}\frac{\partial \rho}{\partial t}\right)$$

$$\rho \propto \delta(r-R)\delta(y)\exp\left(ik(R\phi - ct)\right)$$

$$E_{r,\phi} = \overline{E}_{r,\phi}(\phi)\exp\left(ik(R\phi - ct)\right)$$

$$\overline{E}_r = \overline{E}_r + \overline{E}_{r0}\ ,$$

$$\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial r \overline{E}_{r0}}{\partial r} + \frac{\partial^2 \overline{E}_{r0}}{\partial y^2} = \frac{1}{\varepsilon_0}\frac{\partial \rho}{\partial r}$$

★ Ignore $\frac{\partial^2 \overline{E}}{\partial \phi^2}$ terms (AgoH-YokoYA)

MAXWELL'S EQUATIONS

THEN WE OBTAIN FIRST ORDER DIFFERENTIAL EQUATIONS FOR $\overline{E}_{r,\phi}$.

$$
\begin{aligned}
\frac{\partial \overline{E}_r}{\partial \phi} &= \frac{i}{2(k^2R^2-1)}\Bigg[kR\left(\left(k^2(r^2-R^2)+1\right)(\overline{E}_r+\overline{E}_{r0})+r\frac{\partial}{\partial r}(\overline{E}_r+\overline{E}_{r0})+r^2\left(\frac{\partial^2\overline{E}_r}{\partial r^2}+\frac{\partial^2\overline{E}_r}{\partial y^2}\right)\right)\\
&\quad+\left(k^2(r^2+R^2)-1\right)\overline{E}_\phi+r\frac{\partial\overline{E}_\phi}{\partial r}+r^2\left(\frac{\partial^2\overline{E}_\phi}{\partial r^2}+\frac{\partial^2\overline{E}_\phi}{\partial y^2}\right)\Bigg]\\
\frac{\partial \overline{E}_\phi}{\partial \phi} &= \frac{i}{2(k^2R^2-1)}\Bigg[kR\left(\left(k^2(r^2-R^2)+1\right)\overline{E}_\phi+r\frac{\partial\overline{E}_\phi}{\partial r}+r^2\left(\frac{\partial^2\overline{E}_\phi}{\partial r^2}+\frac{\partial^2\overline{E}_\phi}{\partial y^2}\right)\right)\\
&\quad+\left(k^2(r^2+R^2)-1\right)(\overline{E}_r+\overline{E}_{r0})+r\frac{\partial}{\partial r}(\overline{E}_r+\overline{E}_{r0})+r^2\left(\frac{\partial^2\overline{E}_r}{\partial r^2}+\frac{\partial^2\overline{E}_r}{\partial y^2}\right)\Bigg]
\end{aligned}
$$

- Further Approximation is possible as Agoh-Yokoya did, but not done here.

SOLVER

$$\frac{d\boldsymbol{f}}{d\phi} = A\boldsymbol{f} + \boldsymbol{b}\ , \qquad \boldsymbol{f} = (\overline{E}_r, \overline{E}_\phi)\ ,$$

$$\boldsymbol{f}(\phi) = \boldsymbol{f}_0 \exp(A\phi) + \boldsymbol{b} \int_0^\phi \exp\left(A(\phi' - \phi)\right) d\phi'$$

✳An uniform shape of the beam pipe has been assumed,

A: Spatial differentiation matrix with boundary condition

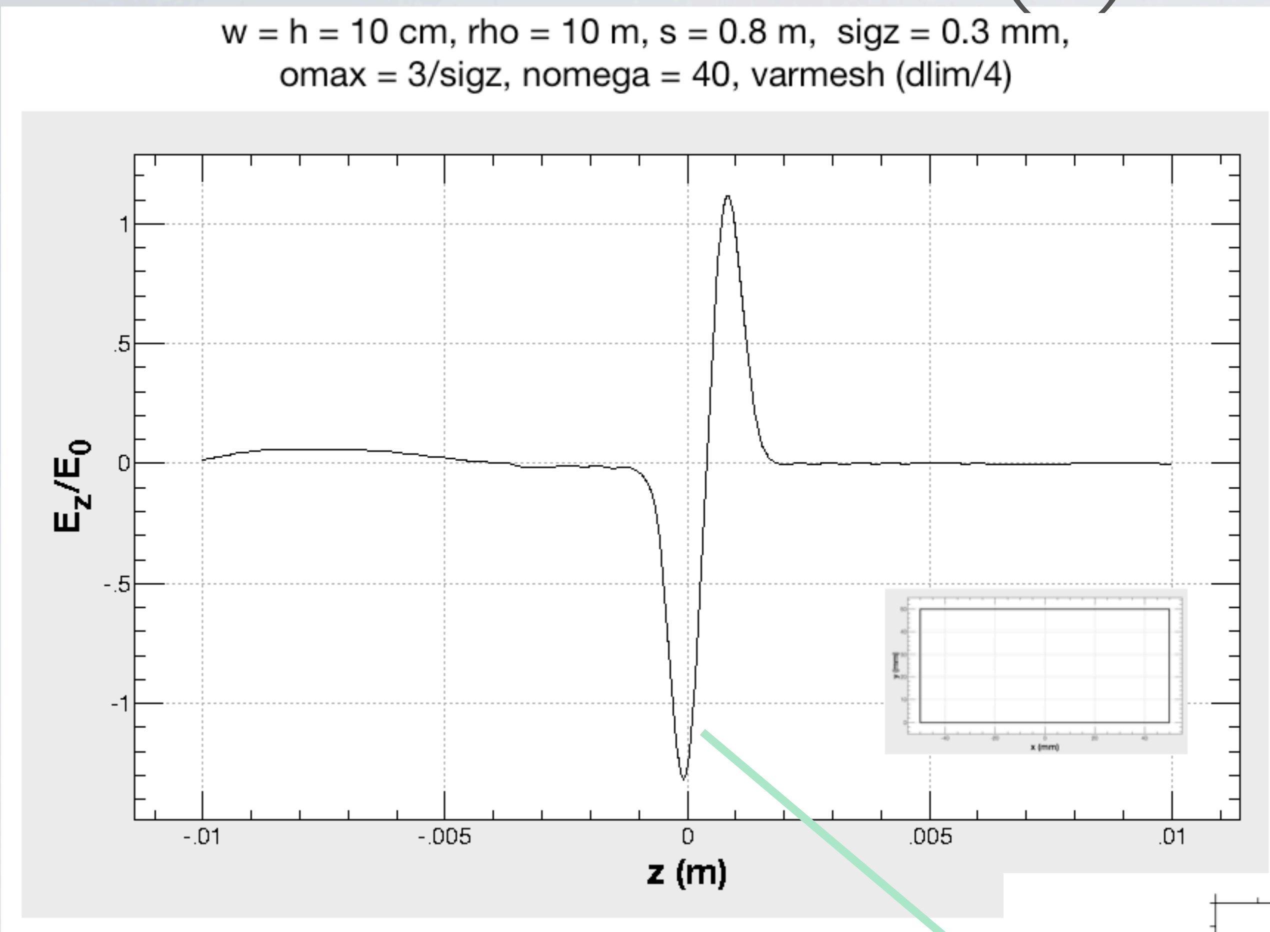
$\boldsymbol{b}$: driving term by $\overline{E}_{r0}$.

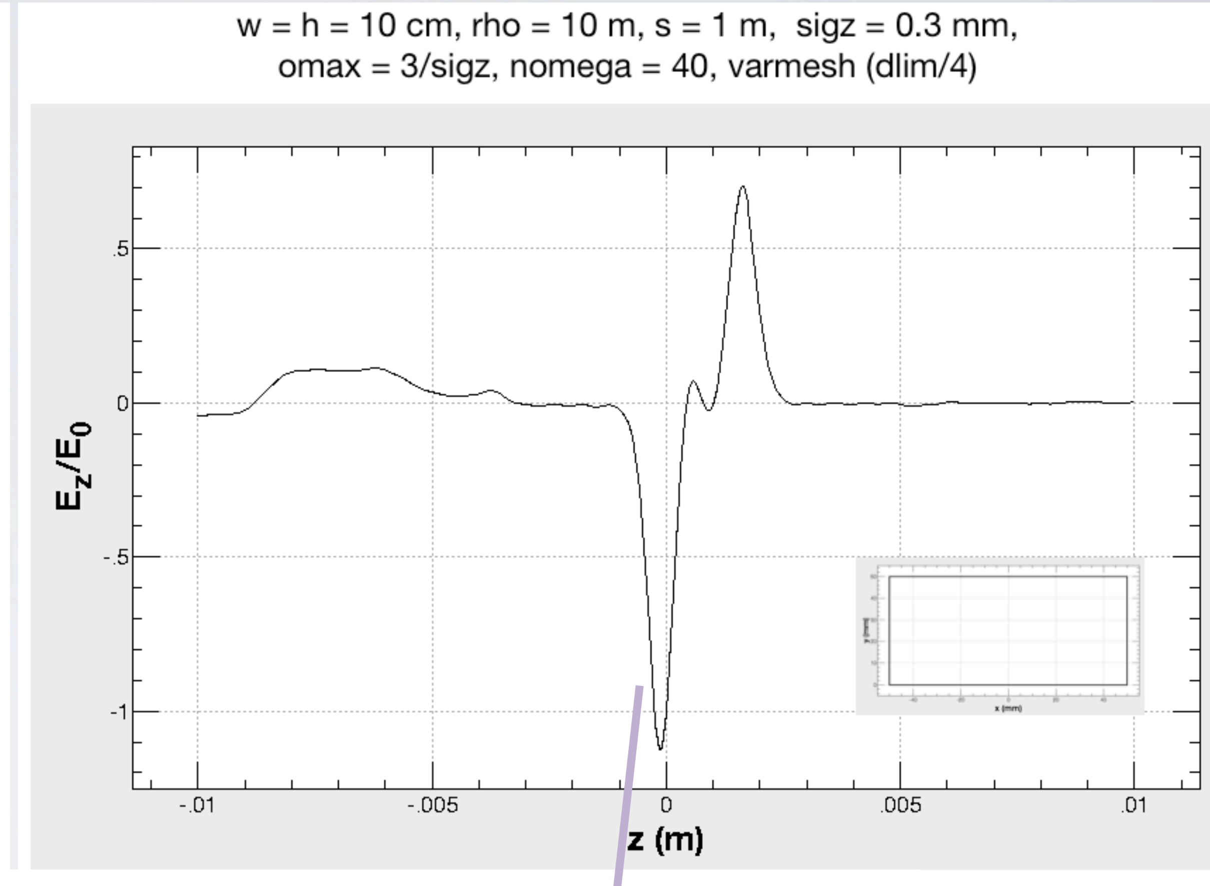
✳The exponent is evaluated by the eigen system of A .

✳The mesh size for A varies with k .

$$\Delta x = \Delta y = \frac{(R/k^2)^{1/3}}{M}\ , \qquad M \gtrsim 4$$

RESULTS(1) ELECTRIC FIELD





THE TRANSIENT ELECTRIC FIELD FOR A SQUARE PIPE AGREES WITH AGOH-YOKOYA'S VERY WELL.

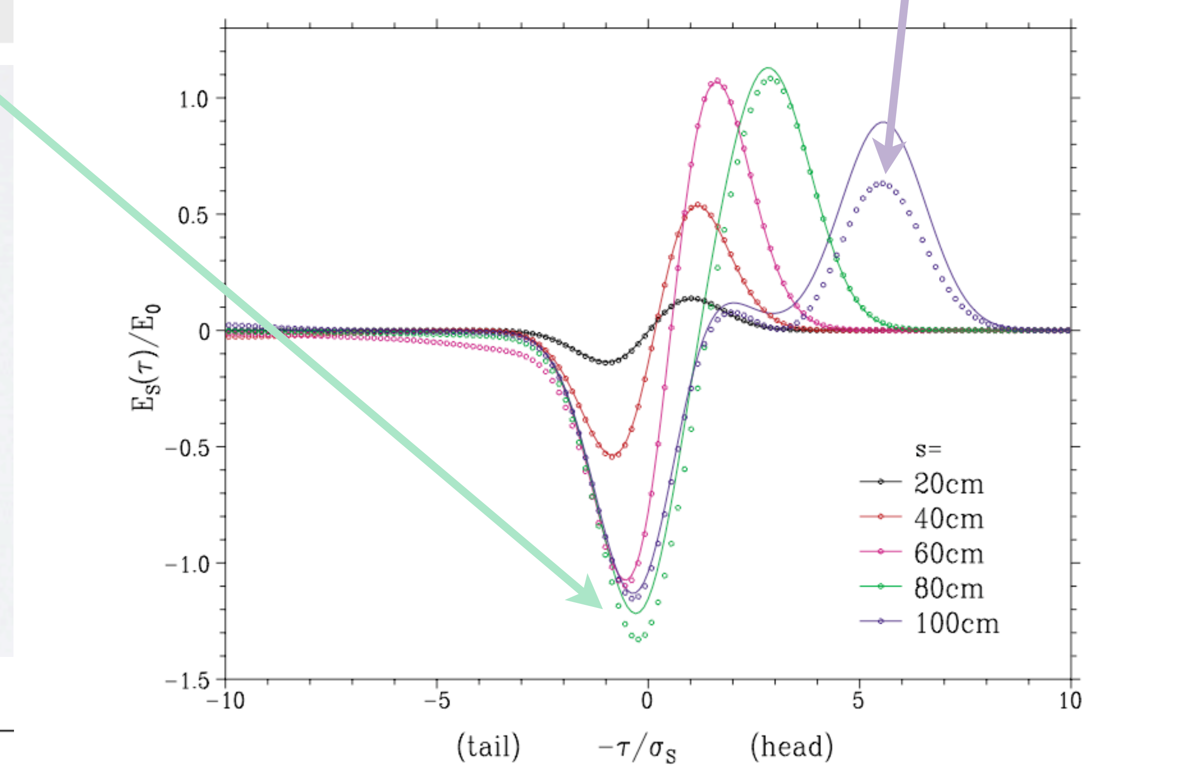


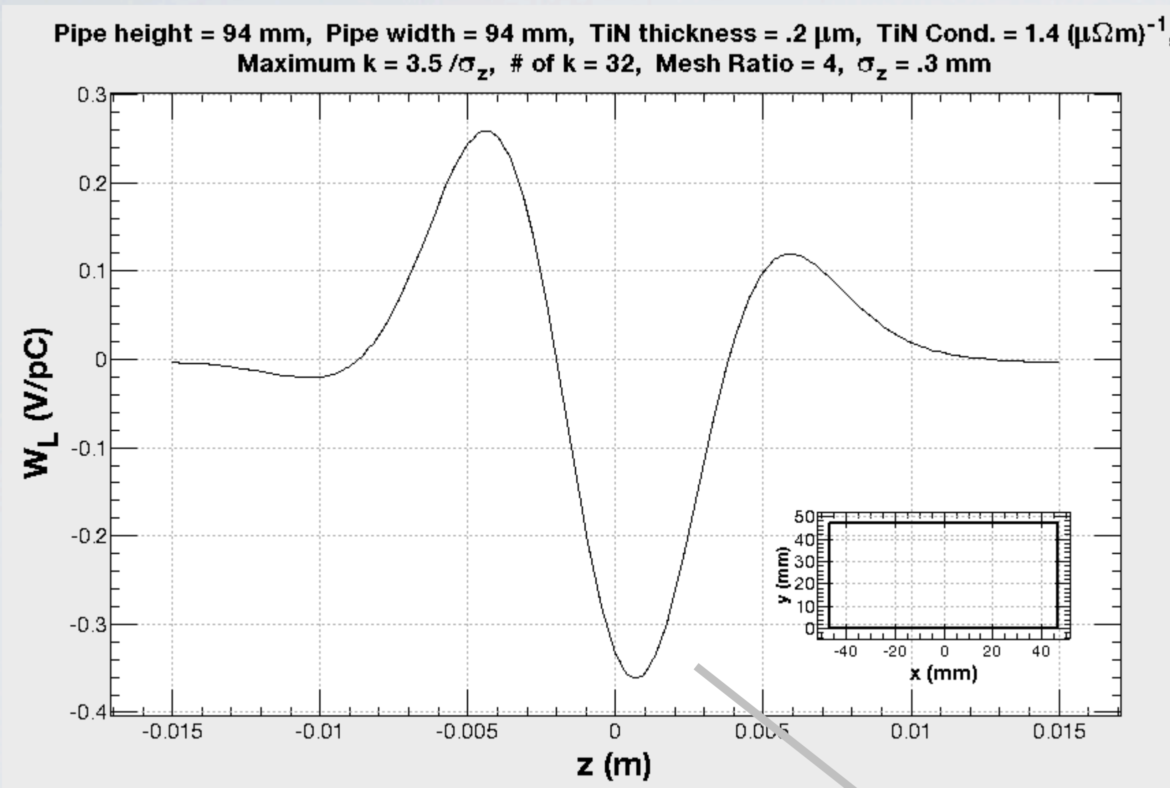
FIG. 4. (Color) The longitudinal electric field E_s in transient state with shielding. The chamber size is $w \times h = 10$ cm $\times$ 10 cm. The other parameters are the same as in Fig. 3.

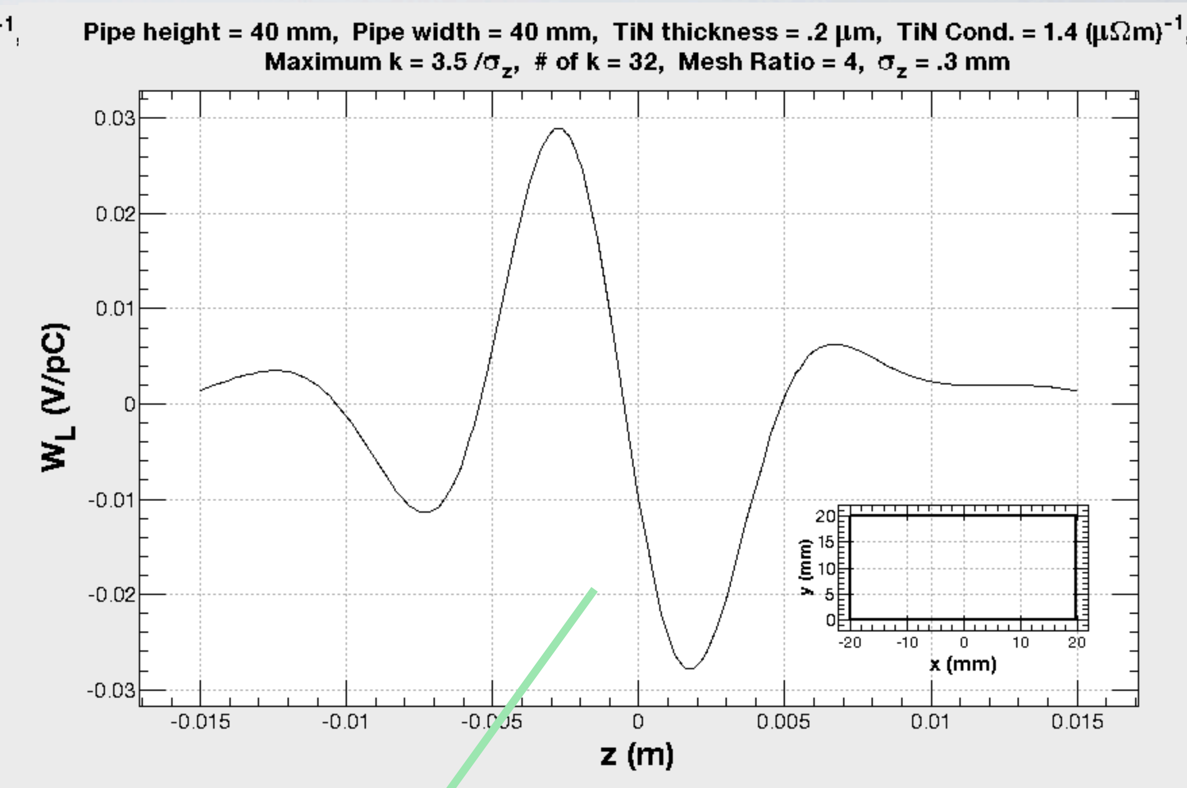
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS
VOLUME **7**, 054403 (2004)

Calculation of coherent synchrotron radiation using mesh

T. Agoh and K. Yokoya

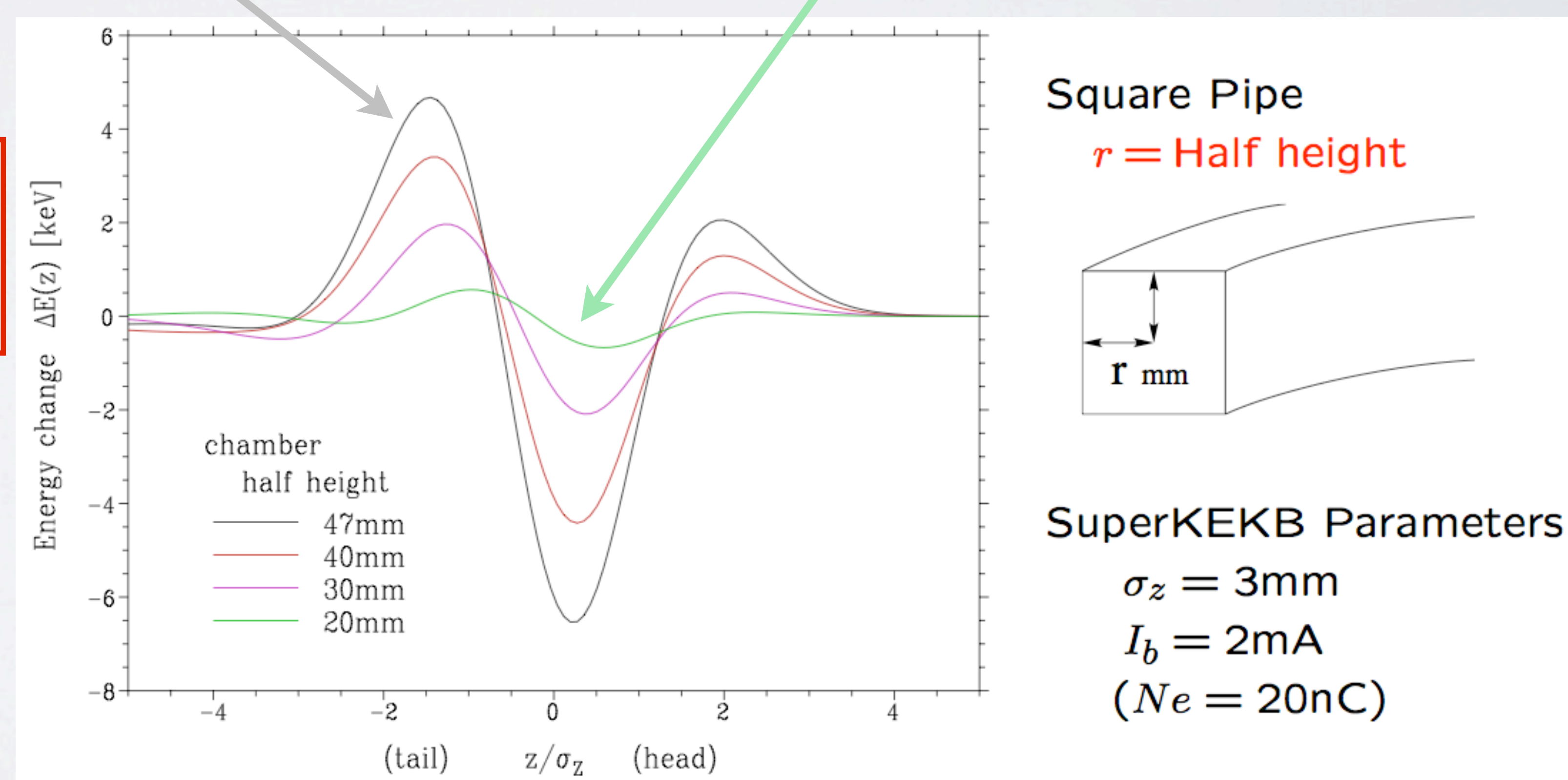
RESULTS(1.1) WAKE FIELD





wake field for 3 mm bunch

THE WAKE FIELD FOR A SQUARE PIPE ALSO AGREES WITH T. AGOH'S VERY WELL.

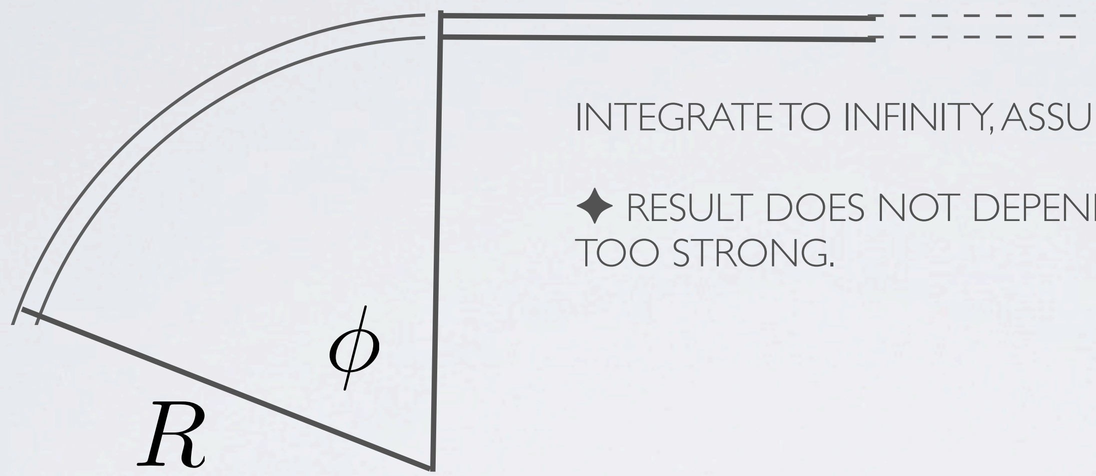


T. AGOH, MAC05

RESULTS(2): WAKES OF SUPERKEKB ANTECHAMBERS

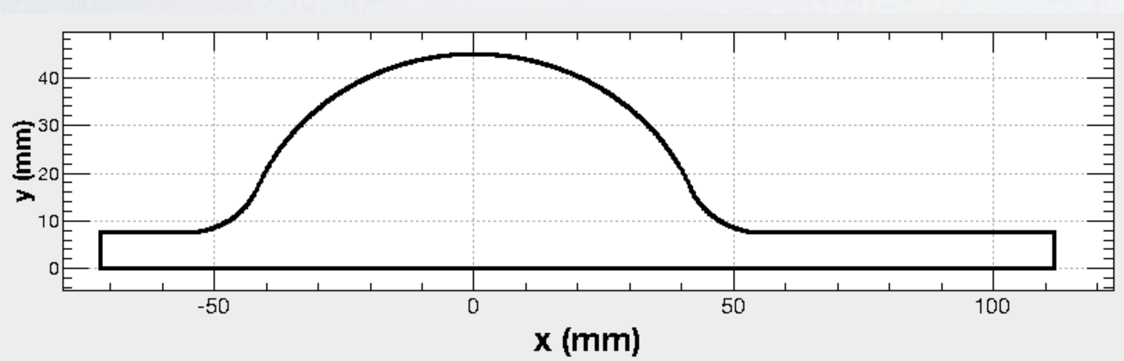
START

$\overline{E}_{r,\phi} = 0$

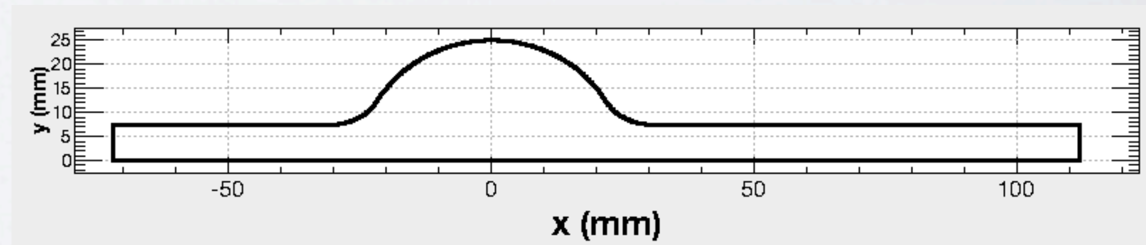


INTEGRATE TO INFINITY, ASSUMING DAMPING BY SURFACE RESISTIVITY.

✦ RESULT DOES NOT DEPEND ON THE RESISTIVITY UNLESS DAMPING IS TOO STRONG.



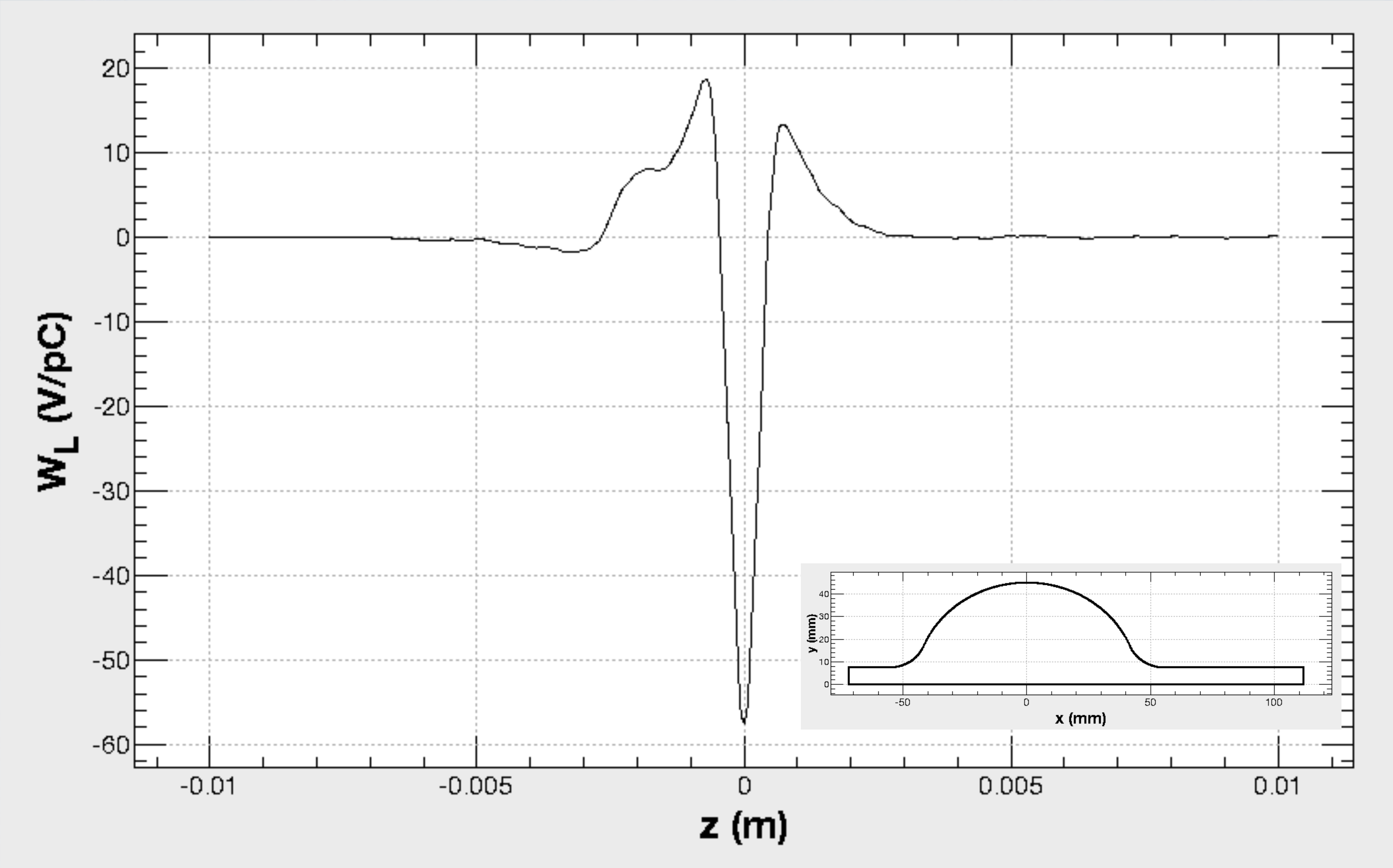
$a = 45\ \mathrm{mm}$



$a = 25\ \mathrm{mm}$

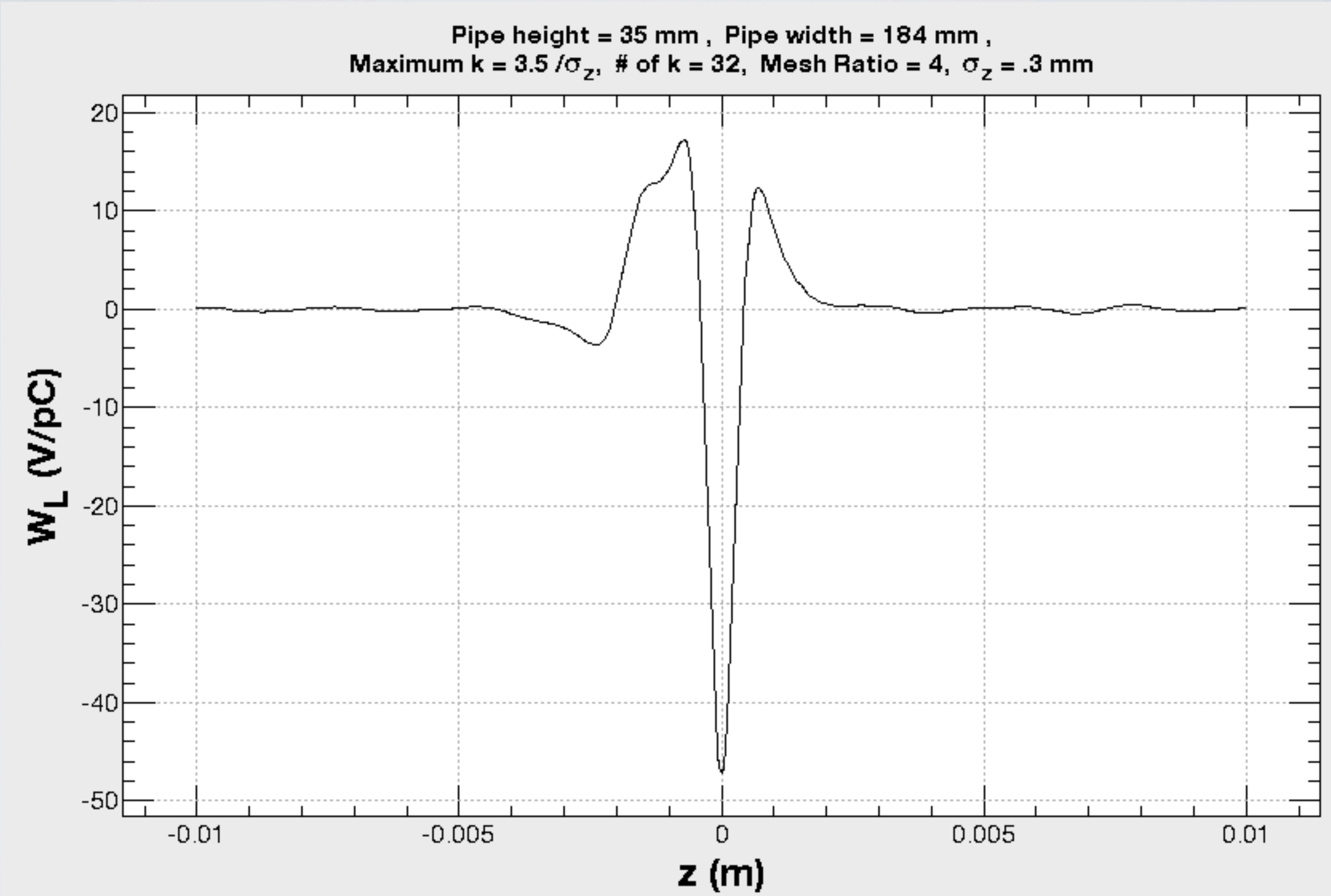
CROSS SECTIONS BY Y. SUETSUGU

rac = 45 mm, rho = (B2P) m, s = (B2P) + (res), sigz = 0.3 mm,
omax = 3.5/sigz, nomega = 32, varmesh (dlim/4)



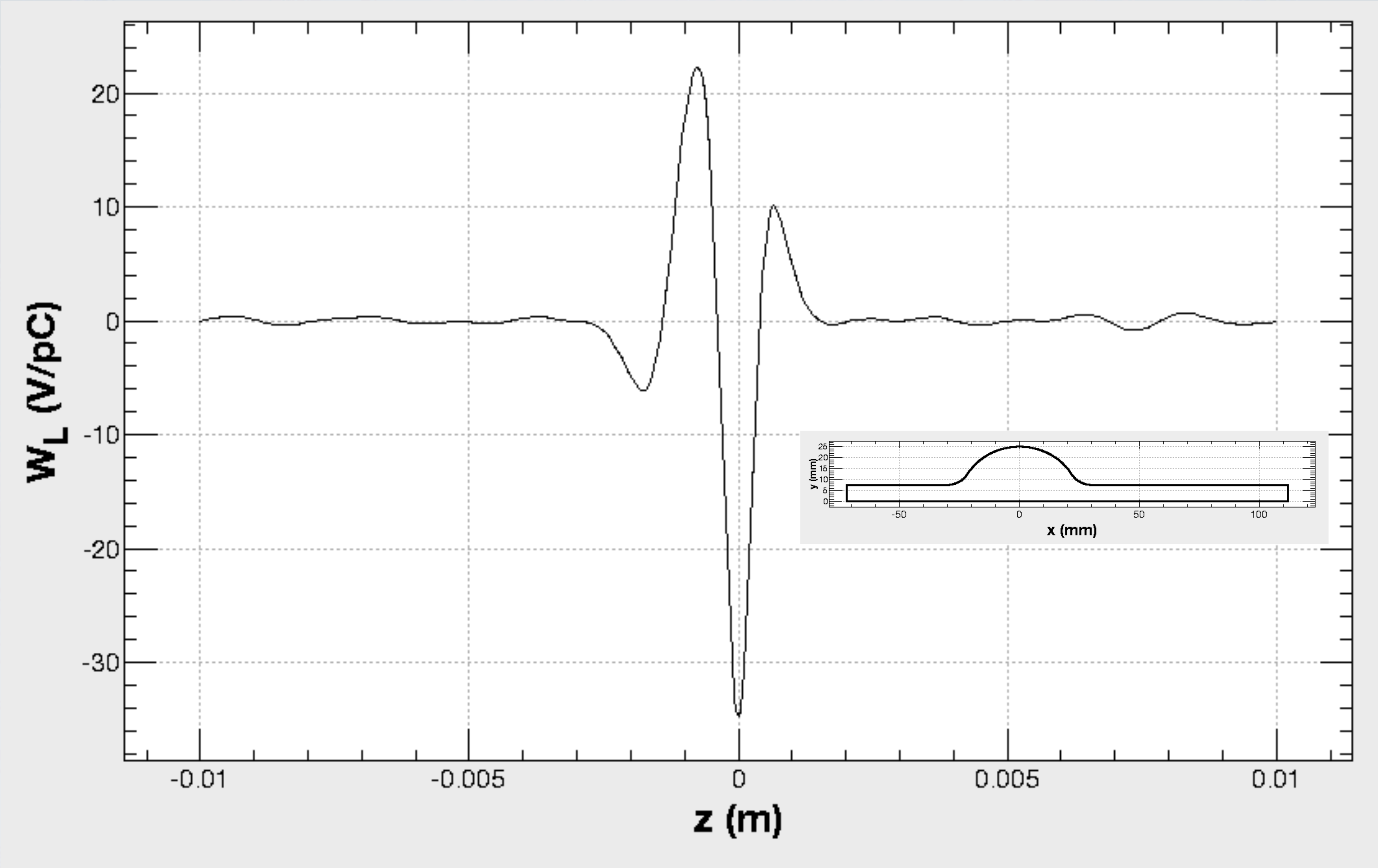
2 Sep 2008

rAC = 35 mm, rho = (B2P) m, s = (B2P) + (res)



4 Sep 2008

rac = 25 mm, rho = (B2P) m, s = (B2P) + (res), sigz = 0.3 mm,
omax = 3.5/sigz, nomega = 32, varmesh (dlim/4)



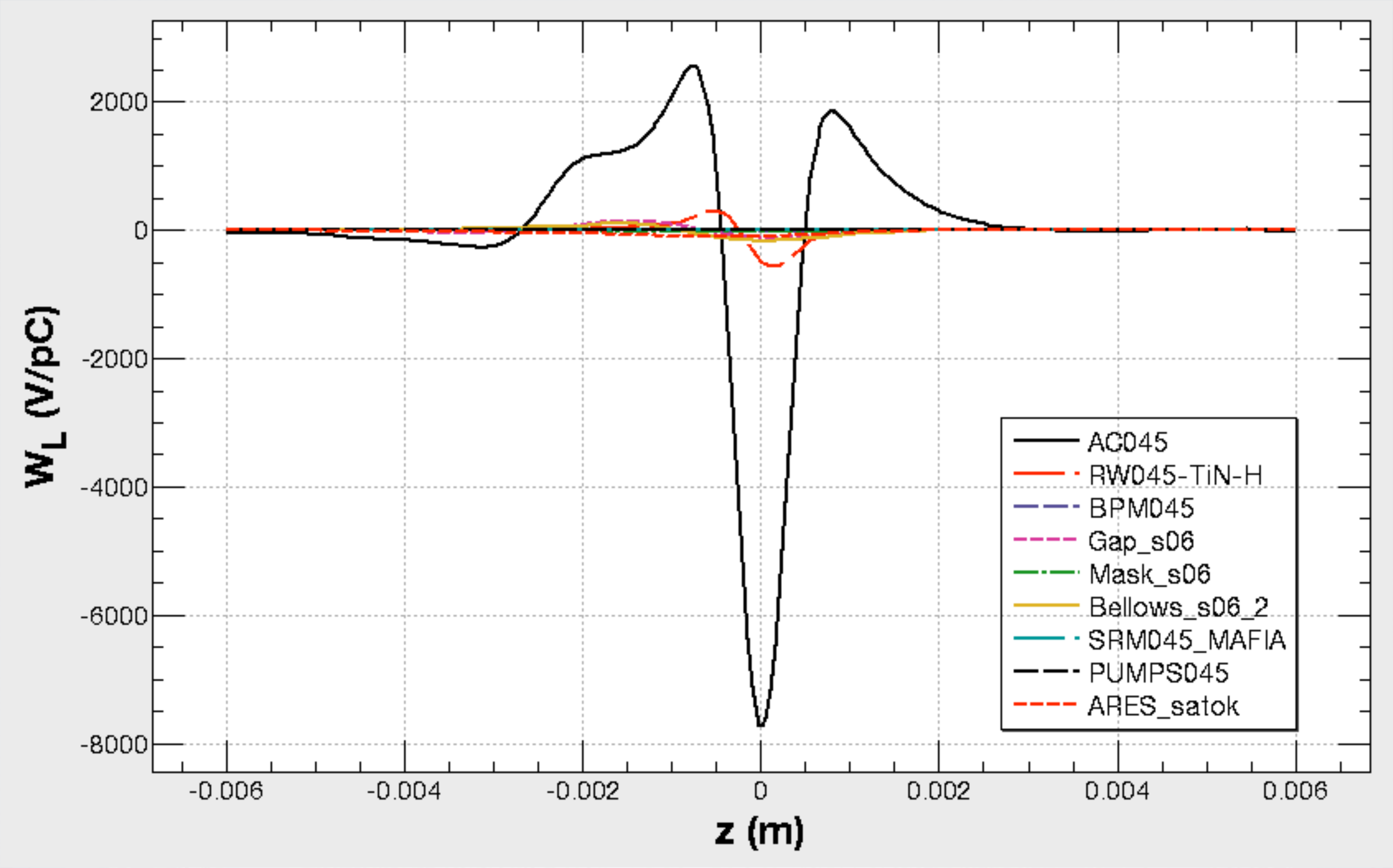
4 Sep 2008

TRACKING SIMULATION OF BUNCH STABILITY

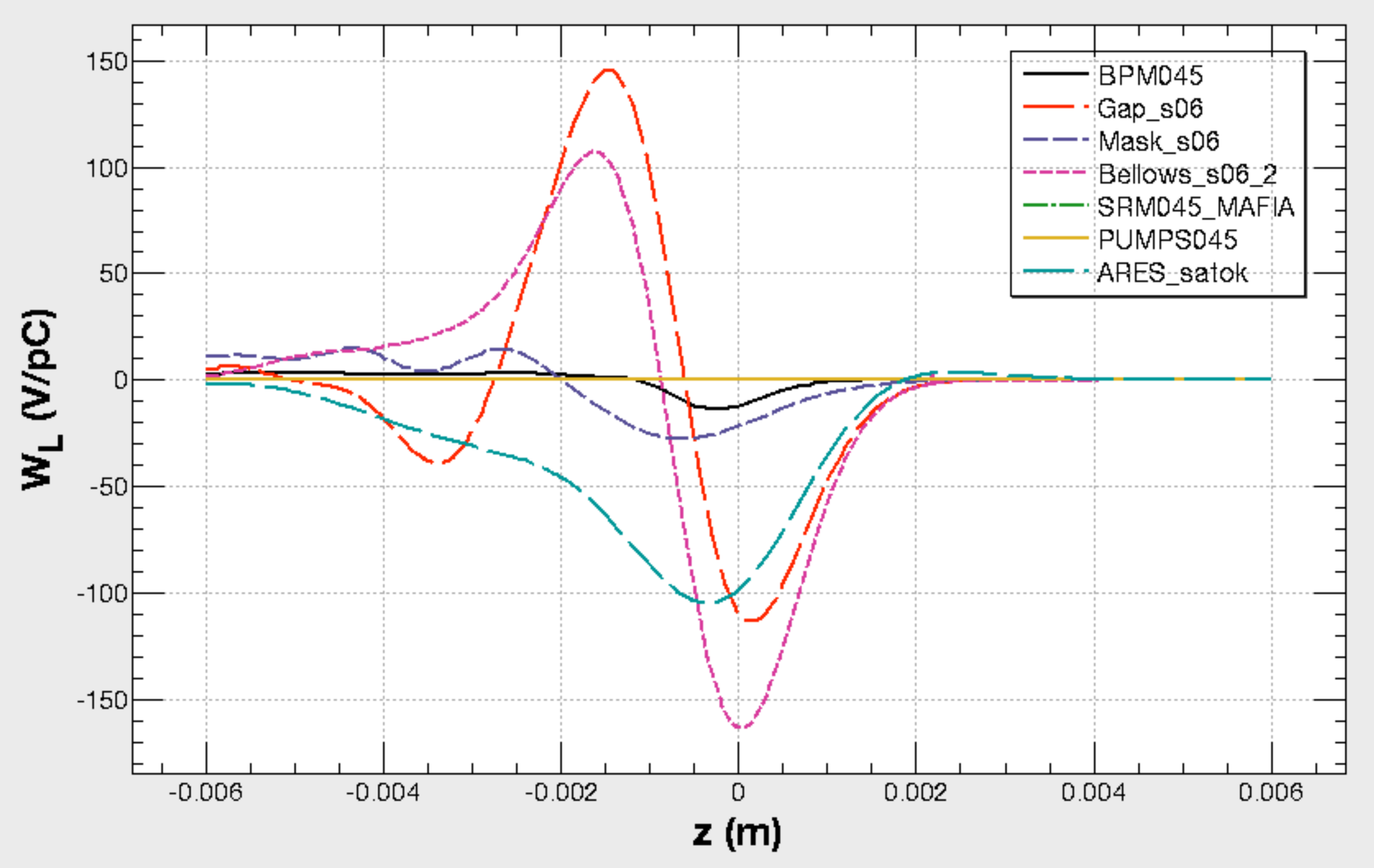
- Sum up all wakes, calculated by Suetsugu, Tobiyama, Shibata, and Satoh.
- TiN coated resistive wall: $\sigma = 1.4\ (\mu\Omega m)^{-1}$ thickness = 0.2 μm, given by Hisamatsu and Suetsugu.
- SuperLER parameters.
- 400,000 macro particles.

rac = 45 mm, rho = (B2P) m, s = (B2P) + (res), TiN

Number of bends = 150



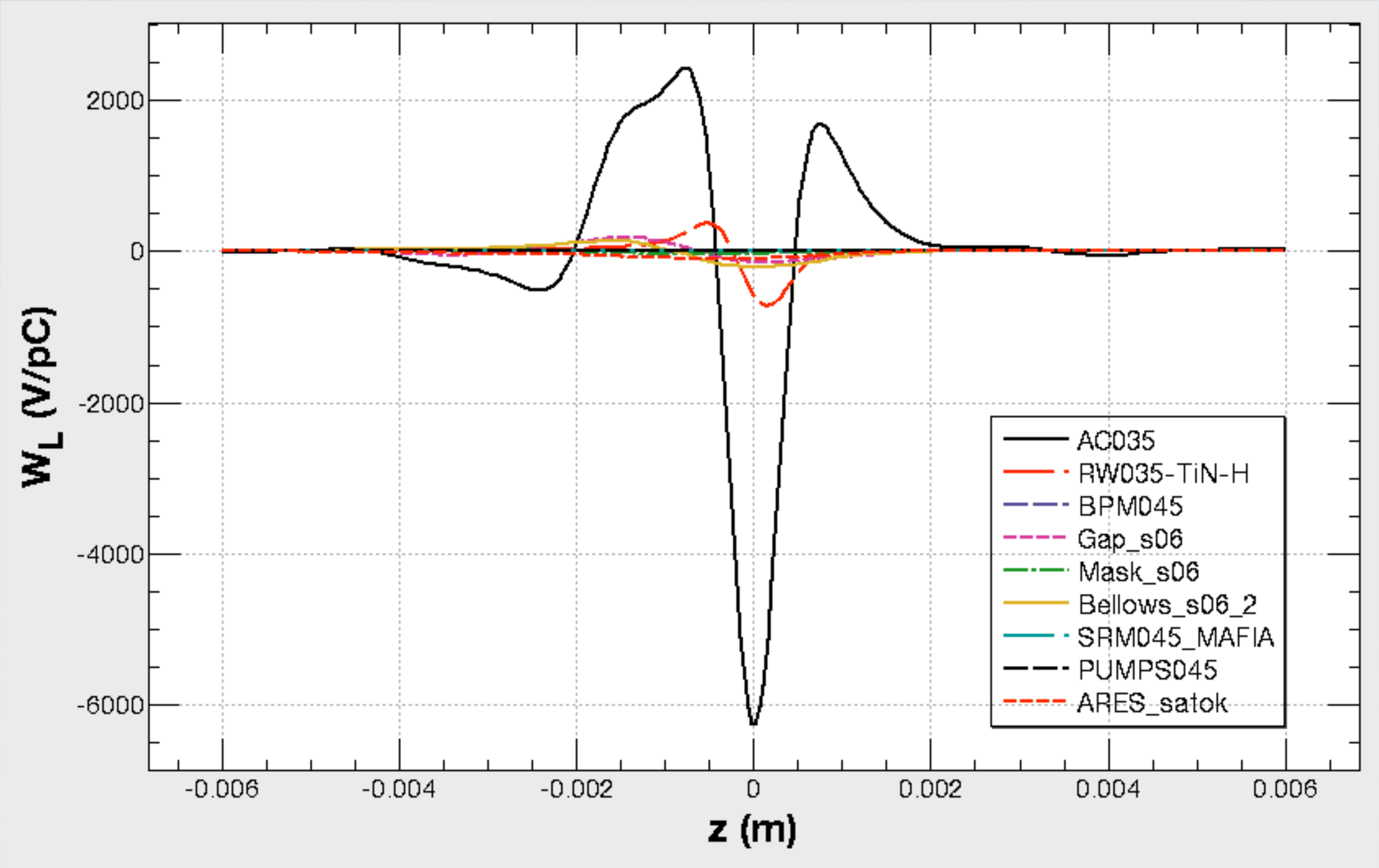
rac = 45 mm



BPM045
Gap_s06
Mask_s06
Bellows_s06_2
SRM045_MAFIA
PUMPS045
ARES_satok
150
100
50
0
-50
-100
-150
W_L (V/pC)
-0.006
-0.004
-0.002
0
0.002
0.004
0.006
z (m)

rac = 35 mm(*), rho = (B2P) m, s = (B2P) + (res), TiN

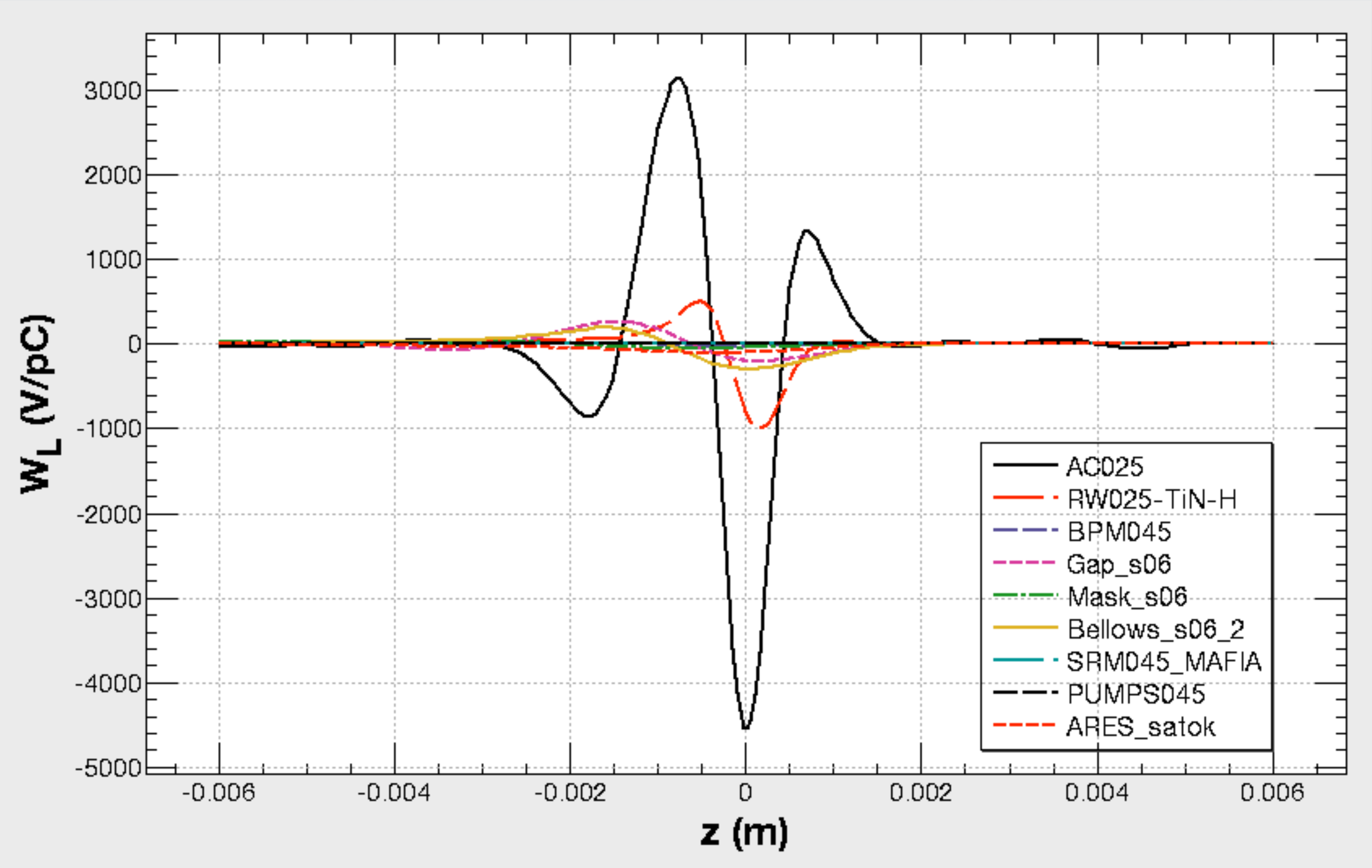
Number of bends = 150



* Some wakes are scaled from a = 45 mm by 1/a.

10 Sep 2008

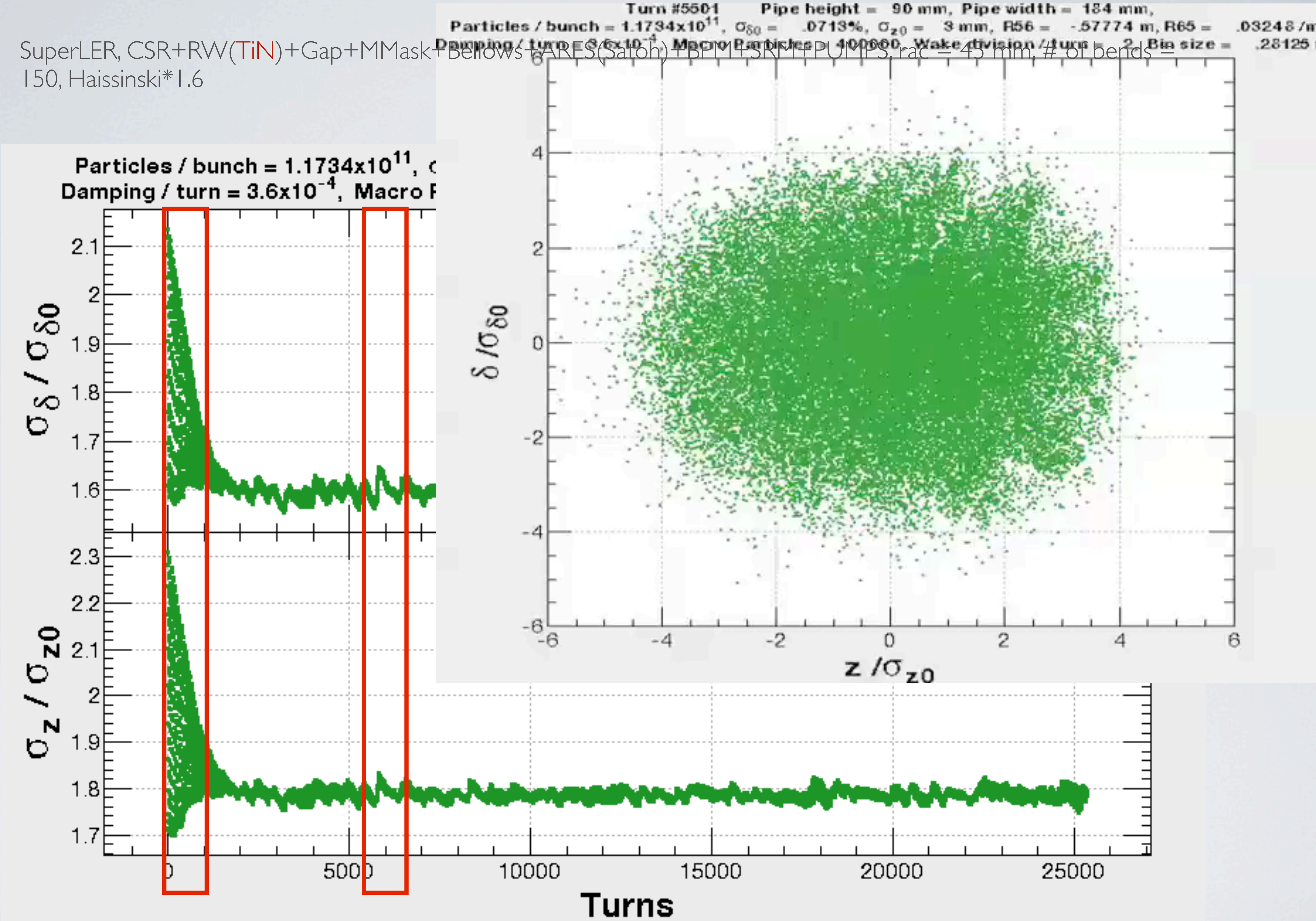
rac = 25 mm(*), rho = (B2P) m, s = (B2P) + (res), TiN
Number of bends = 150



* Some wakes are scaled from a = 45 mm by 1/a.

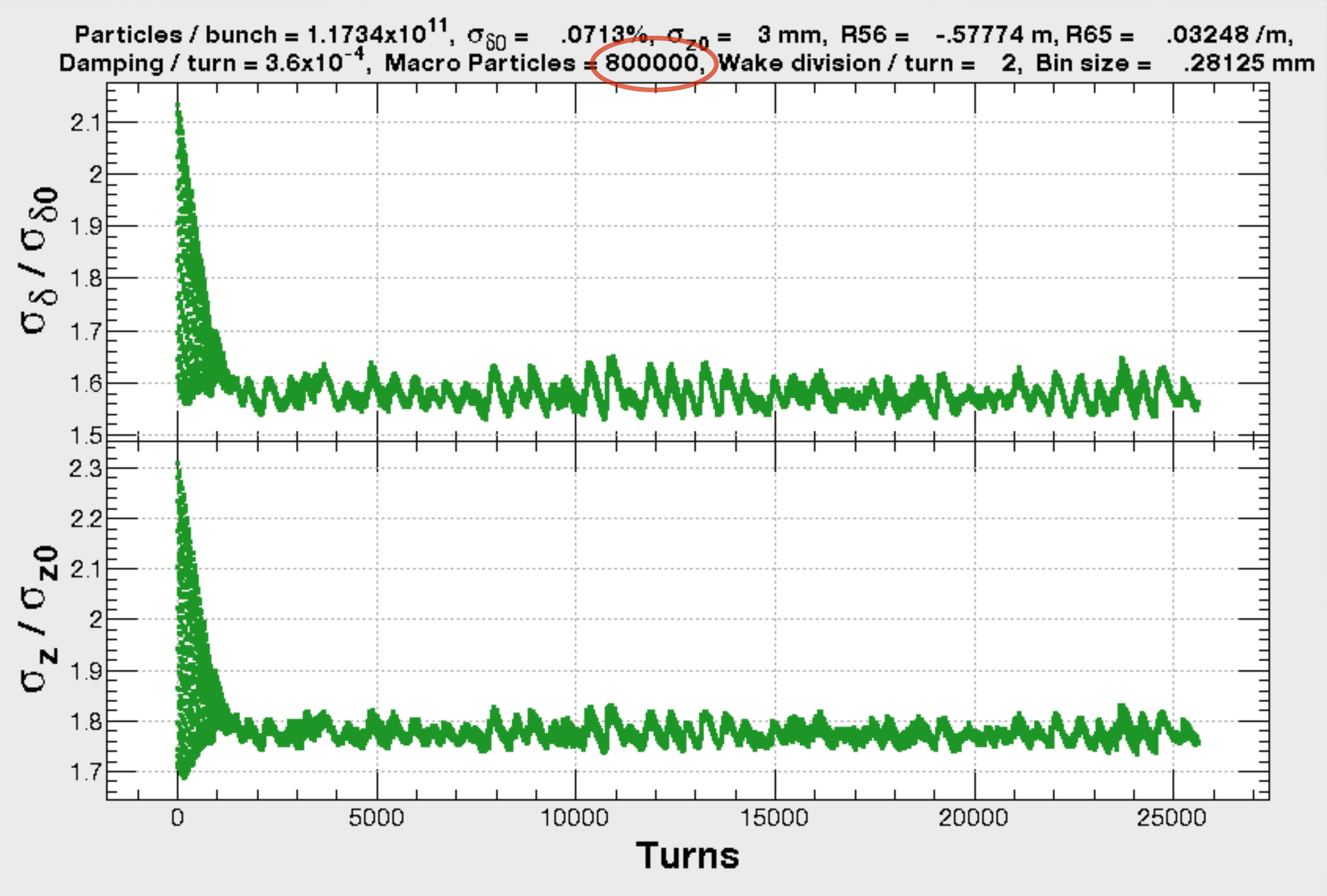
10 Sep 2008

SuperLER, CSR+RW(TiN)+Gap+MMask+Bellows+ARES(Satoh)+BPM+SRM+PUMPS, rac = 45 mm, # of bends = 150, Haissinski*1.6



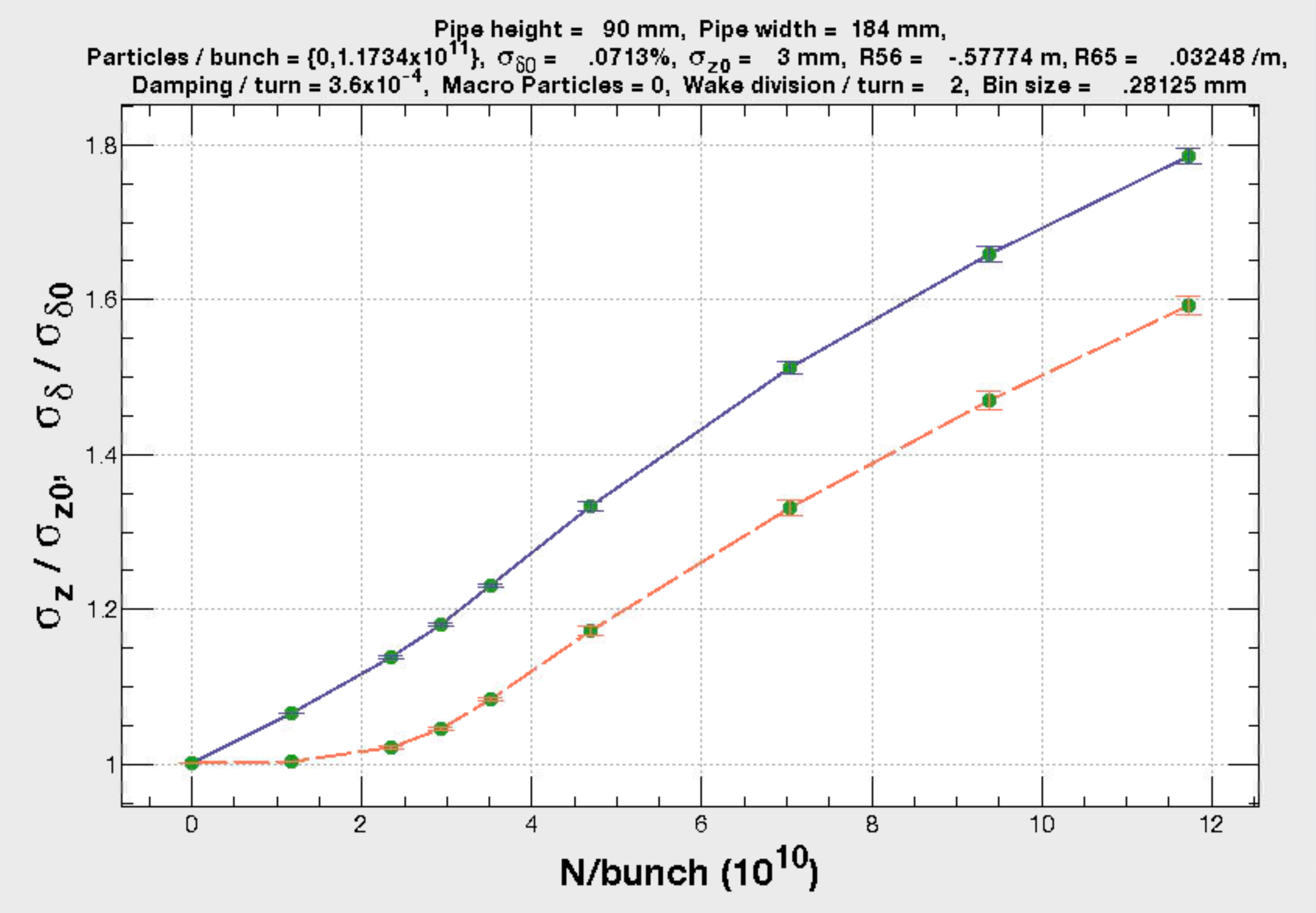
10 Sep 2008

SuperLER, CSR+RW(TiN)+Gap+MMask+Bellows+ARES(Satoh)+BPM+SRM+PUMPS, rac = 45 mm, # of bends = 150, Haissinski*1.6



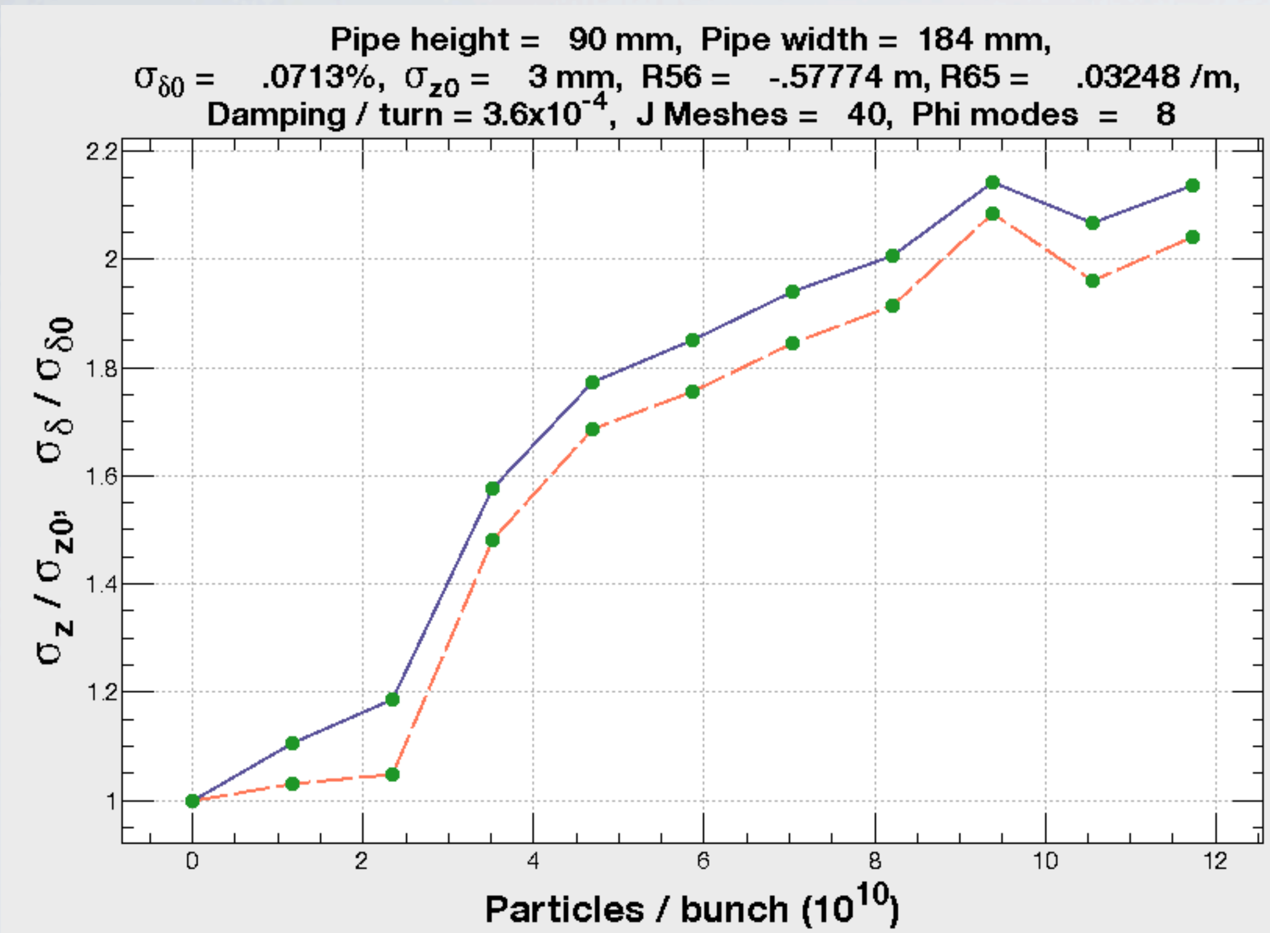
10 Sep 2008

No wigglers

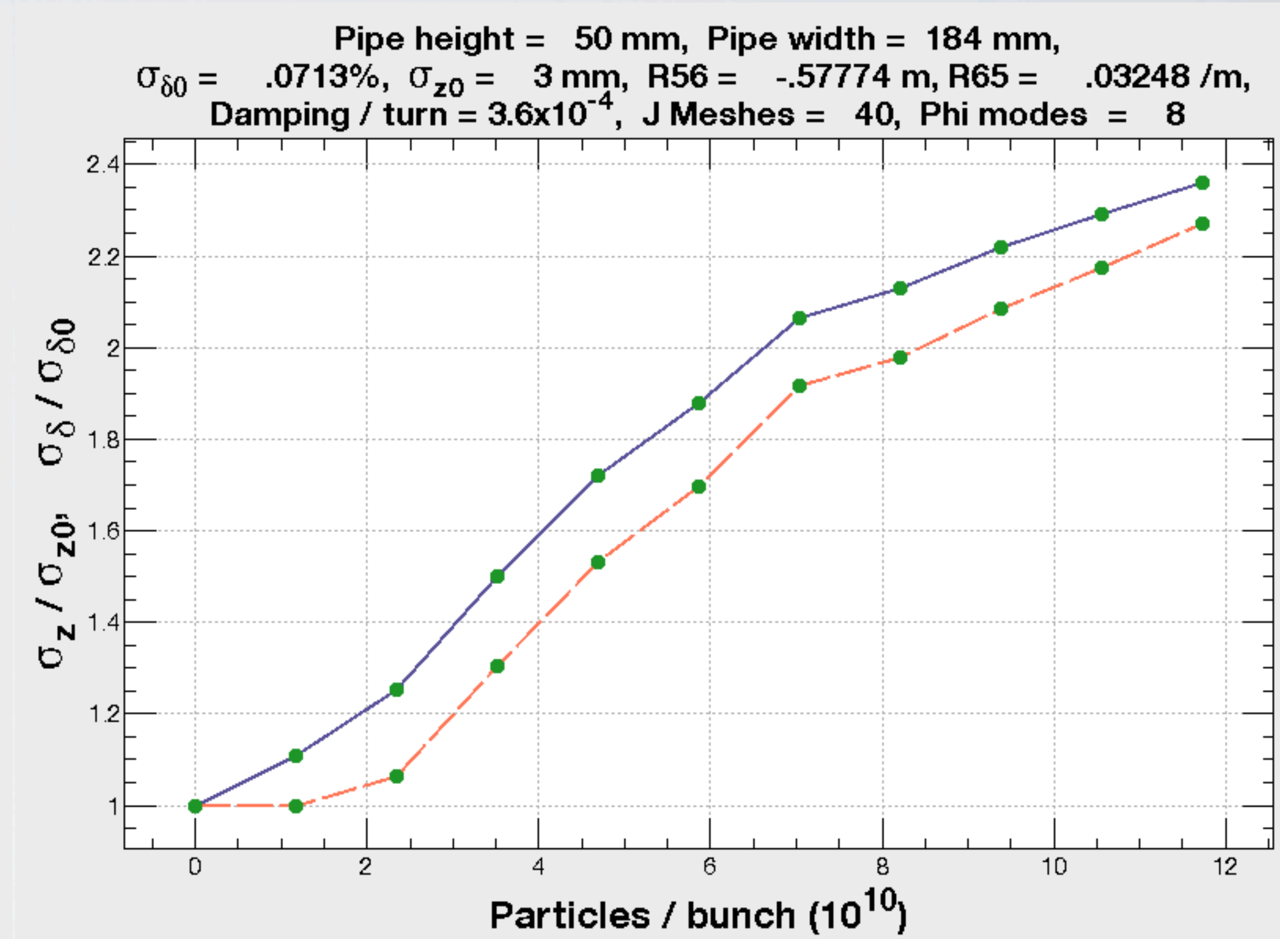


Pipe height = 90 mm, Pipe width = 184 mm,
Particles / bunch = {0,1.1734x10^11}, σδ0 = .0713%, σz0 = 3 mm, R56 = -.57774 m, R65 = .03248 /m,
Damping / turn = 3.6x10^-4, Macro Particles = 0, Wake division / turn = 2, Bin size = .28125 mm
σz / σz0, σδ / σδ0
N/bunch (10^10)

RESULTS WITH "OIDE-YOKOYA" METHOD



rac = 45 mm



rac = 25 mm

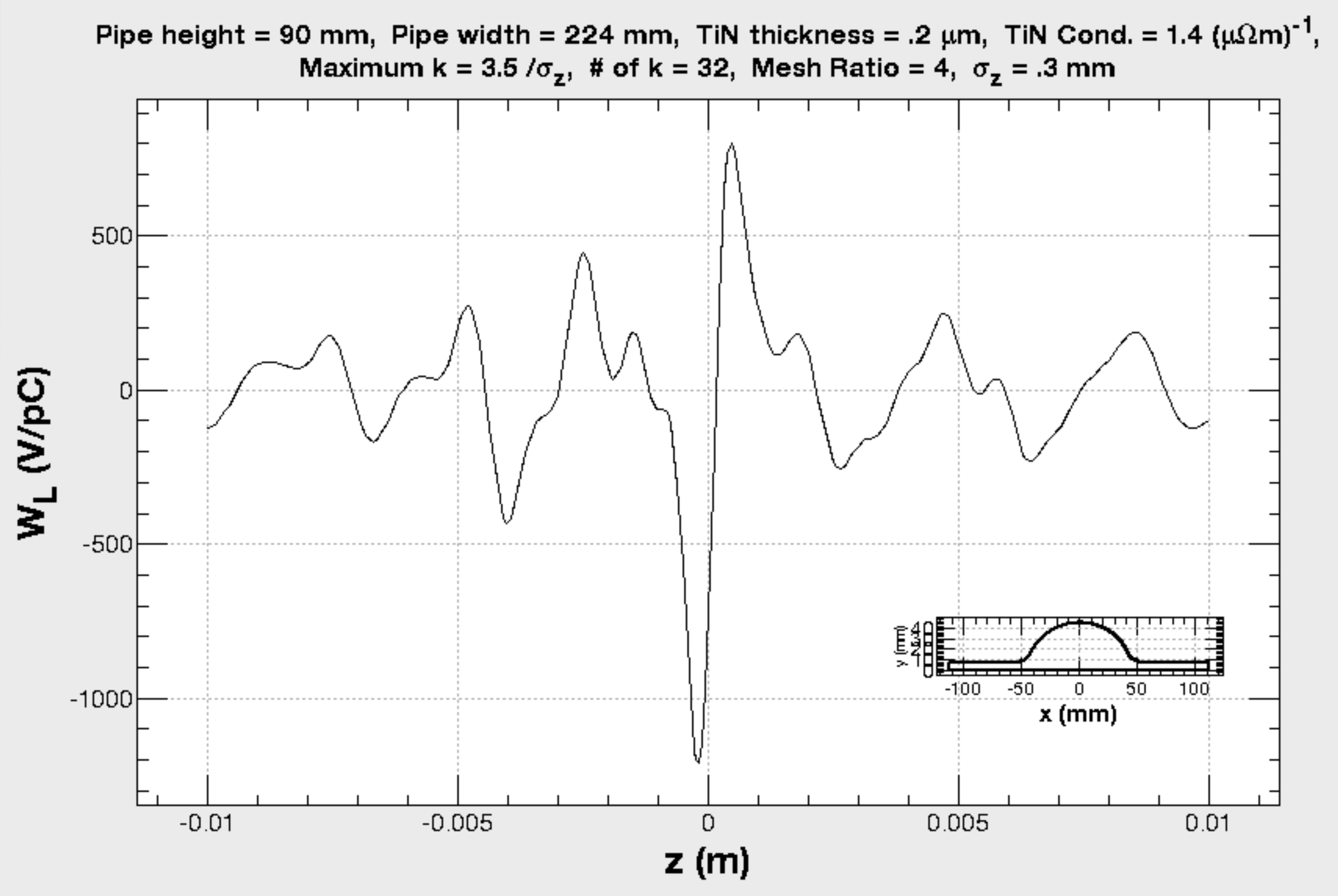
$$
\begin{aligned}
M_{jmj'm'} \;&=\; m^2\omega_j^2\delta_{jj'}\delta_{mm'} + \frac{k}{\pi}mm'\omega_j\omega_{j'}\left(-g_j'\Delta J_j\right)^{1/2}\left(-g_{j'}'\Delta J_{j'}\right)^{1/2} \\
&\times \int_0^{2\pi}\int_0^{2\pi}\cos m\phi\cos m'\phi' F\left(q(J_{j'},\phi') - q(J_j,\phi)\right)d\phi d\phi' .
\end{aligned}
$$

★ This method is more powerful in predicting the threshold than estimating the magnitude of blowup beyond that.

REMARKS & QUESTIONS

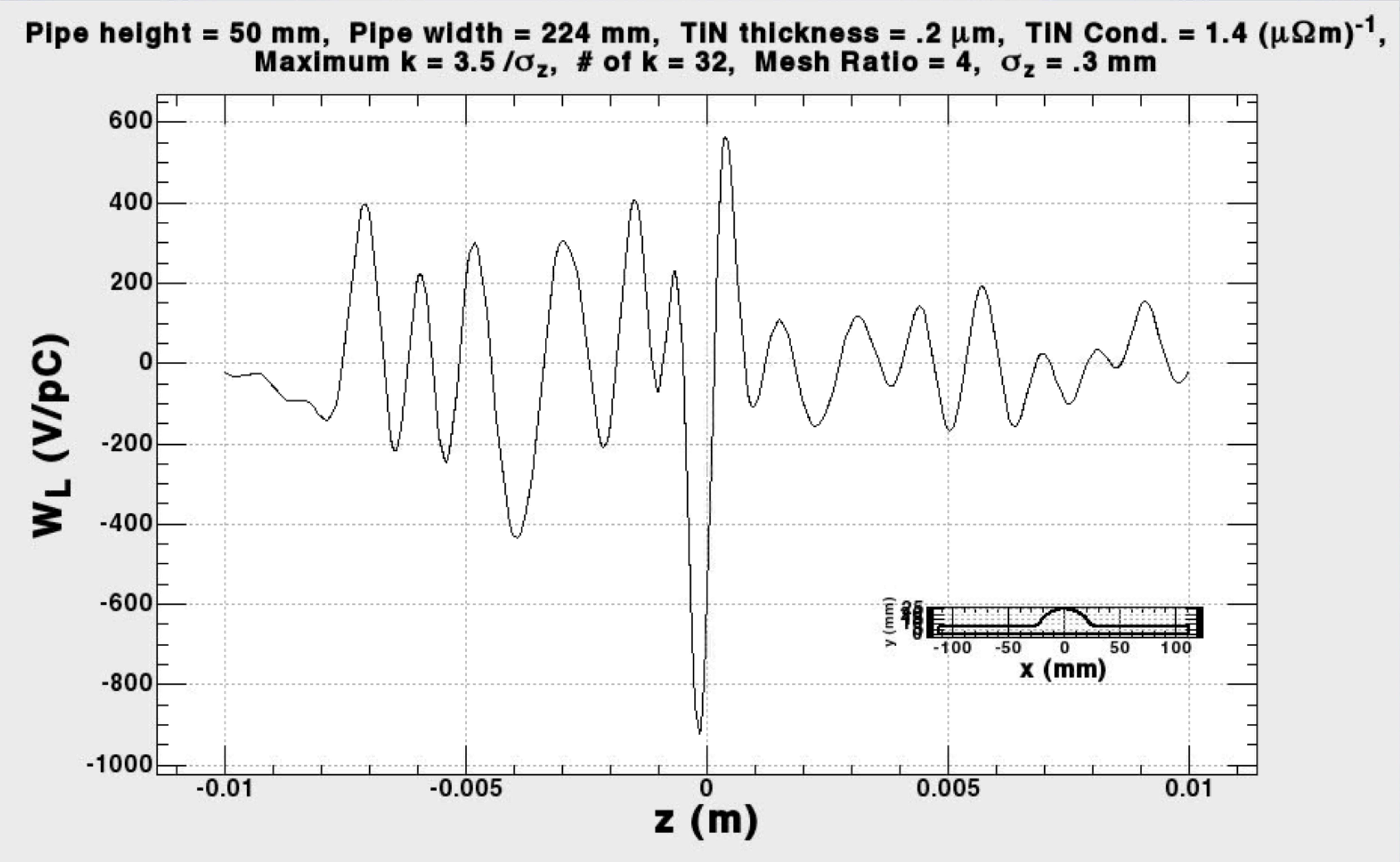
- Effect on W(z) from the straight is quite large. Is this reasonable?
  - Some modes have damping length > 1,000 km.
  - What about in the case of other wakes?
  - The pair of bends, separated by 6 m, does not help.
- Even the bending radius becomes 4 times longer, the wake does not reduce much.

Pseudo Wiggler: 152 poles



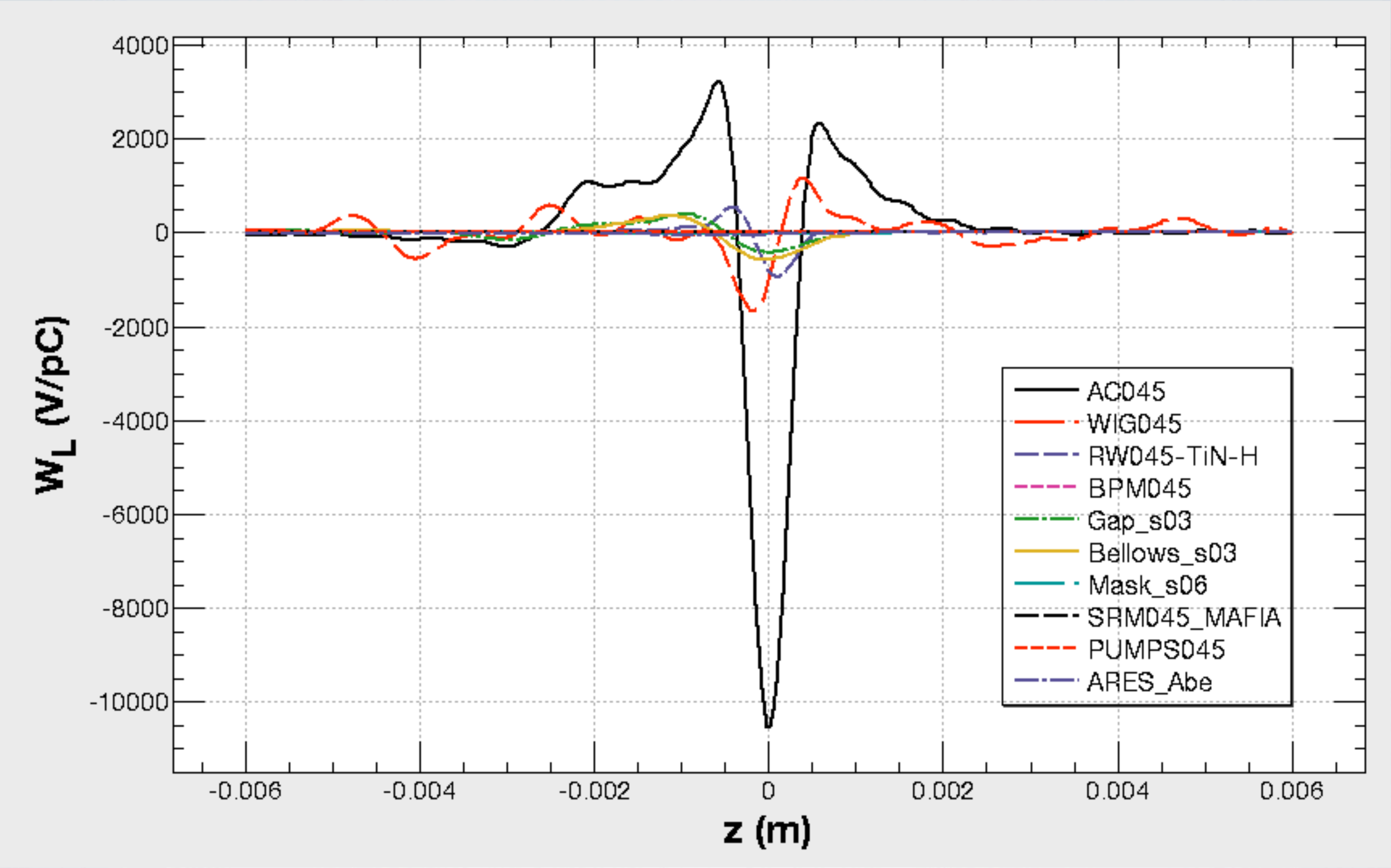
23 Sep 2008

Pseudo Wiggler: 152 poles, 25 mm



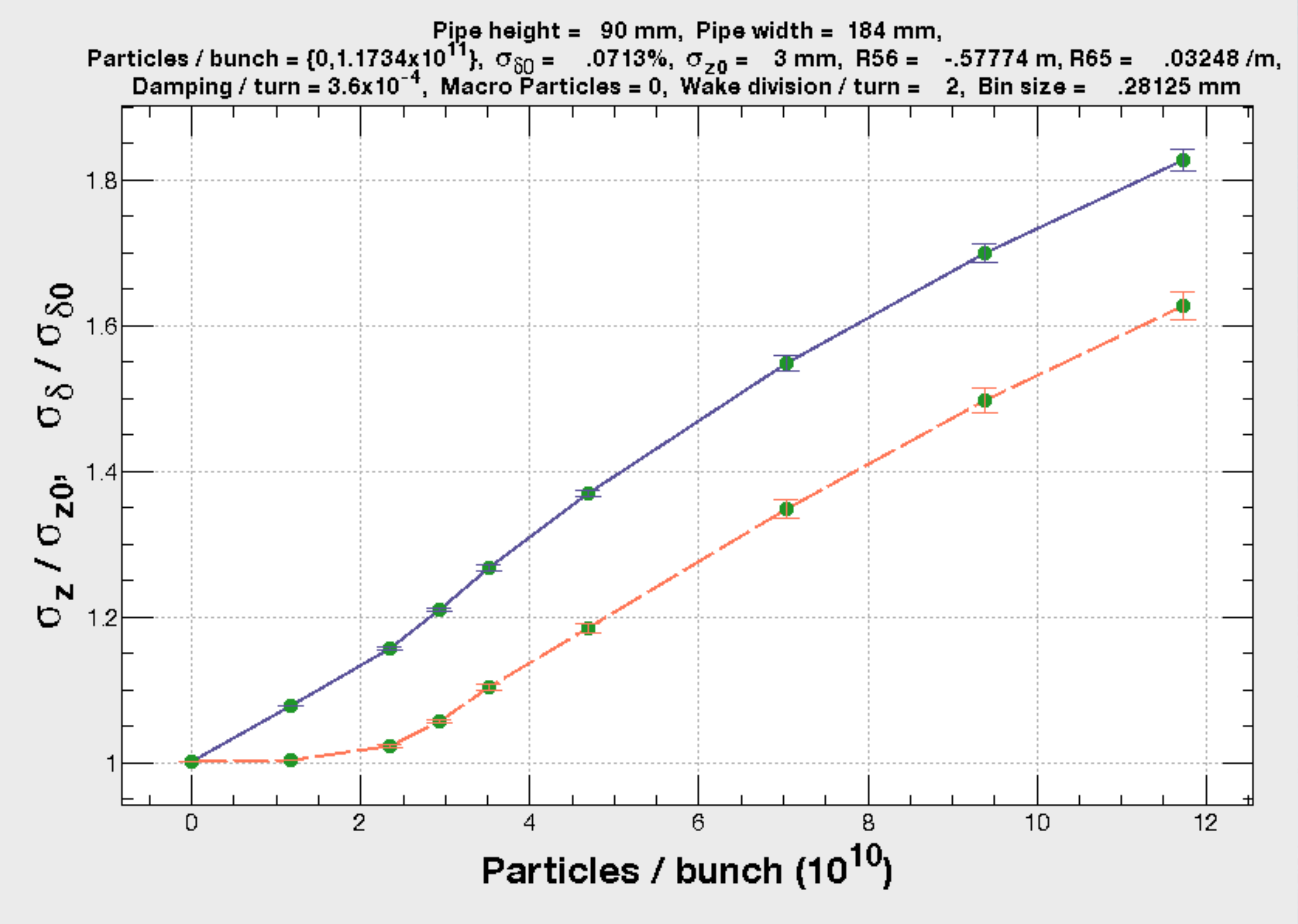
26 Sep 2008

45 mm All



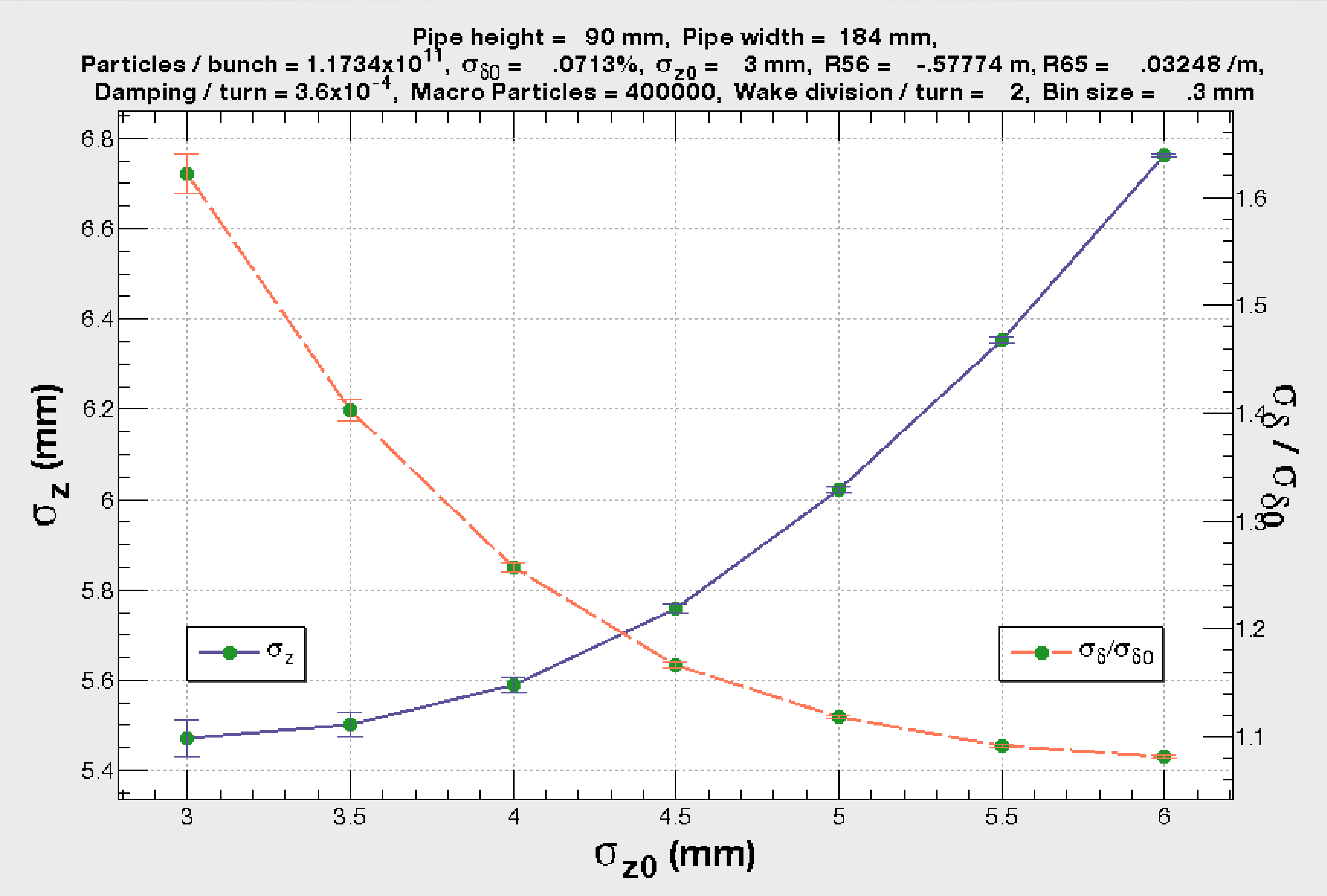
23 Sep 2008

ALL WAKES, INCL. WIGGLERS



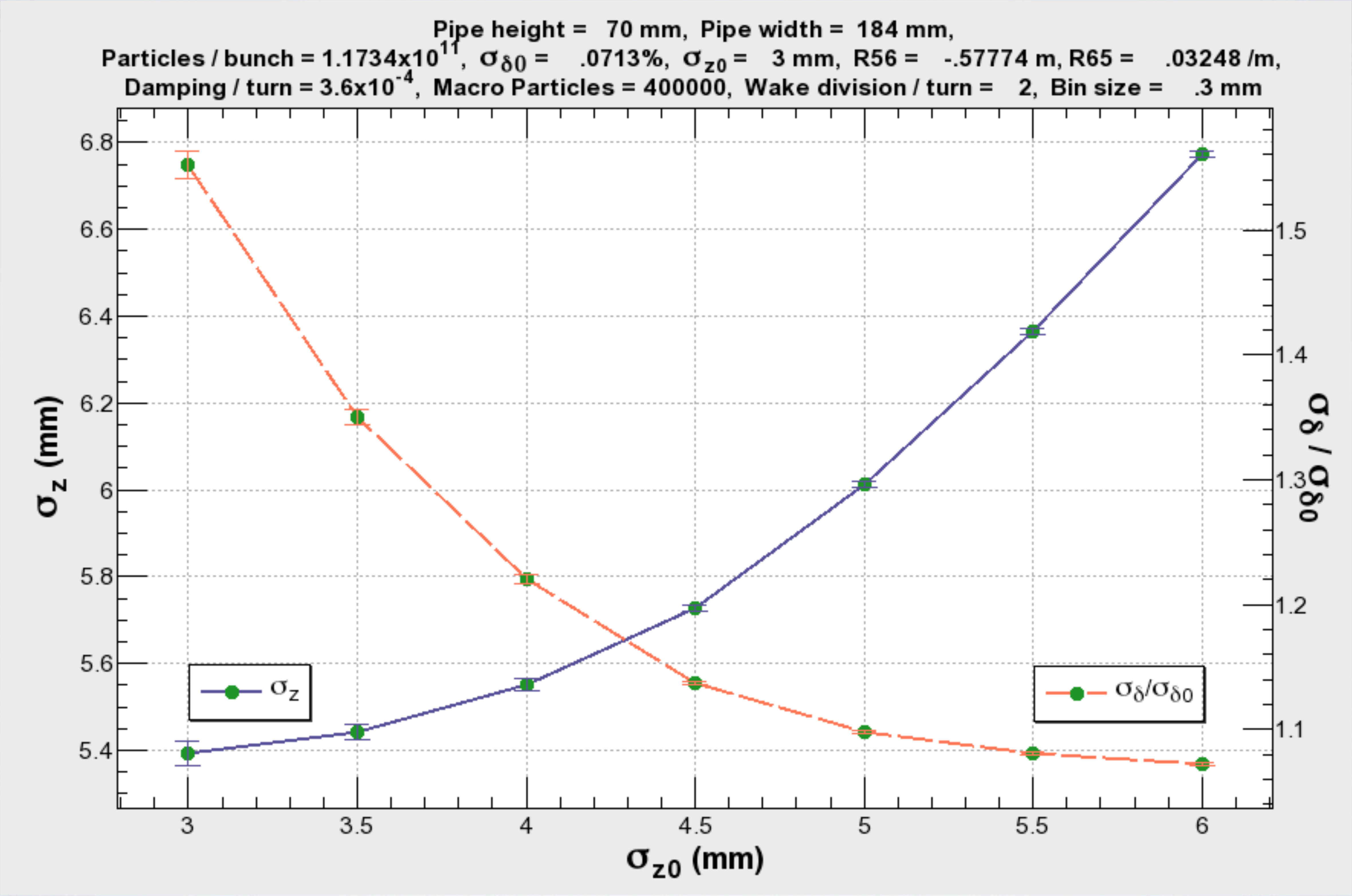
23 Sep 2008

ALL WAKES (45 MM), INCL. WIGGLERS



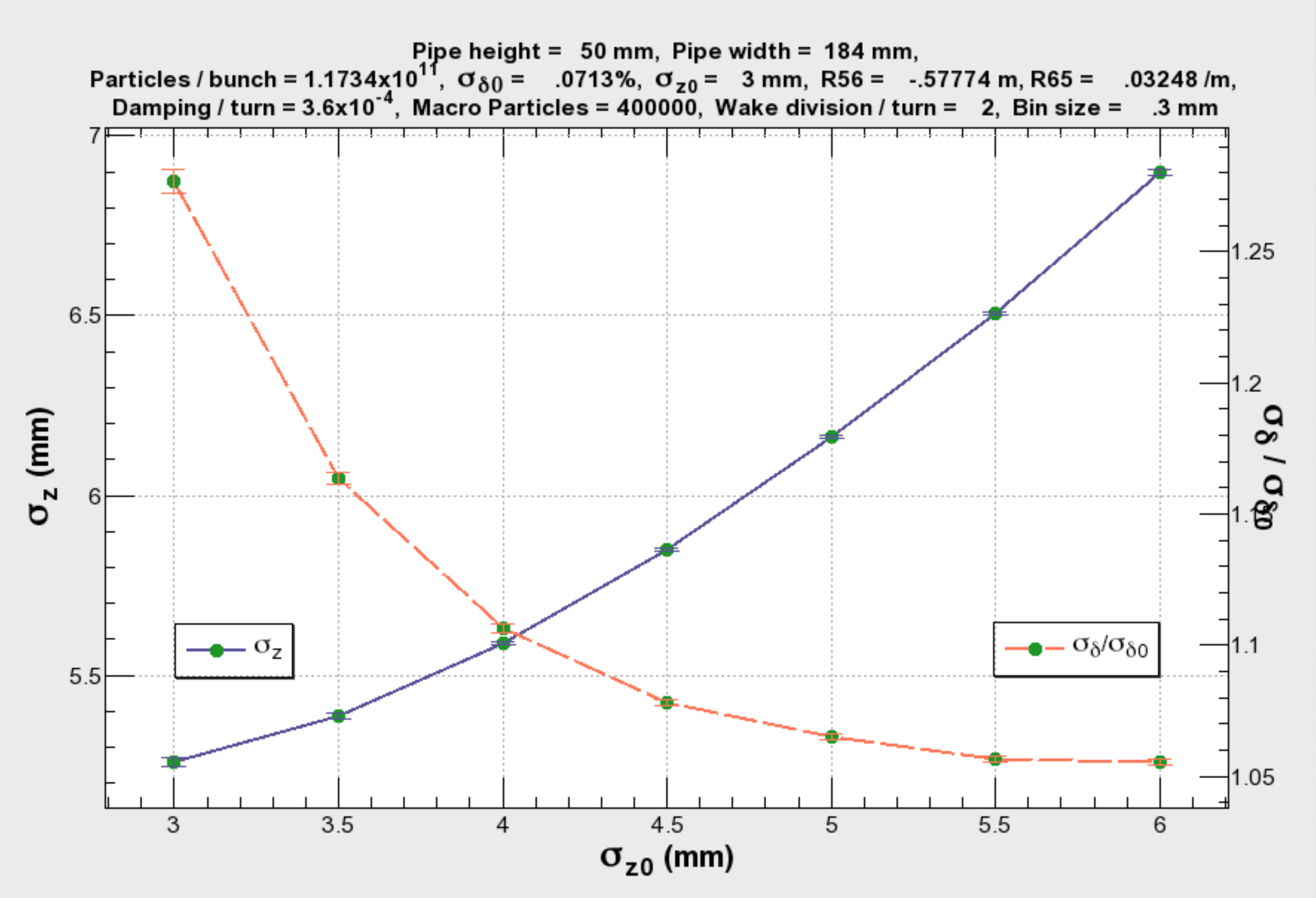
26 Sep 2008

ALL WAKES (35 MM), INCL. WIGGLERS



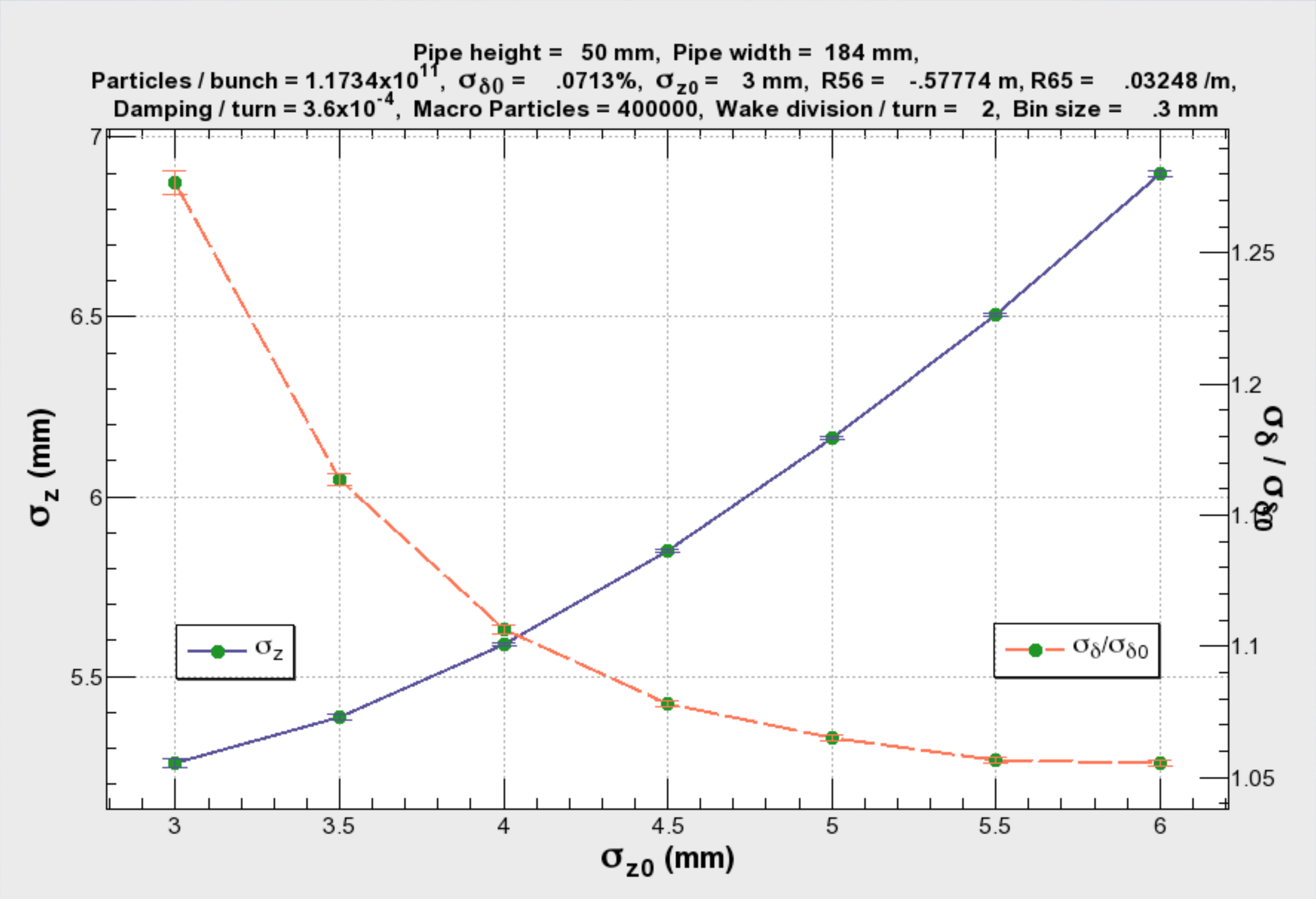
7 Oct 2008

ALL WAKES (25 MM), INCL. WIGGLERS



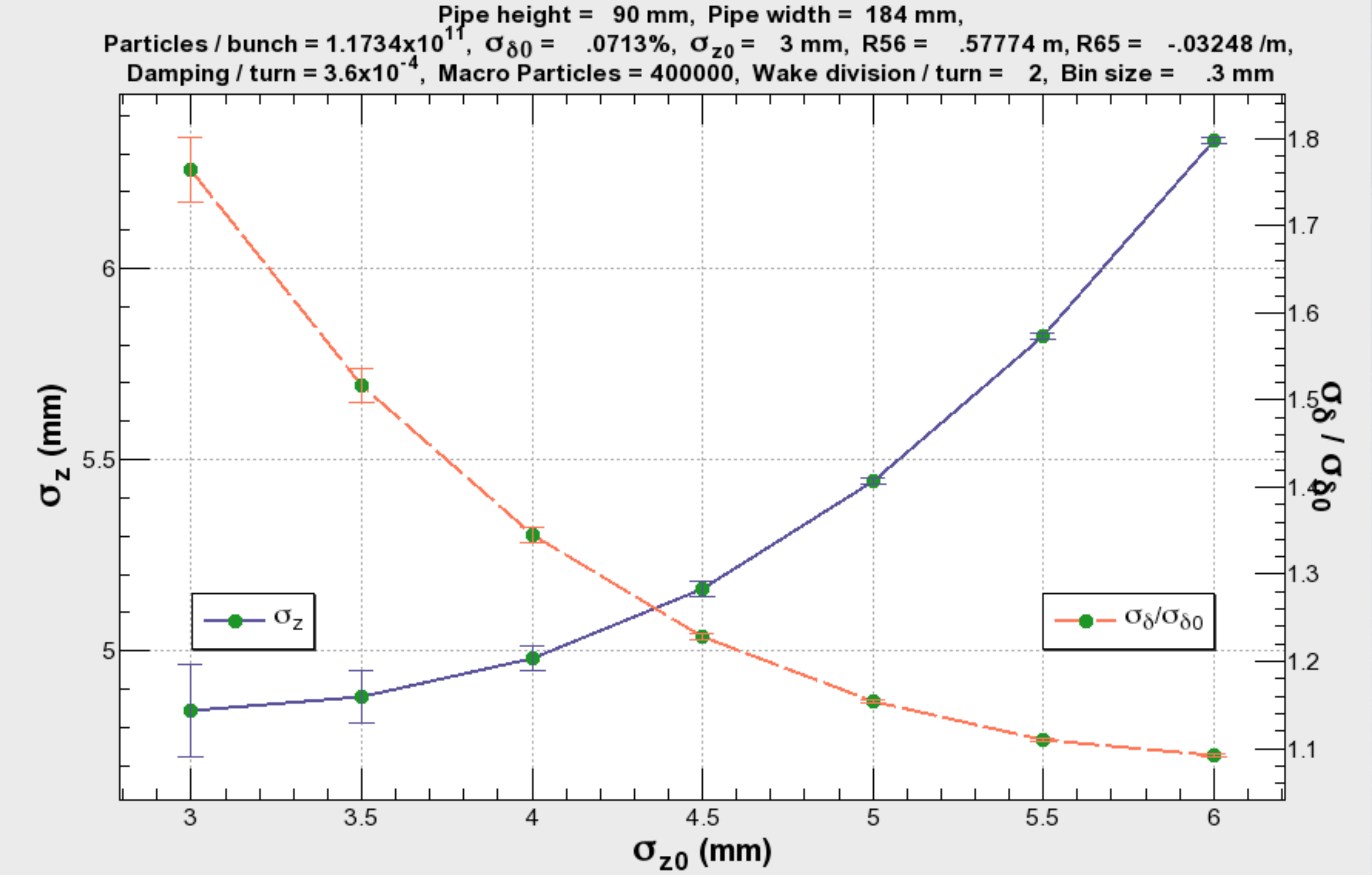
8 Oct 2008

ALL WAKES (25 MM), INCL. WIGGLERS



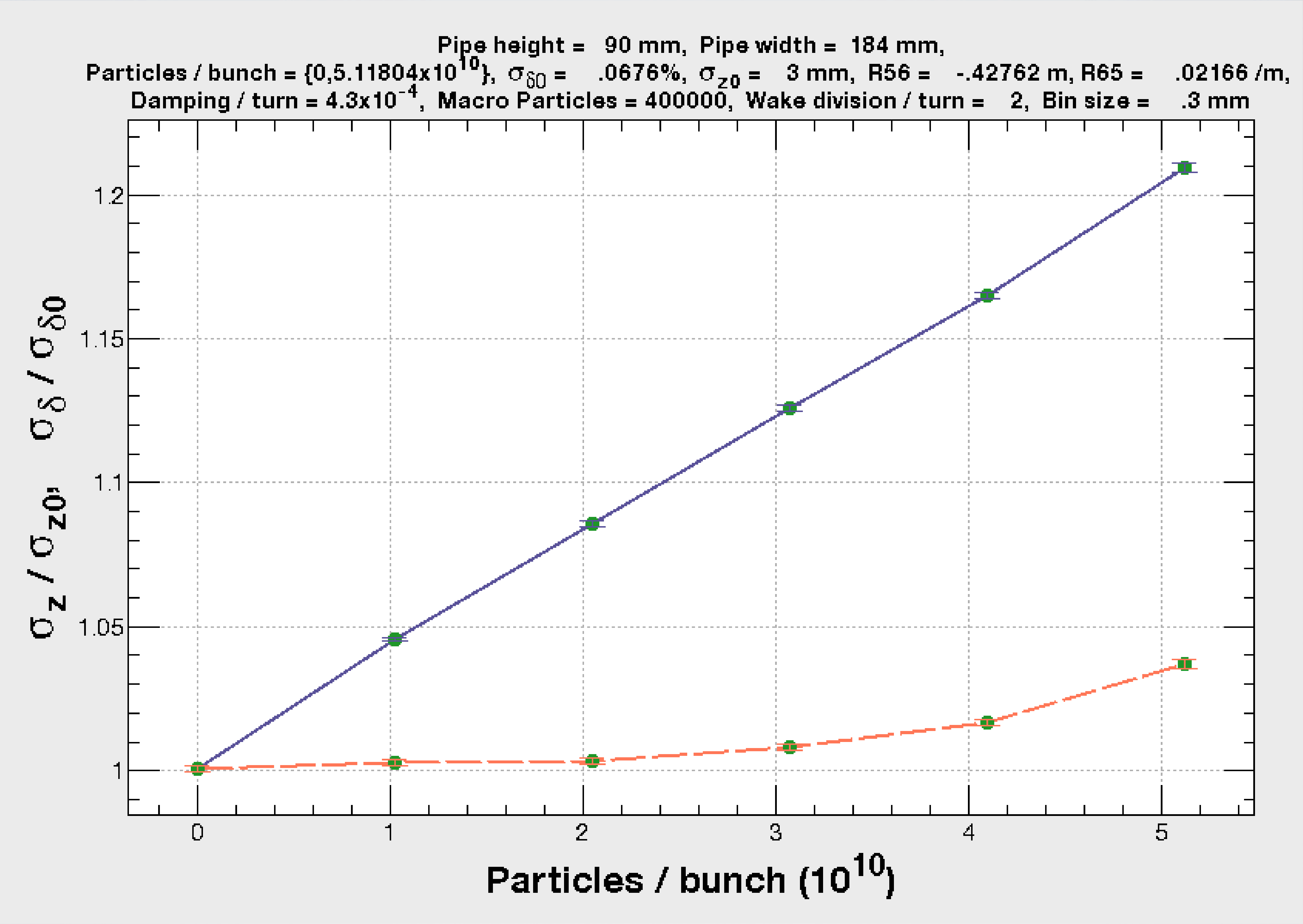
8 Oct 2008

ALL WAKES (45 MM), INCL. WIGGLERS
NEGATIVE ALPHA



9 Oct 2008

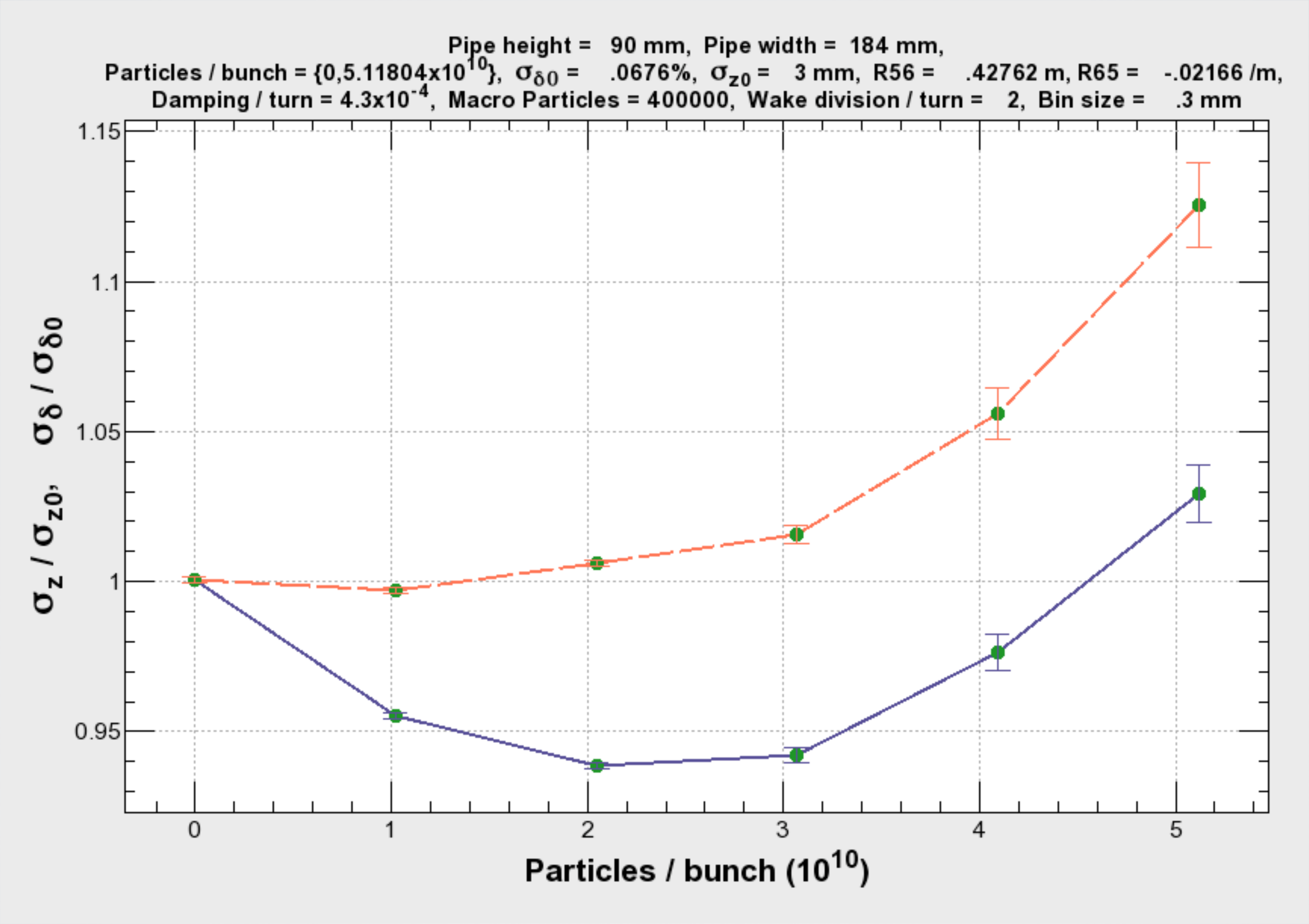
HER



26 Sep 2008

HER

negative alpha



9 Oct 2008

TENTATIVE DESIGN PARAMETERS

		zero bunch current	design bunch current	
LER	σ_z	5	6	mm
	σ_ε	7.1	8.0	10^{-4}
LER neg. alpha	σ_z	**4.5**	**5.3**	mm
	σ_ε	**7.1**	**8.5**	10^{-4}
HER	σ_z	3	3.6	mm
	σ_ε	6.8	7.0	10^{-4}
HER neg. alpha	σ_z	**3**	**3.1**	mm
	σ_ε	**6.8**	**7.7**	10^{-4}

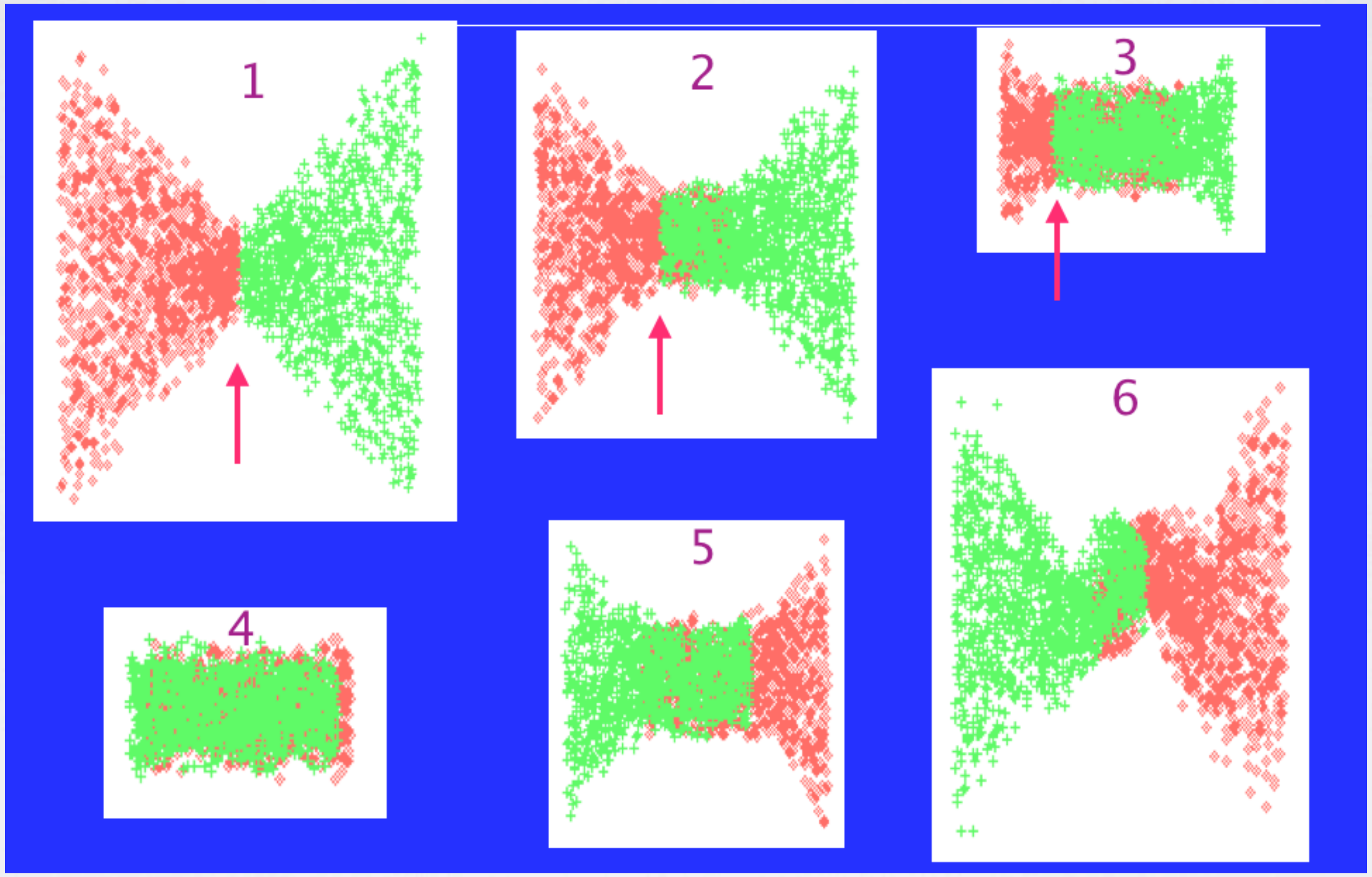
HOW MUCH IS THE IMPACT ON THE LUMINOSITY?

	LER σ_z (mm)	β_x^* (cm)	Lum. (10^{35})
No CSR	3	40	~5
longer σ_z by CSR	5	40	~2
+ LER travel waist	5	40	~4
+ smaller β_x^*	5	20	~6

by K. Ohmi (luminosities may be corrected in the following talk)

TRAVEL WAIST SCHEME

- Known technique for a linear collider (Balakin, et al).
- Move vertical waist backward along z.

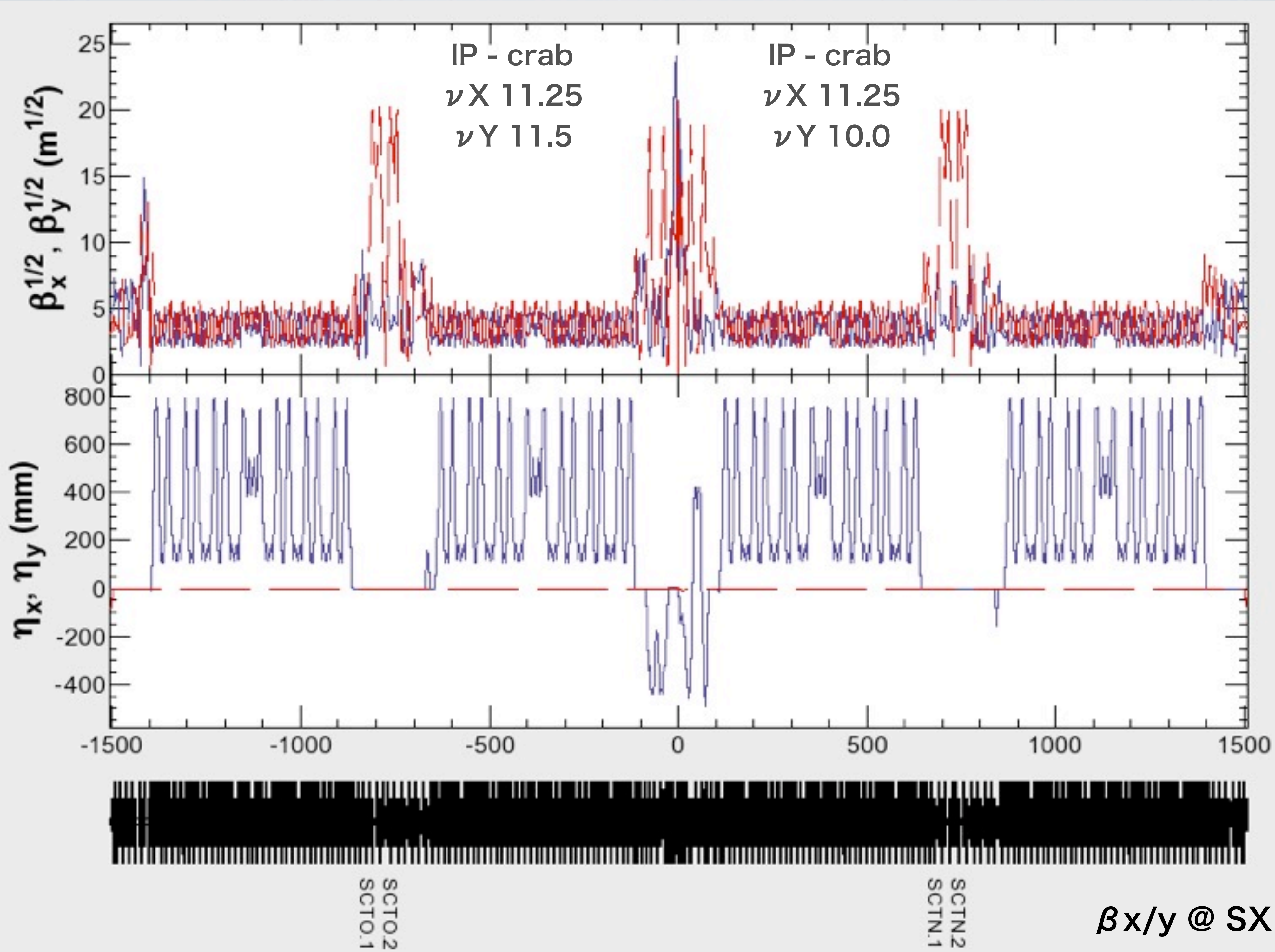


N. Walker

- Two crab cavities, each sits in the middle of -I pair of sextupoles, are necessary for a ring.
- Very hard to accommodate them in the HER.

LER TRAVEL WAIST LATTICE

H. Koiso



Sext - crab - Sext

Sext - Sext = -I'

K2 = -1.846 m^{-2}

Sext - crab - Sext

Sext - Sext = -I'

K2 = -1.846 m^{-2}

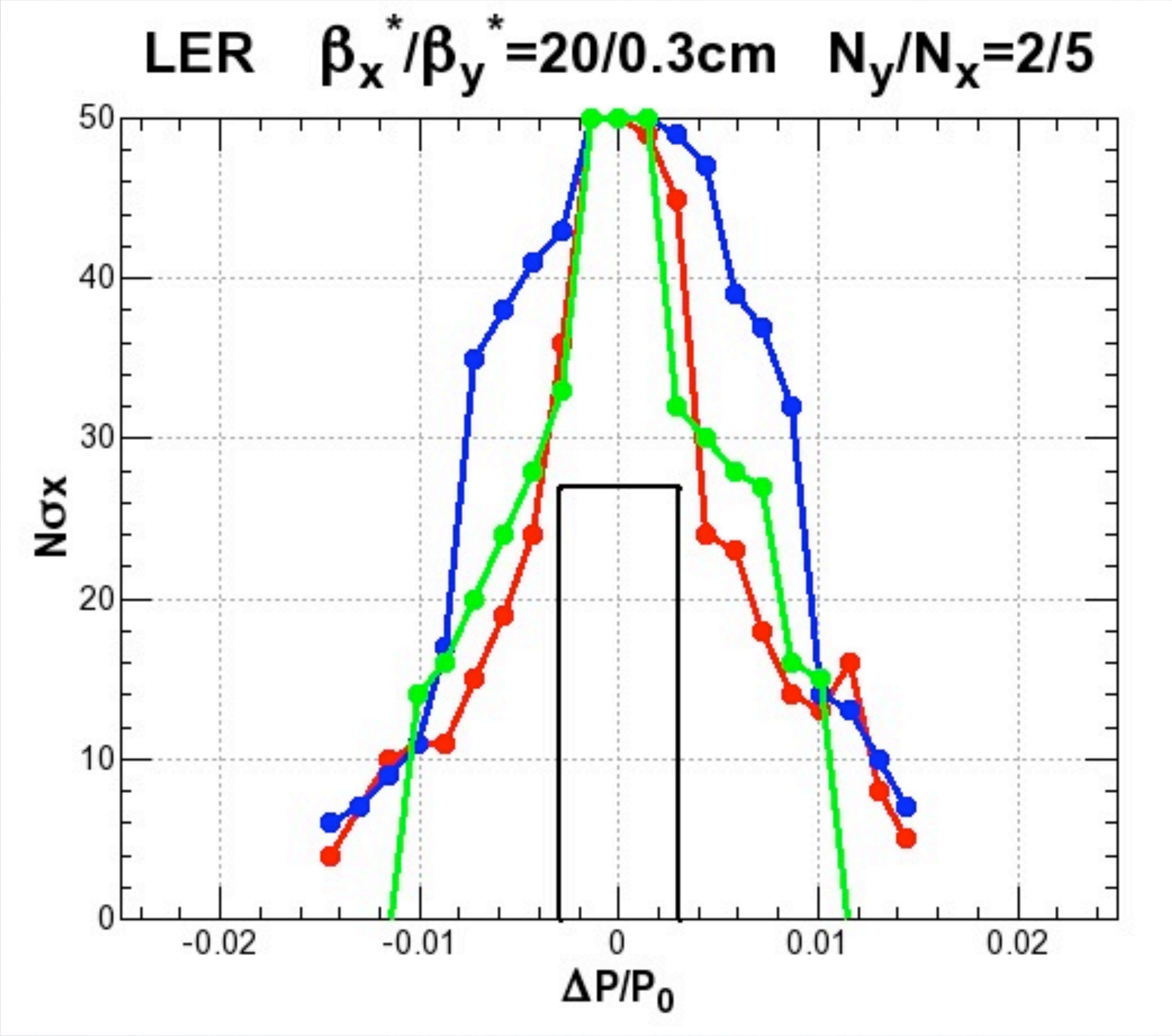
βx/y @ SX = 15/350 m

βx @ crab = 50 m

Vcrab = 1.56 MV

LER DYNAMIC APERTURE WITH TRAVEL WAIST

H. Koiso



RF ON

Crab OFF, OFF, ON

sext thickness: 0.334 m

K2= 0, +-1.846

Acceptance

Ax = 7.5e-6 m

Ay = 1.2e-6 m

Δp/p = 0.003

IR ISSUES

See presentations by Koiso, Ohuchi, Kanazawa, Iwasaki

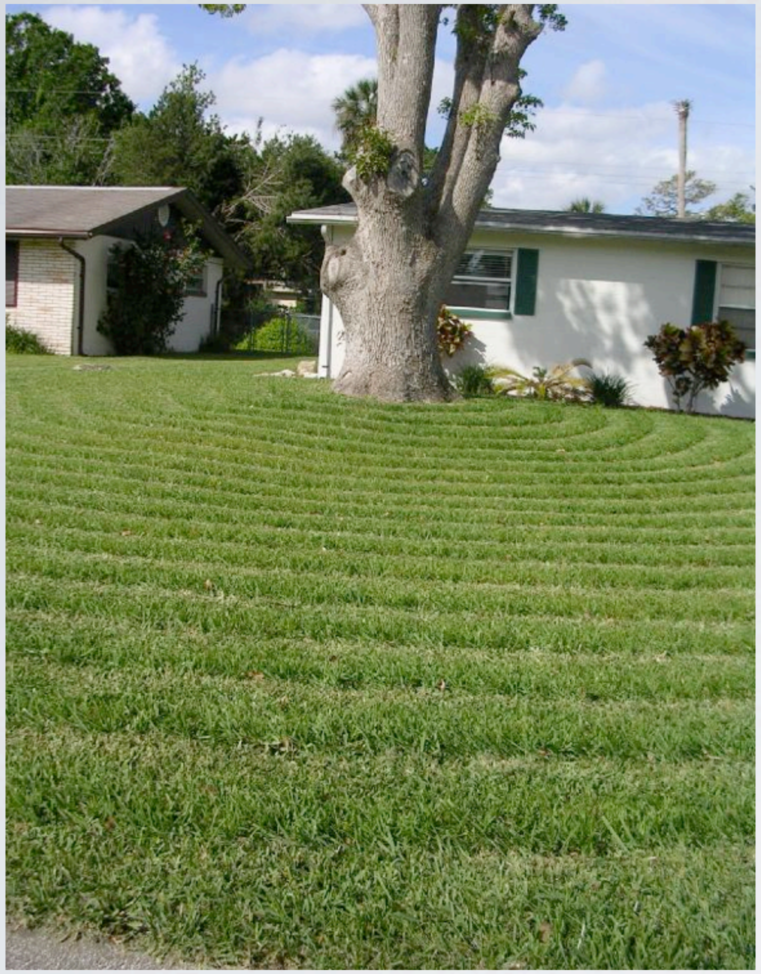
- No consistent solution has been found yet for $\beta_x^* = 20$ cm.
- A solution may exist for $\beta_x^* = 40$ cm, with consistent physical aperture, dynamic beta, injection, Belle acceptance, and synchrotron light.
- A new design of final focus magnets will be critical.
- Technical issues for assembly remain to be solved.

COST ESTIMATION (IN OKU-YEN = 1.1 M$)

Preliminary

	Old estimation Full Spec SuperKEKB	Construction (for 3 years)	Upgrade during operation	Total
Vacuum	116.86	139.36	0	139.36
RF	115.873	16.45	84.25	100.7
Infrastructure	84.3	3	75.2	78.2
Magnet	16.7008	31.9	0	31.9
Crab	17	5	10	15
Beam monitor	17.4684	17.7	4.5	22.2
Injector	58	10	53.7	63.7
Damping Ring (other than RF, monitor)	16.8	0	21.26	21.26
Control	9.4	2	7.4	9.4
IR	8	14.7	0	14.7
Beam transport	2.5	2.5	0	2.5
Total Construction	**462.9022**	**242.61**	**256.31**	**498.92**
Running cost / year				**80 + overhead**

NEIGHBOR'S LAWN LOOKS GREENER?



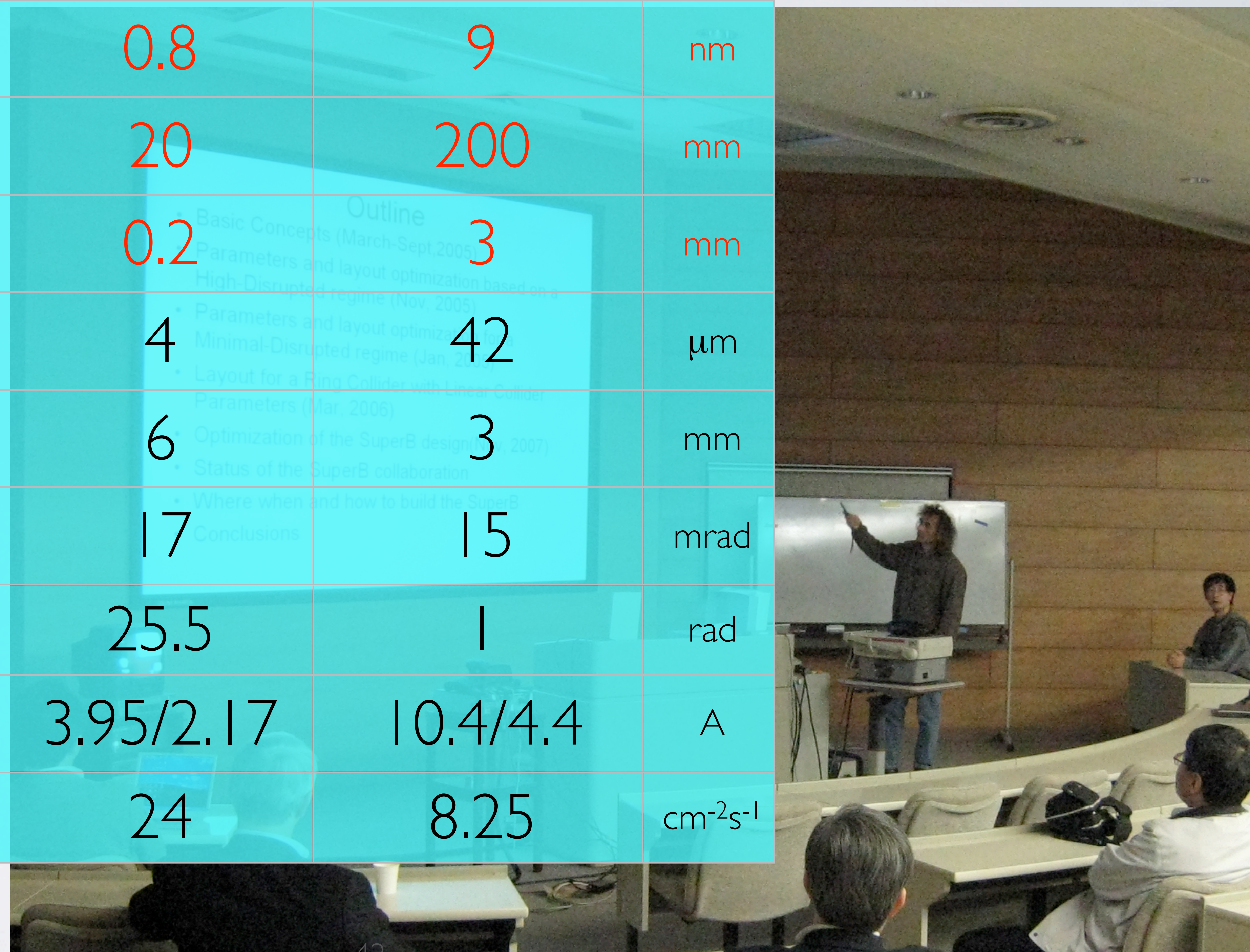
If we can preserve the HER lattice and the beam pipe, the construction cost reduces to less than half.

	Present scheme	Italian Option	remarks
Vacuum	139.36	70	only LER
RF	100.7	10	HOM absorber, low level control
Infrastructure	78.2	?	
Magnet	31.9	50	LER low emittance
Crab	15	-	
Beam monitor	22.2	30	
Injector	63.7	20	No charge switch
Damping Ring (other than RF, monitor)	21.26	22	necessary
Control	9.4	9.4	
IR	14.7	20	
Beam transport	2.5	2.5	
Total Construction	**498.92**	**233.9**	
Running cost / year	**80 + OH**	**60 +OH**	

COMPARISON OF MACHINE PARAMETERS

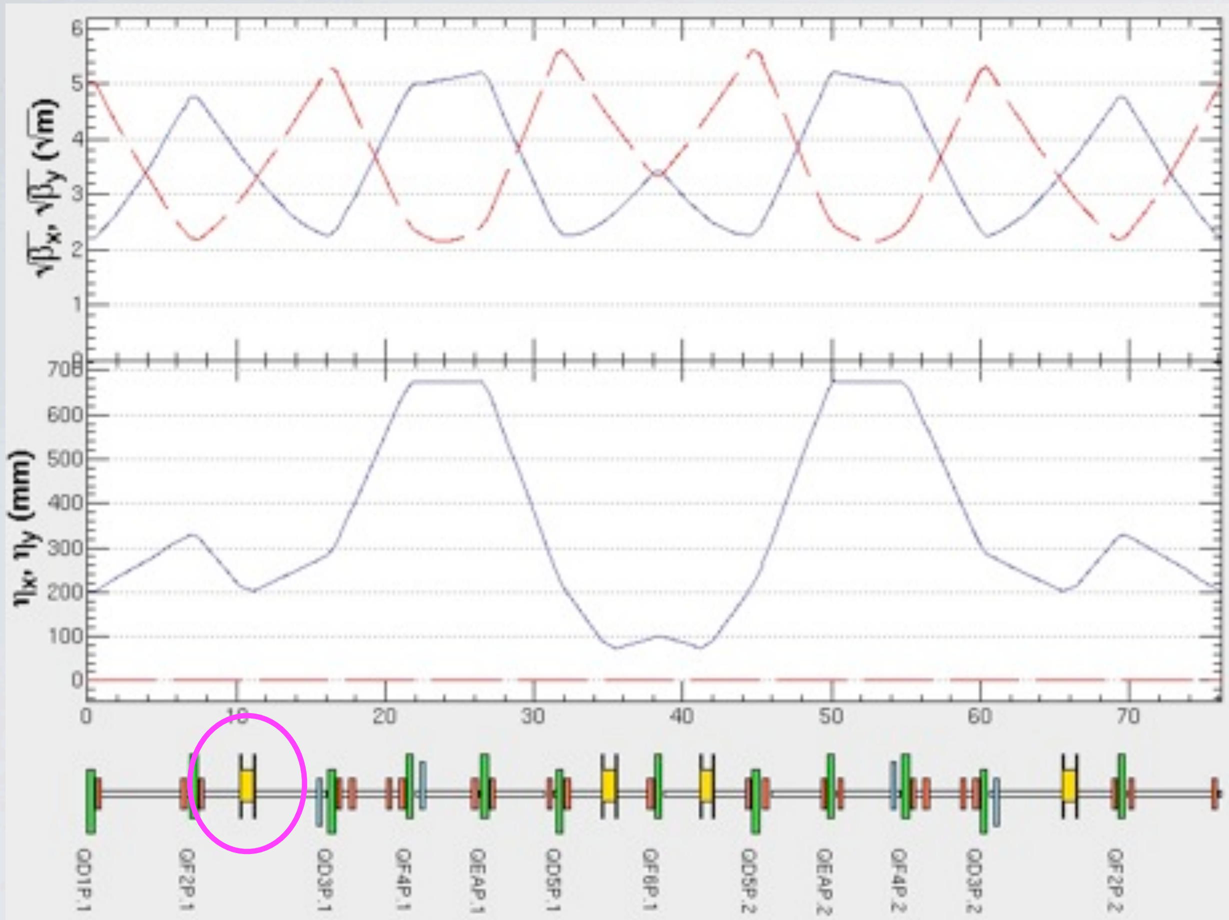
P. Raimondi

		SuperB (Upgrade)	SuperKEKB (2006)	
Emittance	ε_x	0.8	9	nm
Horizontal beta	β_x^*	20	200	mm
Vertical beta	β_y^*	0.2	3	mm
Horizontal beam size	σ_x^*	4	42	µm
Bunch length	σ_z	6	3	mm
Half crossing angle	ϕ_x	17	15	mrad
Piwinski angle	φ	25.5	1	rad
Current(LER/HER)	I_b	3.95/2.17	10.4/4.4	A
Luminosity ($\times 10^{35}$)	L	24	8.25	$cm^{-2}s^{-1}$



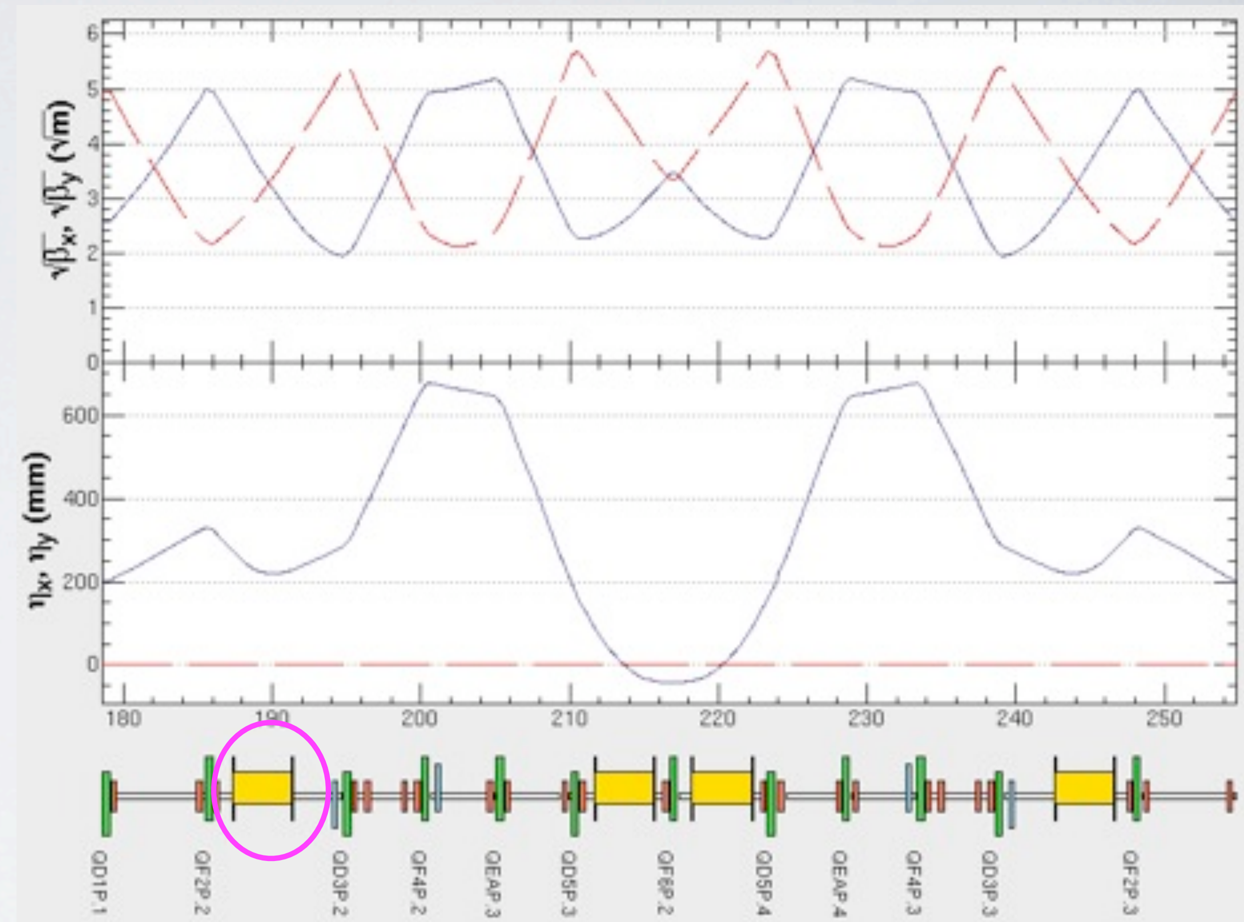
Compatibility with Italian option

LER arc cell **Preliminary**



L bend = 0.9 m

ε_x = 6.8 nm



L bend = 4.0 m

ε_x = 2.2 nm

- The arc cell lattice of the KEKB LER (left) can be modified to the low-emittance version (right), by weakening the magnetic field of the dipoles.
- No need for changing other components, beam pipes, geometry.
- The interaction region must be rebuilt.

H. Koiso

WE NEED ADVICE FROM YOU.

- What about an idea to raise the priority of the detailed design work with an Italian option for SuperKEKB?
  - parameters
  - beam-beam simulation
  - IR design
  - lattice, dynamic aperture, beam lifetime, injection, ...
  - crab waist
  - beam diagnostics and control, emittance & collision tuning, ...
  - and more ...