Comparison of machine impedance lculation with beam based measuremen

Karl Bane and Demin Zhou

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Y. Suetsugu, M. Tobiyama

rnational Workshop on Impedances and Beam Instabilities in Part
Accelerators

an a “bottom-up” approach to a pseudo-Green function wake calculat
ope to obtain the broad-band impedance of a modern, complicated sto
ng such as KEKB and SuperKEKB (SKEKB)? Or do we need to resort t
g. a *Q*= 1 resonator model with the parameters obtained by machine
easurements?

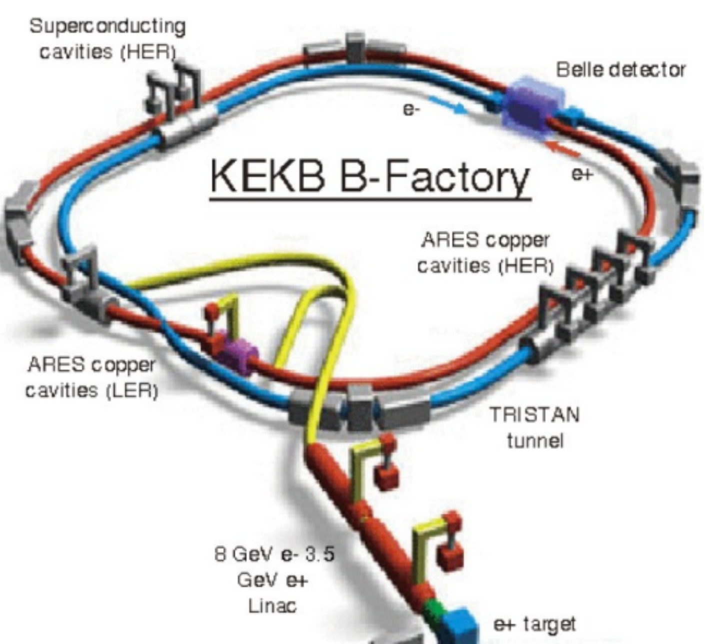
arlier streak camera measurements at KEKB and SKEKB were in clear
sagreement with simulations using the calculated pseudo-Green functi
akes for the machines. What can we learn from a revisit to this proble
ocusing in particular on measurements of RF phase vs current?

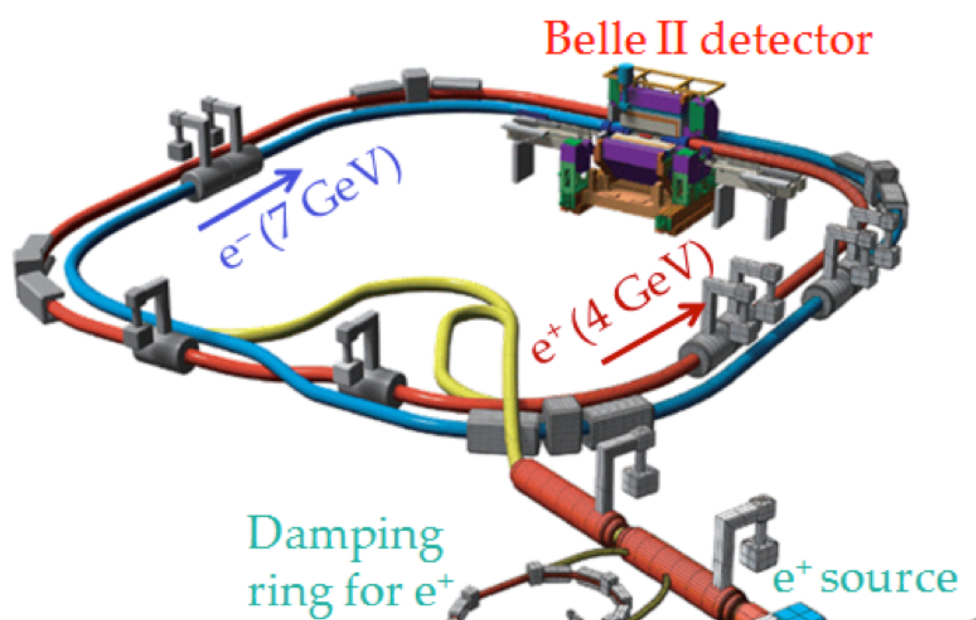
. Ieri and H. Koiso, (*The 14th Symposium on Accelerator Science and
echnology, Tsukuba, Japan,* 2003) presented beam phase vs. current
easurements for KEKB LER. There were systematic errors. We prese
ere measurements that were performed again, in 2009, on KEKB LER.

/hile KEKB and SKEKB are running, many RF system parameters are
ontinually being logged. Can we extract phase vs. current data from th

ntroduction
D wakefield computations
MWI simulation
eam phase measurement
OM power
ummary

	LER		HER	
	SKEKB	KEKB*	SKEKB	KEKB*
E (GeV)	4	3.5	7.007	8
I_{bunch} (mA)	1.44	1.03	1.04	0.75
ε_x (nm)	3.2	18	4.6	24
ε_y (pm)	8.64	180	12.9	240
α_p (10^{-4})	3.25	3.31	4.55	3.43
σ_δ (10^{-4})	8.08	7.73	6.37	6.3
σ_z (mm)	5	4.6	4.9	5.2





otivation: Streak camera measurements in KEKB LER

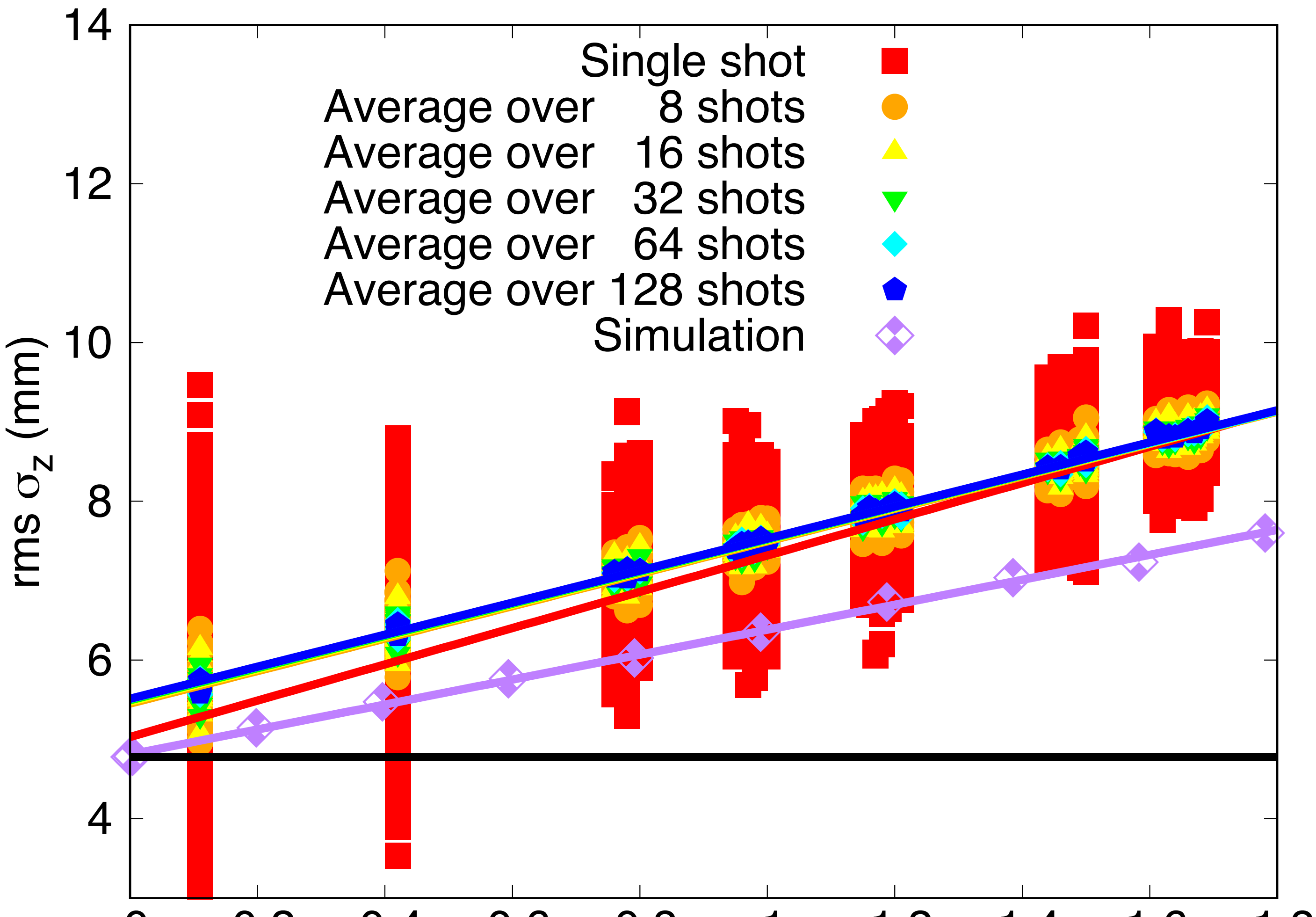
Data taken on Oct. 26, 2009 with nominal bunch length 4.78 mm

ingle-shot measurement (128 shots per bunch current)

verage over different number of shots: Converge to same result

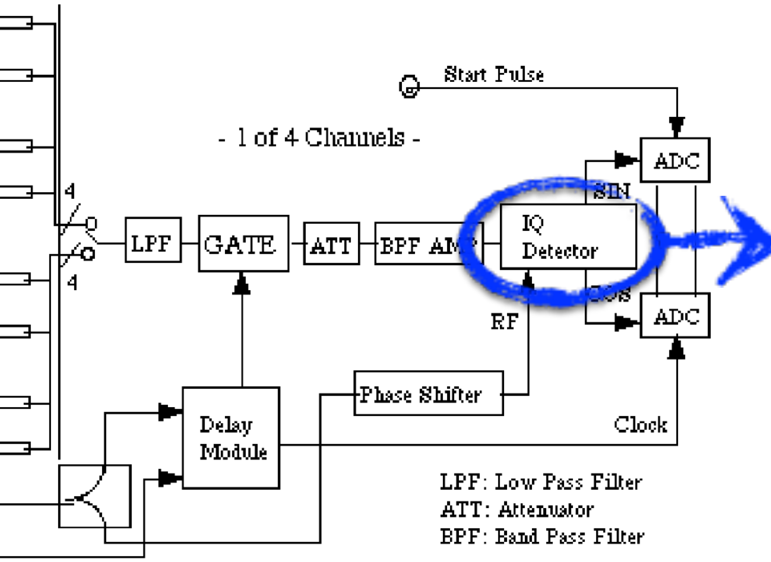
hot noise and timing jitter expected to be small

here were systematic errors in the SC system?

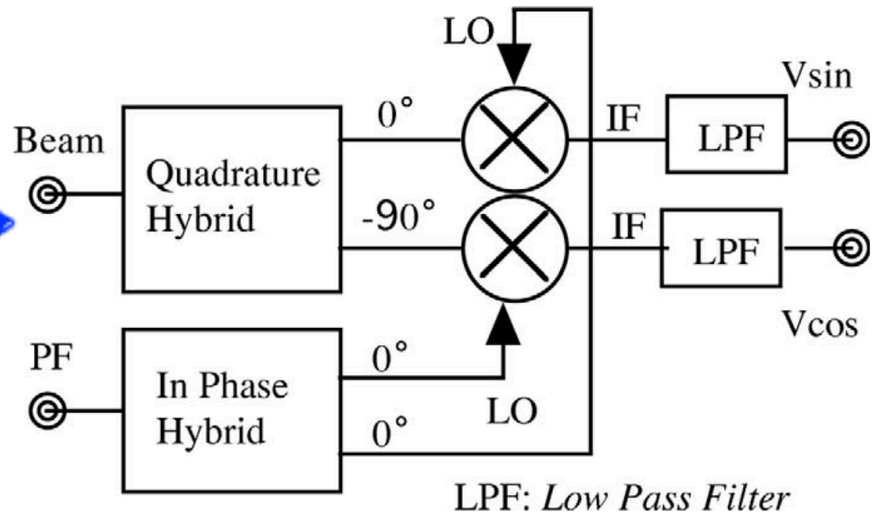


eam phase measurement using gated BPM

Refer to T. Ieiri et al., NIMA 606 (2009) 248-256



ock diagram of a GBPM



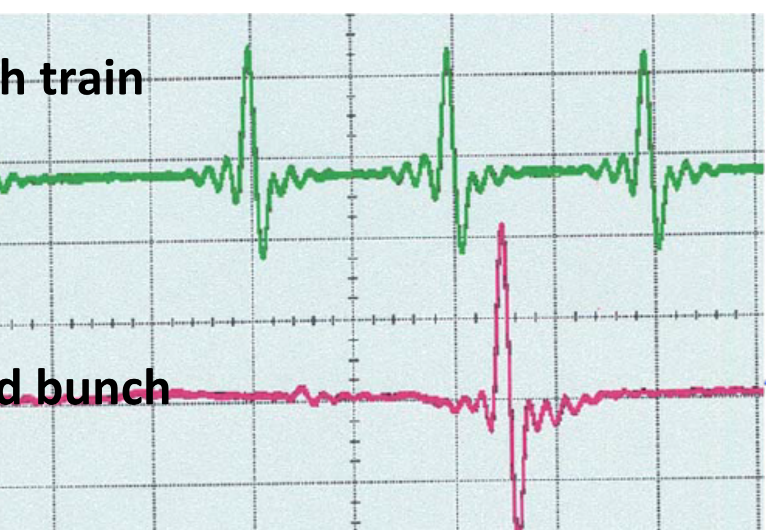
Principle of IQ detector

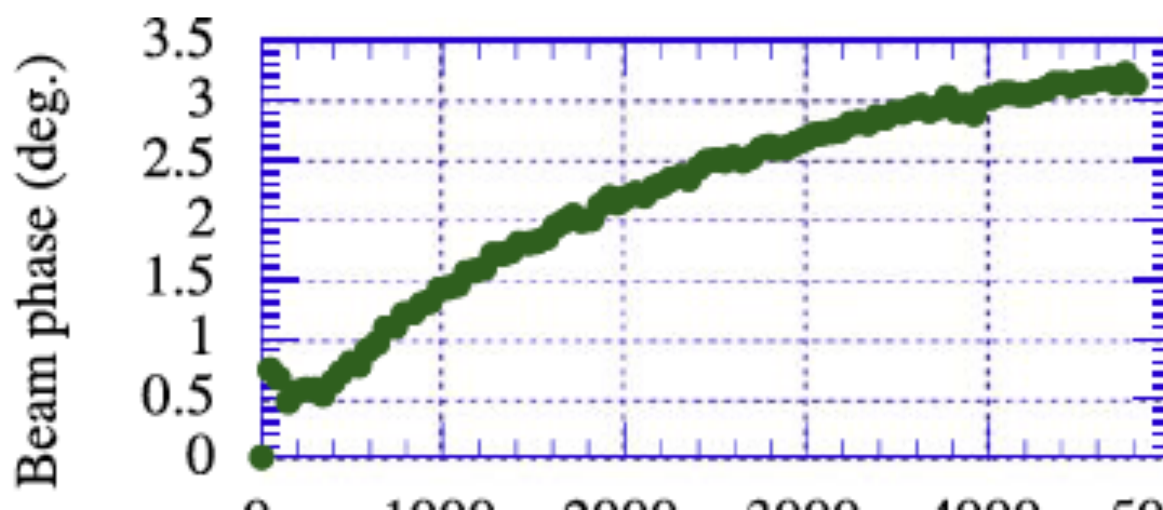
Equations:

$$V_{\rm sin} = \frac{1}{2} V_{\rm b} V_{\rm rf} \sin($$

$$V_{\rm cos} = -\frac{1}{2} V_{\rm b} V_{\rm rf} \cos$$

$$\phi_{\rm b} - \phi_{\rm rf0} = \tan^{-1}$$





eam power in a storage ring

- Total beam power = SR power (P_{SR}) + HOM power (P_{HOM})
  = $I_{beam} V_{rf}$ Sin[ϕ_{rf}]
- P_{SR}=U_0 I_{beam} with U_0 calculated from lattice model or from
urement
- oss factor $\kappa_{||}$ can be numerically computed or extracted from P
 through experiment

$$\mathrm{eam} = P_{\mathrm{SR}} + P_{\mathrm{HOM}} = I_{\mathrm{beam}}[\mathrm{mA}]V_{\mathrm{rf}}\sin[\phi_{\mathrm{rf}}]$$

$$\mathrm{R}[\mathrm{kW}] = U_0[\mathrm{MV}] \cdot I_{\mathrm{beam}}[\mathrm{mA}]$$

$$\mathrm{IOM} = \kappa_{||}(\sigma_{\mathrm{s}}) \cdot I_{\mathrm{beam}}^2 \cdot T_0/N_{\mathrm{bunch}}$$

caling laws for machine parameters of a storage ring

$$ {}_0 = C_\gamma \frac{E^4}{\rho} \propto E^4 \qquad\qquad U_0 = V_{\mathrm{rf}} \sin \phi_s $$

$$ {}_s = \frac{c|\eta_c|\sigma_\delta}{2\pi \nu_s f_{\mathrm{rev}}} $$

$$ = \sqrt{\frac{heV_{\mathrm{rf}}|\eta_c \cos \phi_s|}{2\pi \beta^2 E}} \propto \sqrt{\frac{|\cos \phi_s|}{E}} $$

$$ = \sqrt{C_q \gamma^2 \frac{< |\rho^{-3}| >_z}{J_\epsilon < \rho^{-2} >_z}} \propto E $$

aled machine parameters of KEKB LER

ssume the KEKB operation followed the scaling laws over beam ener

ssume momentum compaction is energy-independent

nergy [GeV]	3.594074	3.5	3.314401	3.12
ltage [MV]	8	8	8	7
s [MeV/turn]	1.820	1.637	1.316	1.0
bunch length [mm]	4.78	4.58	4.20	4.
ch. tune	0.0236	0.024	0.0248	0.0
spread [10^{-4}]	7.465	7.27	6.884	6.4
amping time [ms]	20.716	21.6	25.436	30.
ference [m]	3016.25	3016.25	3016.25	301

npedance sources in the ring

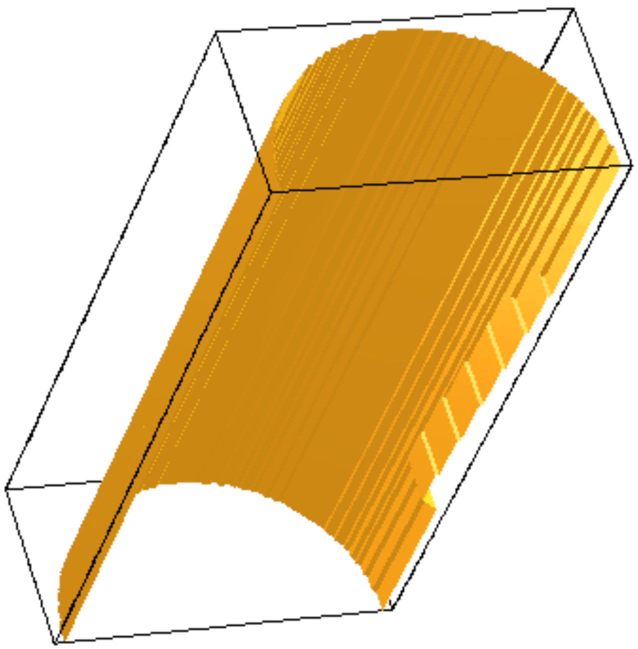
T. Abe, K. Shibata,
T. Ishibashi, M. Tobiyama, e

Geometric wakes, resistive wall, CSR, and CWR

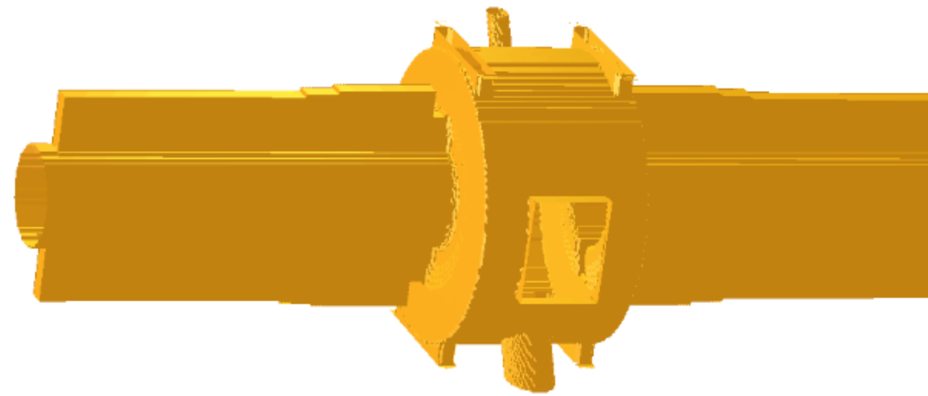
Component	Number	Code
ARES cavity	20	GdfidL
Movable mask	16	GdfidL
SR mask (arc/wiggler)	1000 (905/95)	GdfidL
Bellows	1000	GdfidL
Flange gap	2000	GdfidL
BPM	440	GdfidL
Pumping port	3000	GdfidL
Crab cavity	1	ABCI
FB kicker/BPM	1/40	GdfidL
Tapers ARES/Crab/Abort/Injection IR(IP/QCSL/QCSR)	4/2/2/2 6(2/2/2)	GdfidL
Gate valves f94/f150/94x150	26/13/2	GdfidL

xamples of 3D components modeled by GdfidL

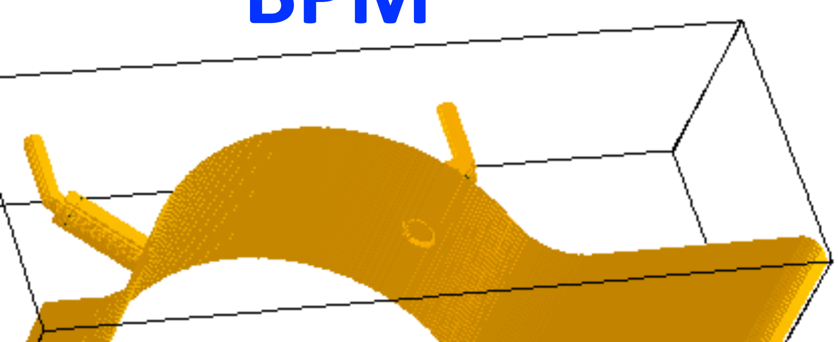
Movable mask



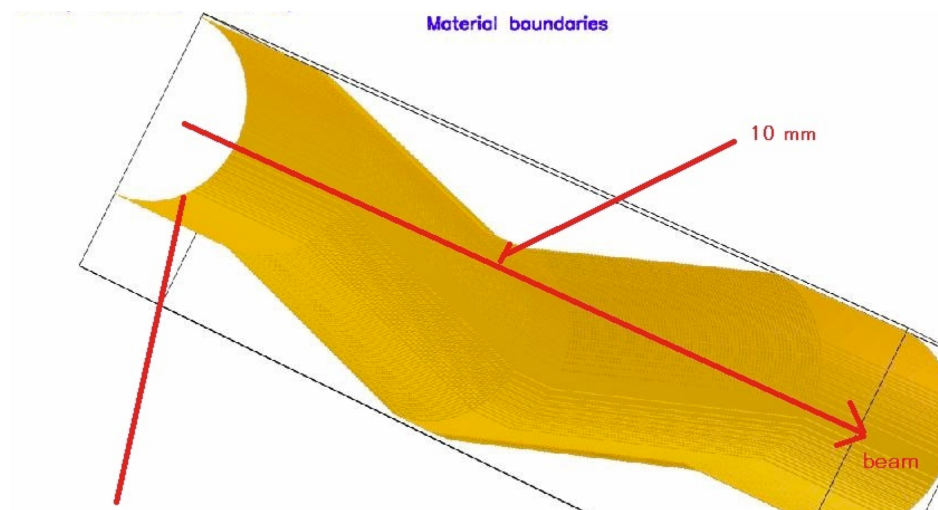
ARES RF cavity



BPM



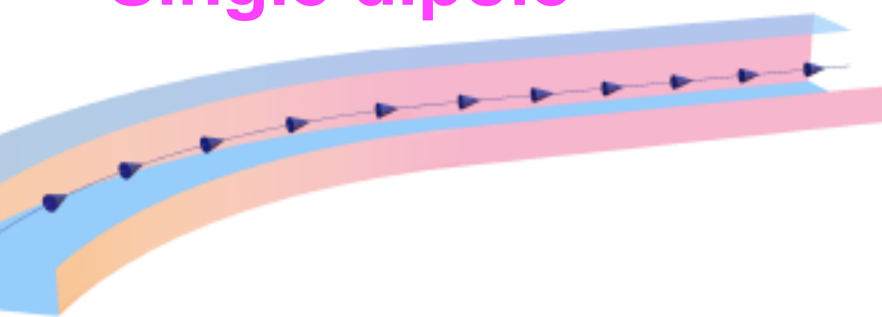
Movable mask



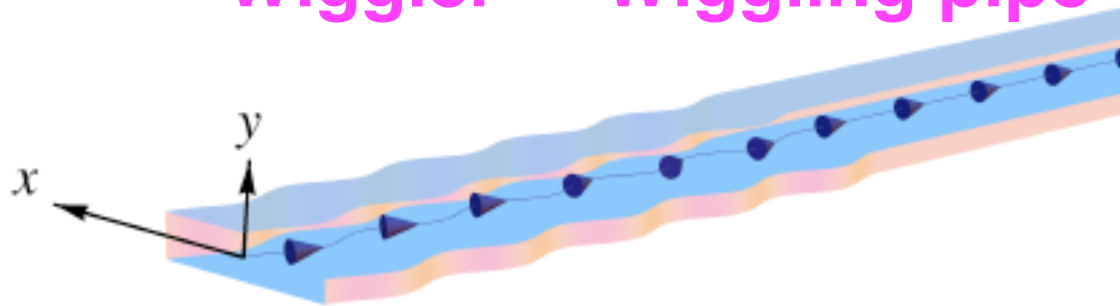
SR in storage rings ➟ Chamber shielding ➟ CSRZ code

eatures of CSRZ: Arbitrarily curved chamber; Small erical noise; Multi-bend interference; Treat wigglers;

Single dipole

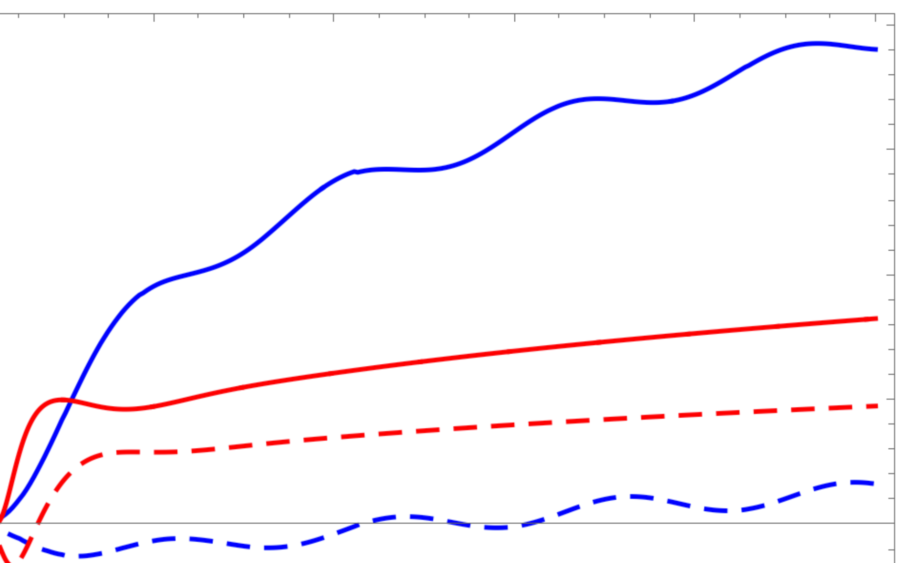


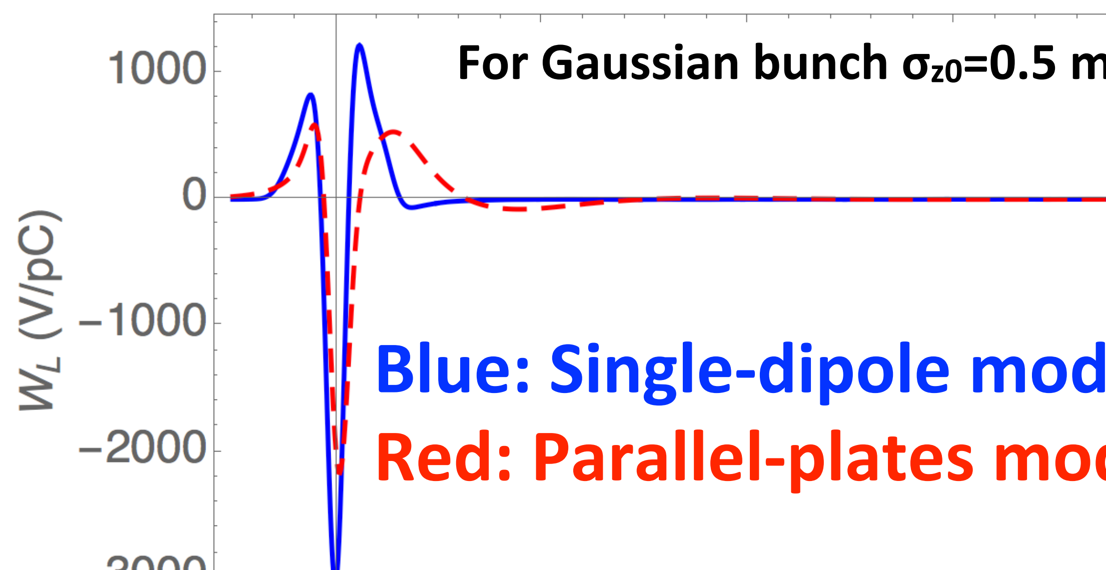
Wiggler - "Wiggling pipe"



RZ model for KEKB dipole:

0.89 m, R=15.87 m, Square chamber with ϕ=94 mm

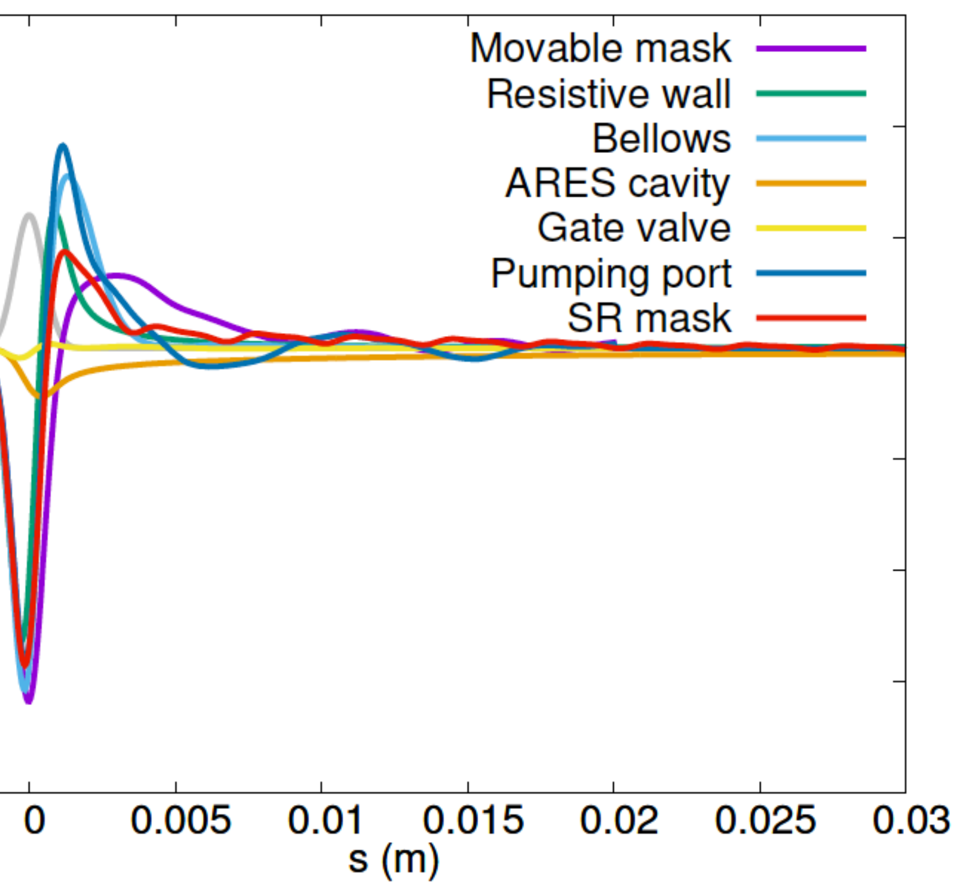


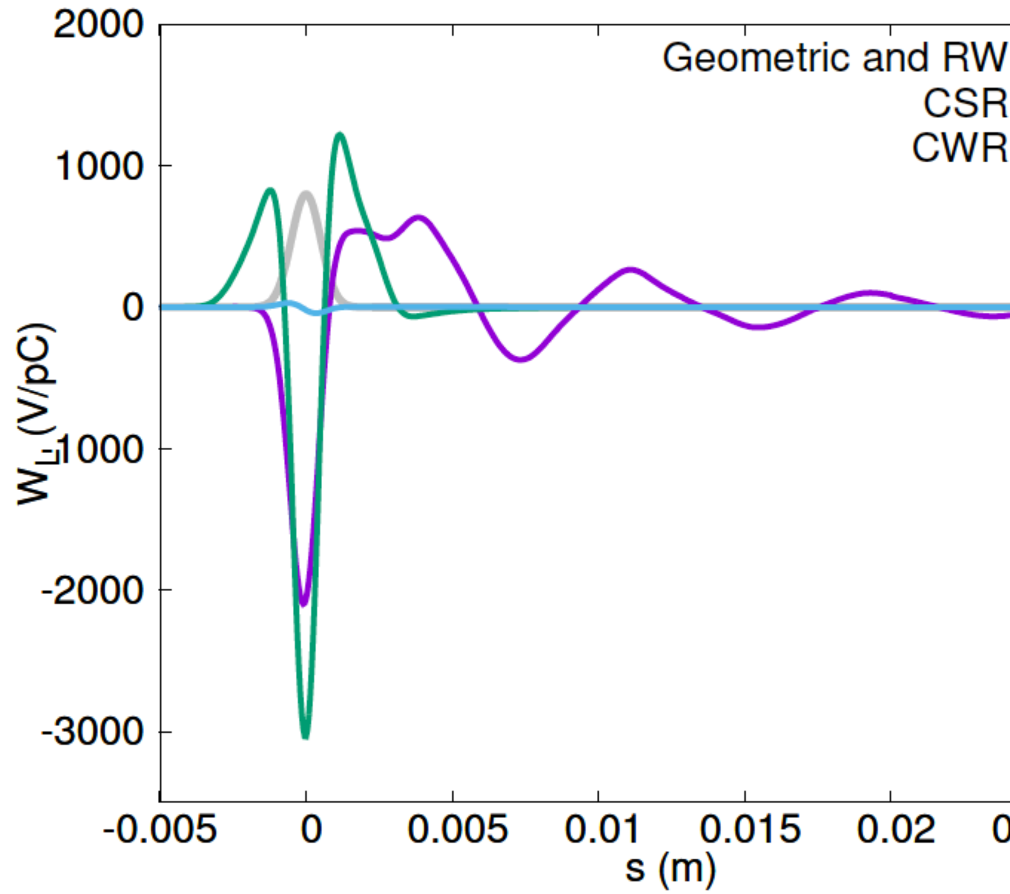


seudo-Green wake function

Gaussian bunch σ_z=0.5 mm

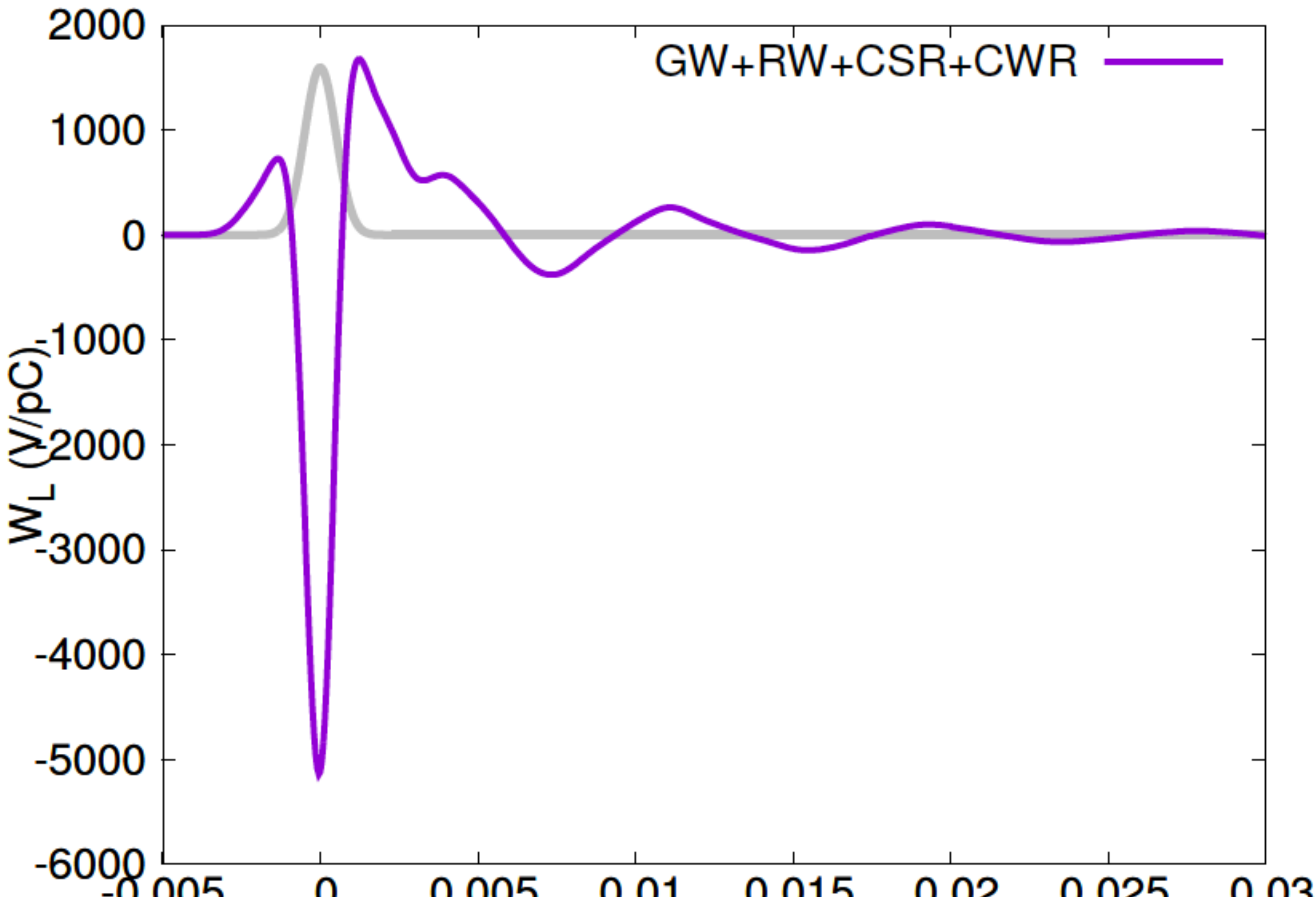
CSR and CWR: CSRZ code with rectangular chamber





seudo-Green wake function

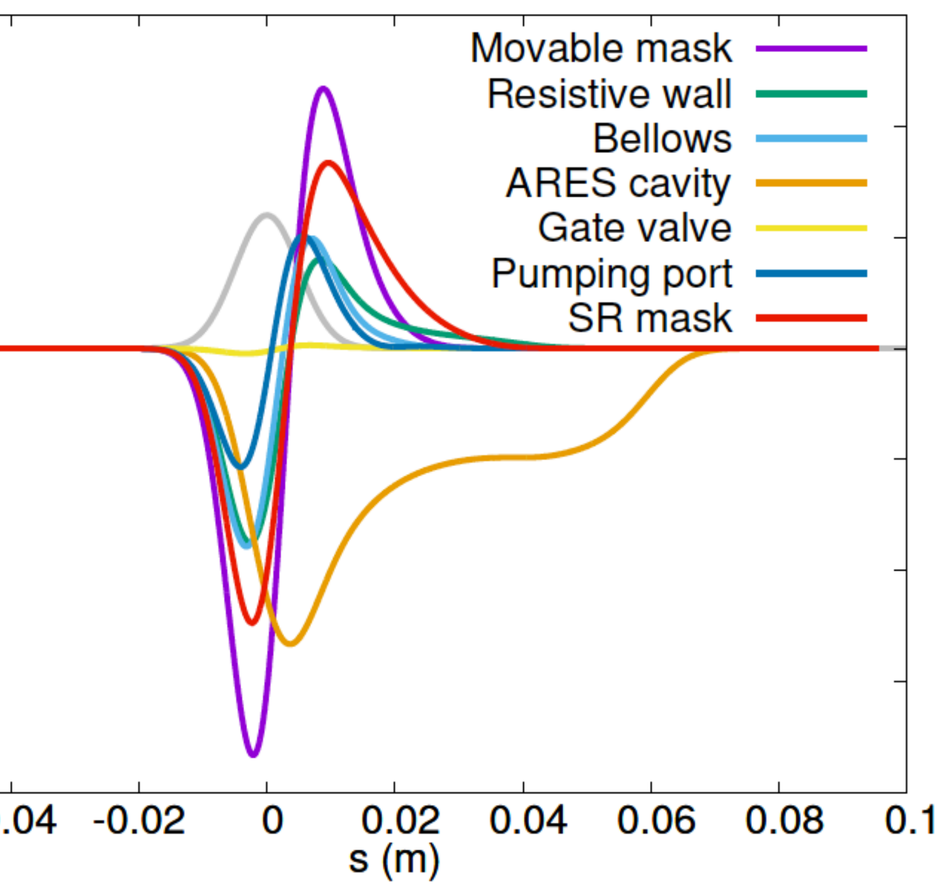
Total wake with Gaussian bunch σ_z=0.5 mm

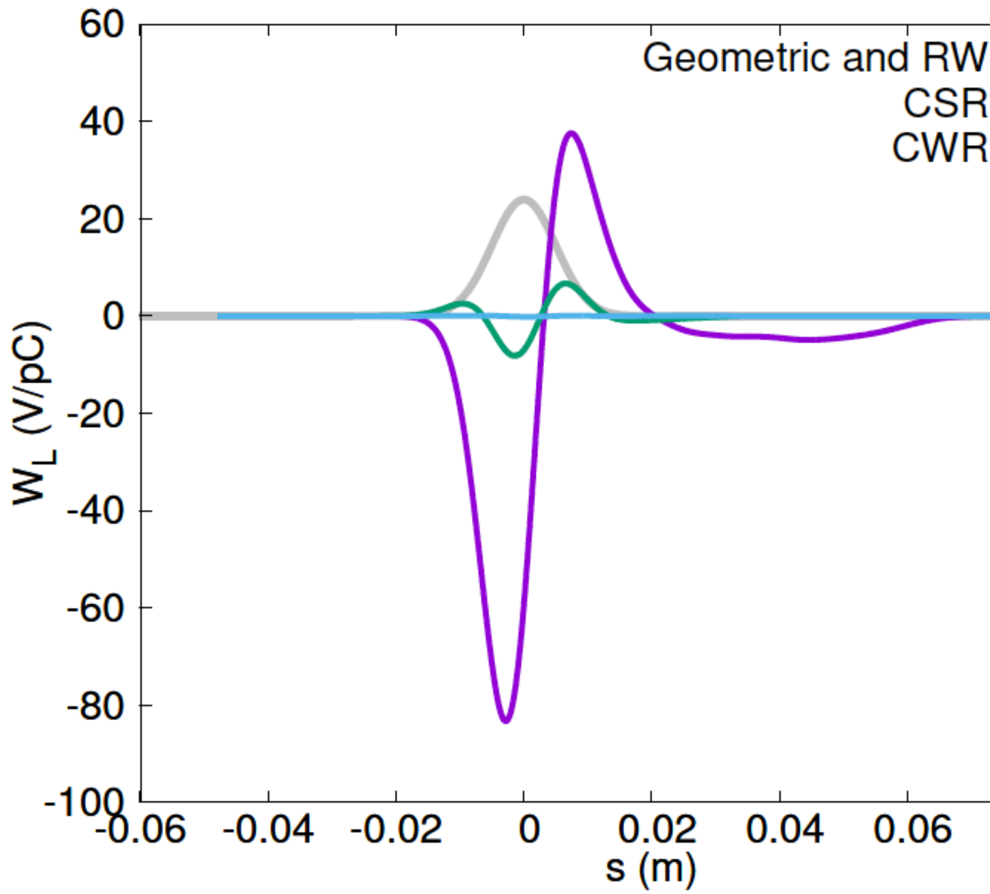


seudo-Green wake function

Nominal bunch length σ_{z0}=4.78mm @E=3.594 GeV, V_{rf}=8 MV

CSR and CWR: CSRZ code with rectangular chamber





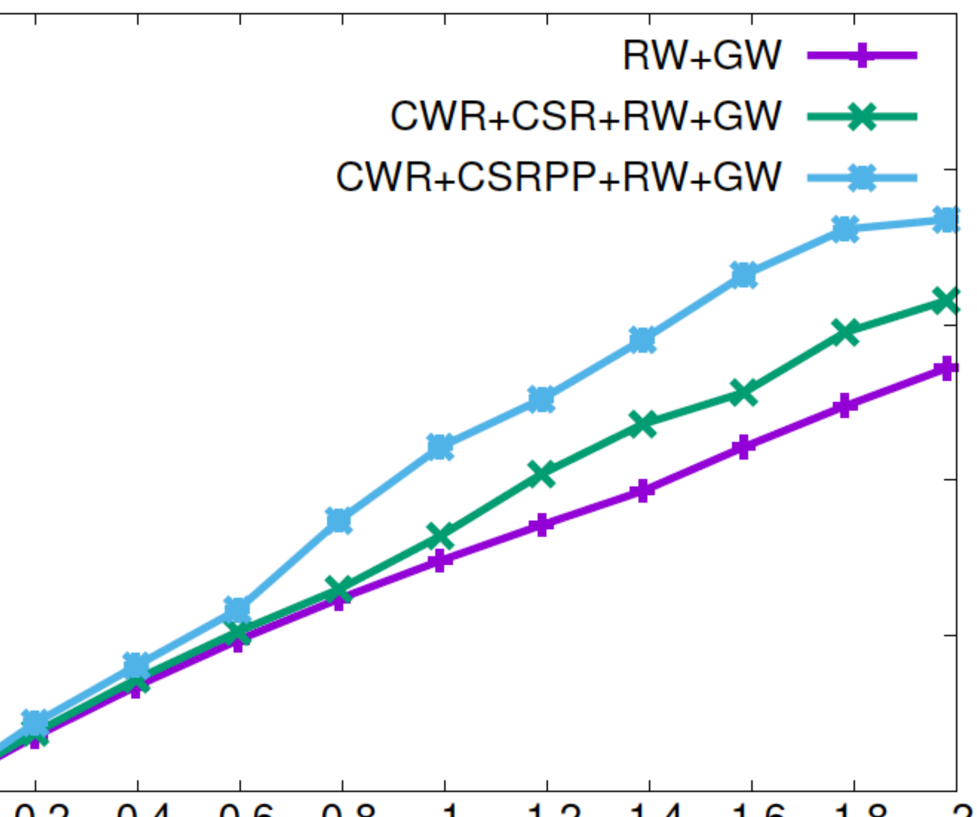
npedance budget for LER: Comparison of KEKB and SK

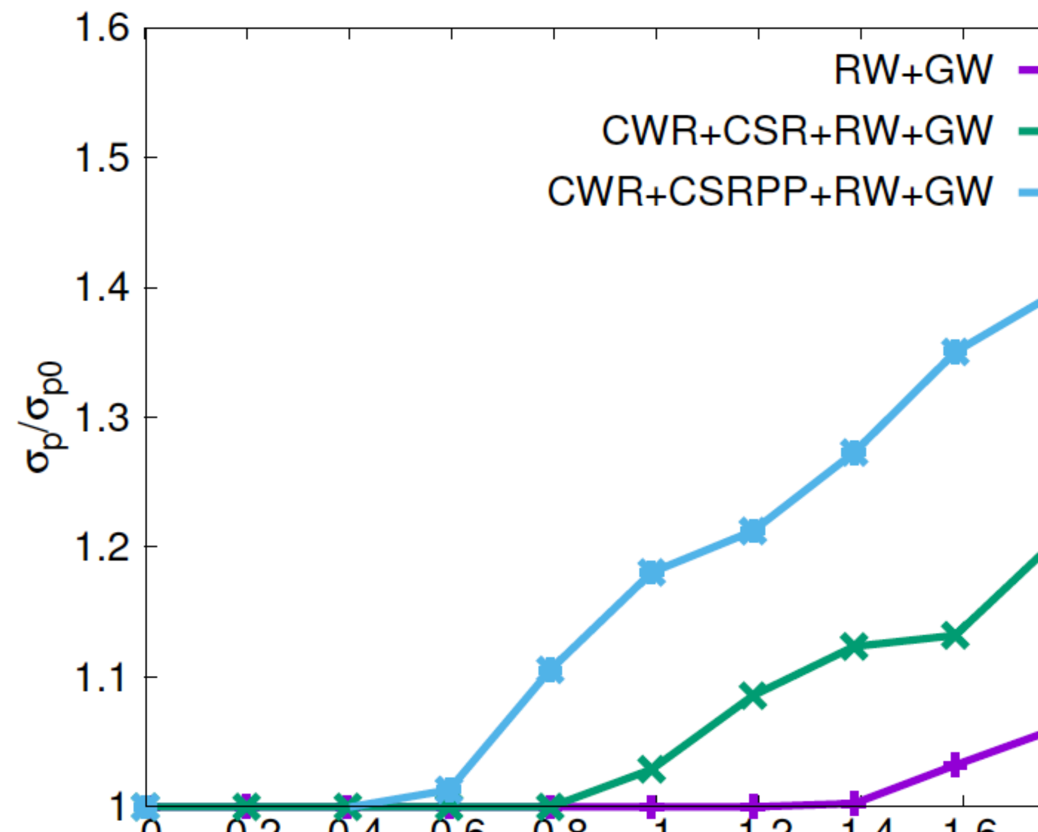
mponent	Super-LER			KEKB-LER		
	$k_{\|\|}$	R	L	$k_{\|\|}$	R	L
ES cavity	8.9	524	-	9.2	545	-
ab cavity	-	-	-	1.0	60.1	-
llimator	1.1	62.4	13.0	7.6	447	11.9
s. wall	3.9	231	5.7	3.7	222	5.5
llows	2.7	159	5.1	3.0	178	6.6
nge	0.2	13.7	4.1	1.1	62.1	18.5
mp. port	0.0	0.0	0.0	0.5	28.8	5.5
mask	0.0	0.0	0.0	5.0	298	8.5
duct	0.0	2.2	0.5	0.2	9.9	0.6
M	0.1	8.2	0.6	0.8	46.8	0.8
kicker	0.4	26.3	0.0	0.2	13.2	0.0
BPM	0.0	1.1	0.0	0.2	13.5	0.7
te valve	-	-	-	0.1	4.2	0.2
per	0.0	0.7	0.1	0.3	16.6	1.3
ng. kicker	1.8	105	1.2	-	-	-
pove pipe	0.1	5.7	0.9	-	-	-
ctrode	0.0	2.2	2.3	-	-	-

Note: Antechamber is SKEKB LER, suppressin impedances from flang pumping ports and SR

mulations with input of Pseudo-Green wake

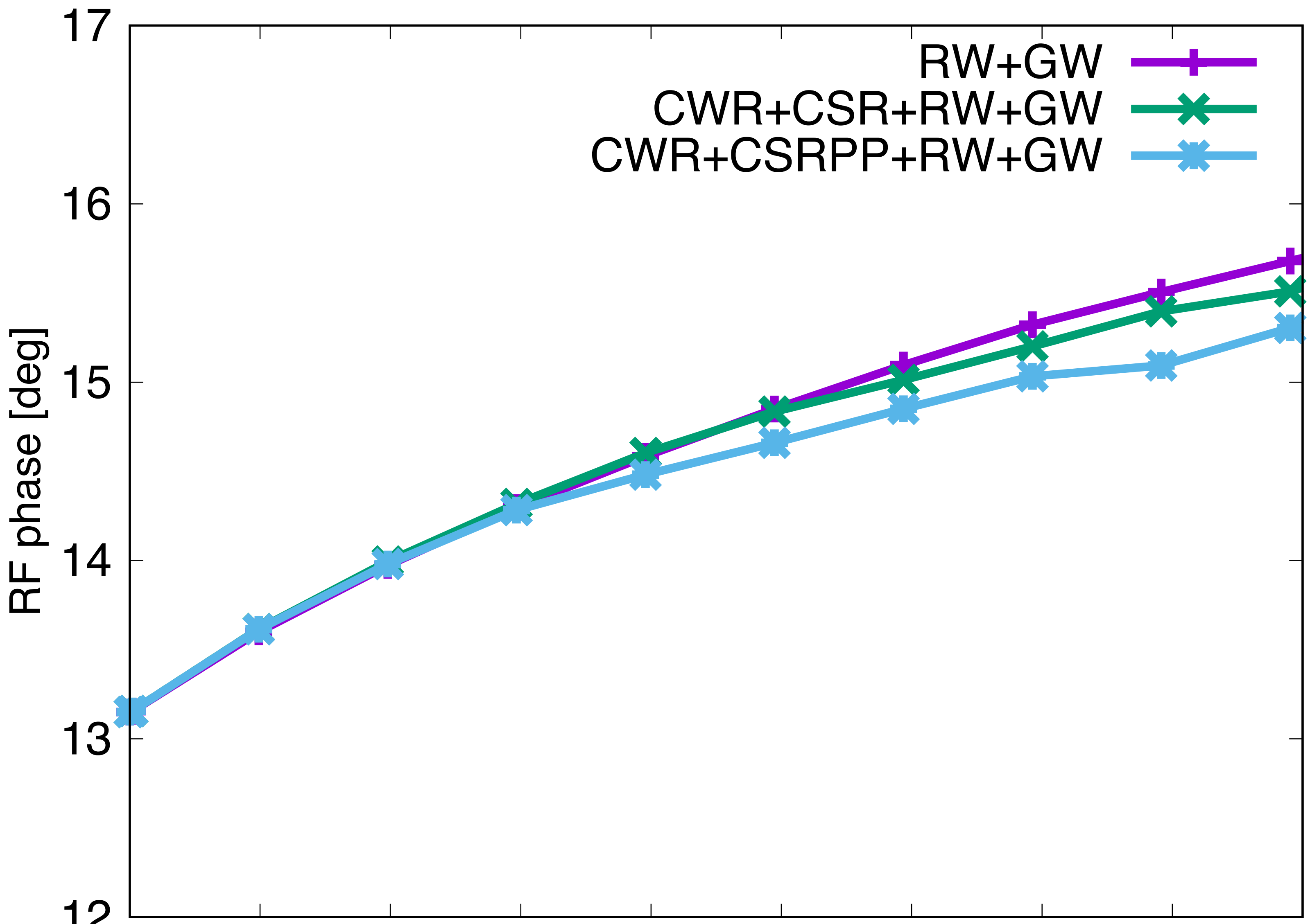
- Use Warnock-Cai's VFP solver for simulation
- Nominal bunch length σ_{z0}=4.78mm @E=3.594 GeV, V_{rf}=8 MV
- nterplay of CSR and other wakes decreases MWI threshold
- Chamber shielding is important in CSR





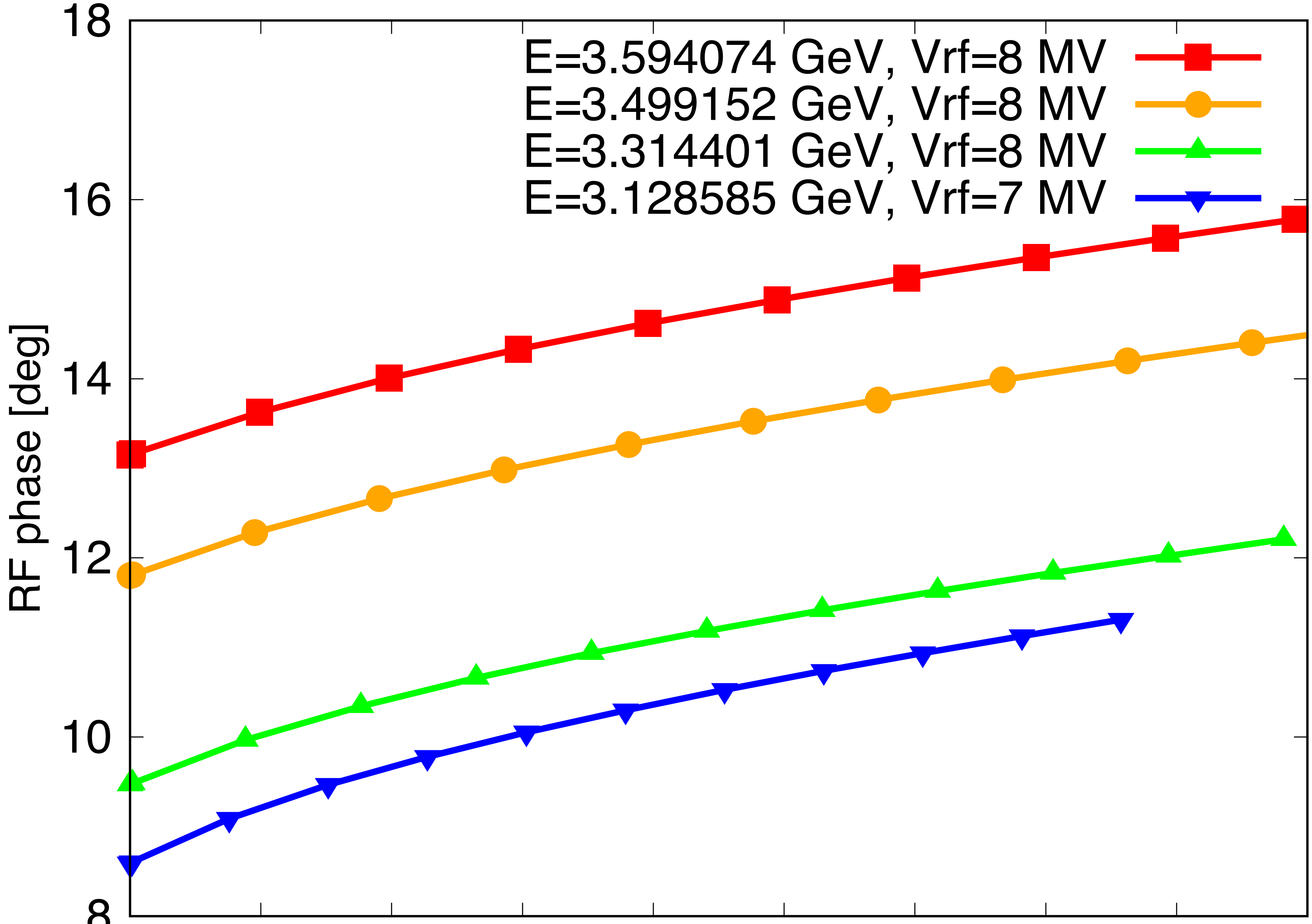
mulations with input of Pseudo-Green wake

- Jse Warnock-Cai's VFP solver for simulation
- Nominal bunch length σ_{z0}=4.78mm @E=3.594 GeV, V_{rf}=8 MV
- Simulated RF phase vs. bunch current



xpected RF phase vs. beam energy for KEKB LER

- Use the same Pseudo-Green function wake
- Use Warnock-Cai's VFP solver for simulation
- RF phase calculated from simulated bunch profile (Haissinski
ion)



ated BPM measurements on beam phase

Re-analysis on the data taken on Oct. 26, 2009

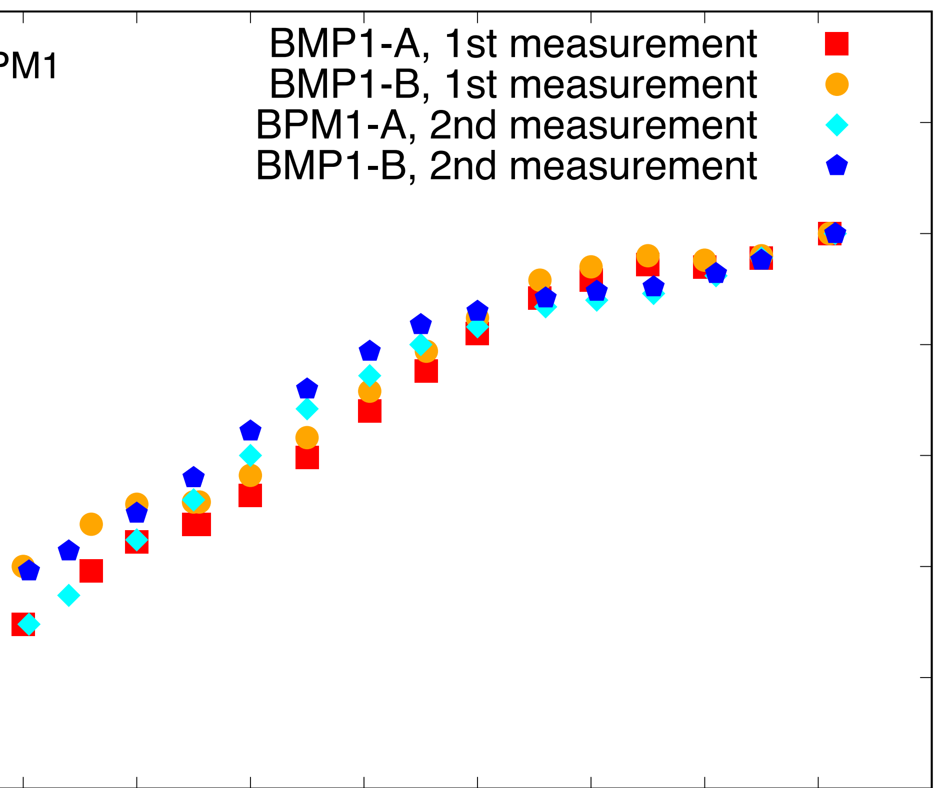
E=3.594 GeV and V_{rf}=8 MV

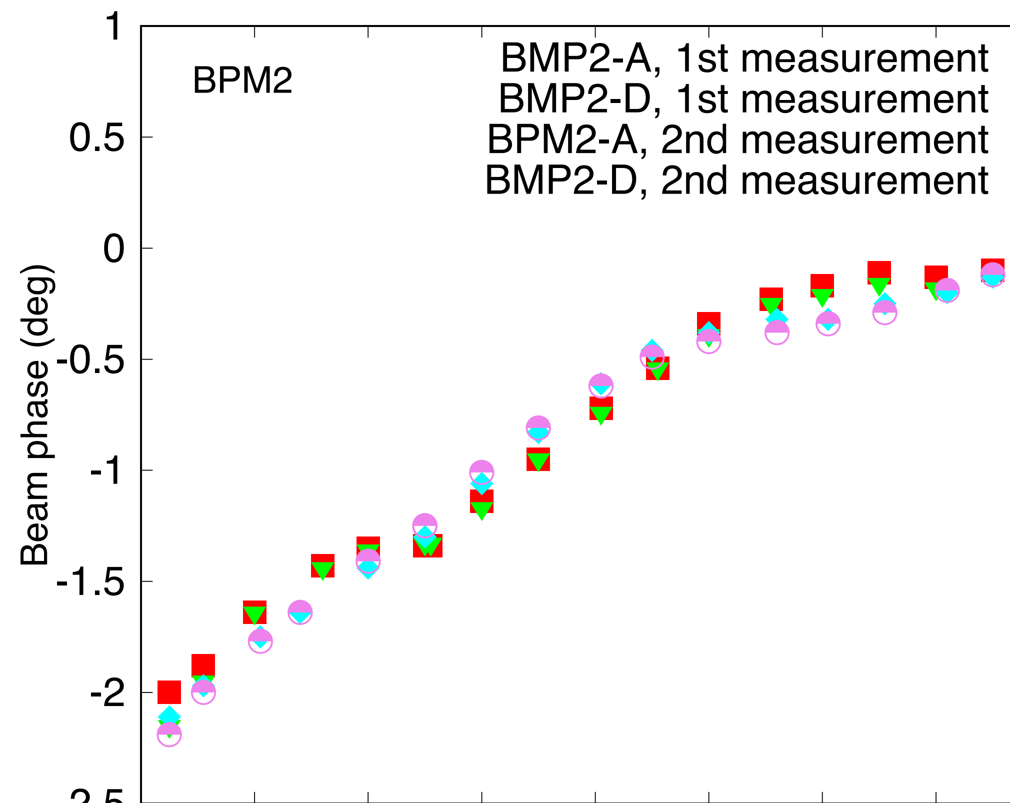
Good reproducibility in GBPM data but larger variations at lo

n currents

Only relative beam phase obtained, and assumed the same

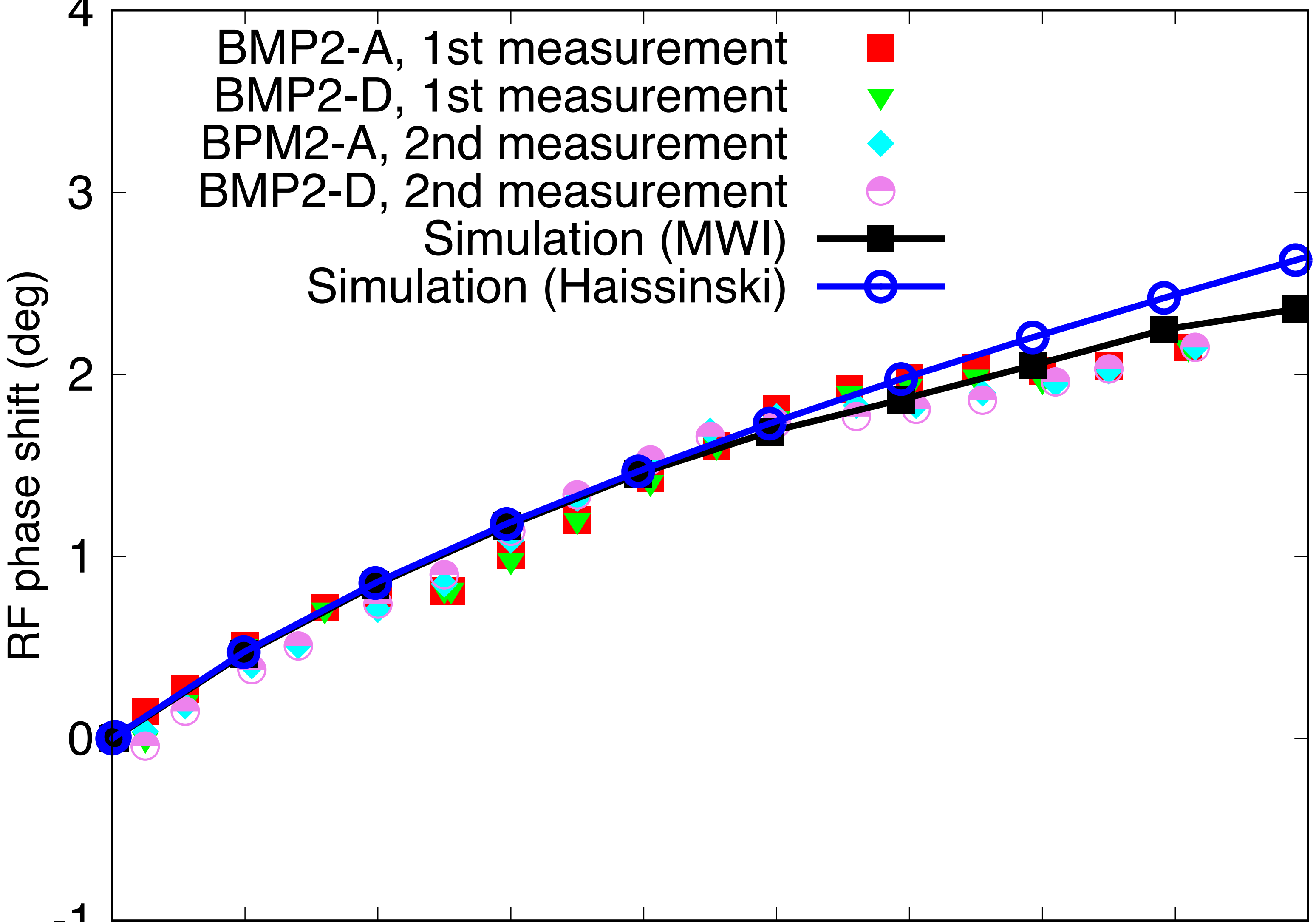
ence phase at highest bunch current





omparison with MWI simulations

- Use Warnock-Cai's VFP solver for simulation
- E=3.594 GeV and V_{rf}=8 MV
- Beam phase at zero current taken as -2.15 deg (extracted fro rimental data)

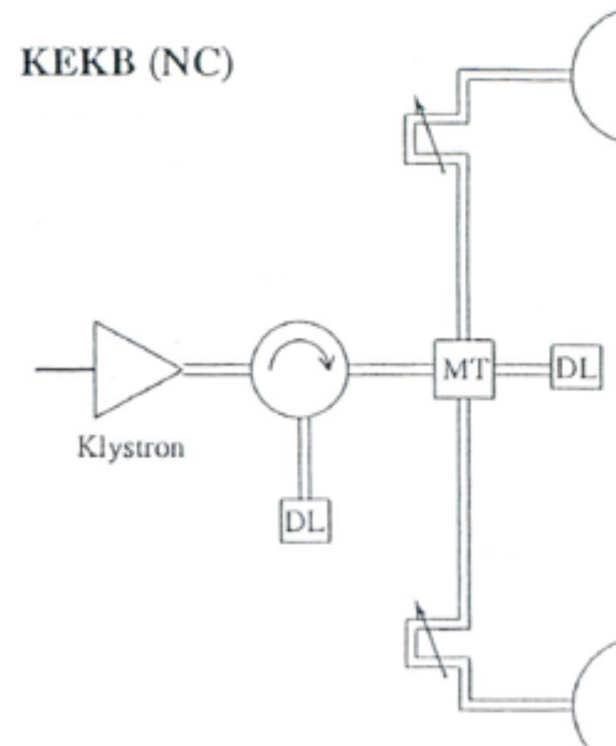


he method

- Refer to A. Novokhatski's work on PEP-II (PAC'07)
- Use the log data for RF systems in KEKB
- Power of wall loss at each cavity: P_{wall}=154 kW@V_c=0.5 MV
- The calibration factor k for each klystron is determined by
  $(I_{beam}$=0)=0

$$\ldots_{am}(I_{beam}) = \sum k \cdot P_{klystron} - \sum (P_{wall} + P_{reflection} + P_{coupling})$$
$$= \sum P_{RFinput} - \sum (P_{wall} + P_{reflection} + P_{coupling})$$

ote: Summation is done for all
ystrons and RF cavities



gged data in KEKB:

- $_{ystron}$: Klystron output power
- $_{eflection}$: Power reflected from RF cavity
- $_{oupling}$: Power to DL (dummy load)

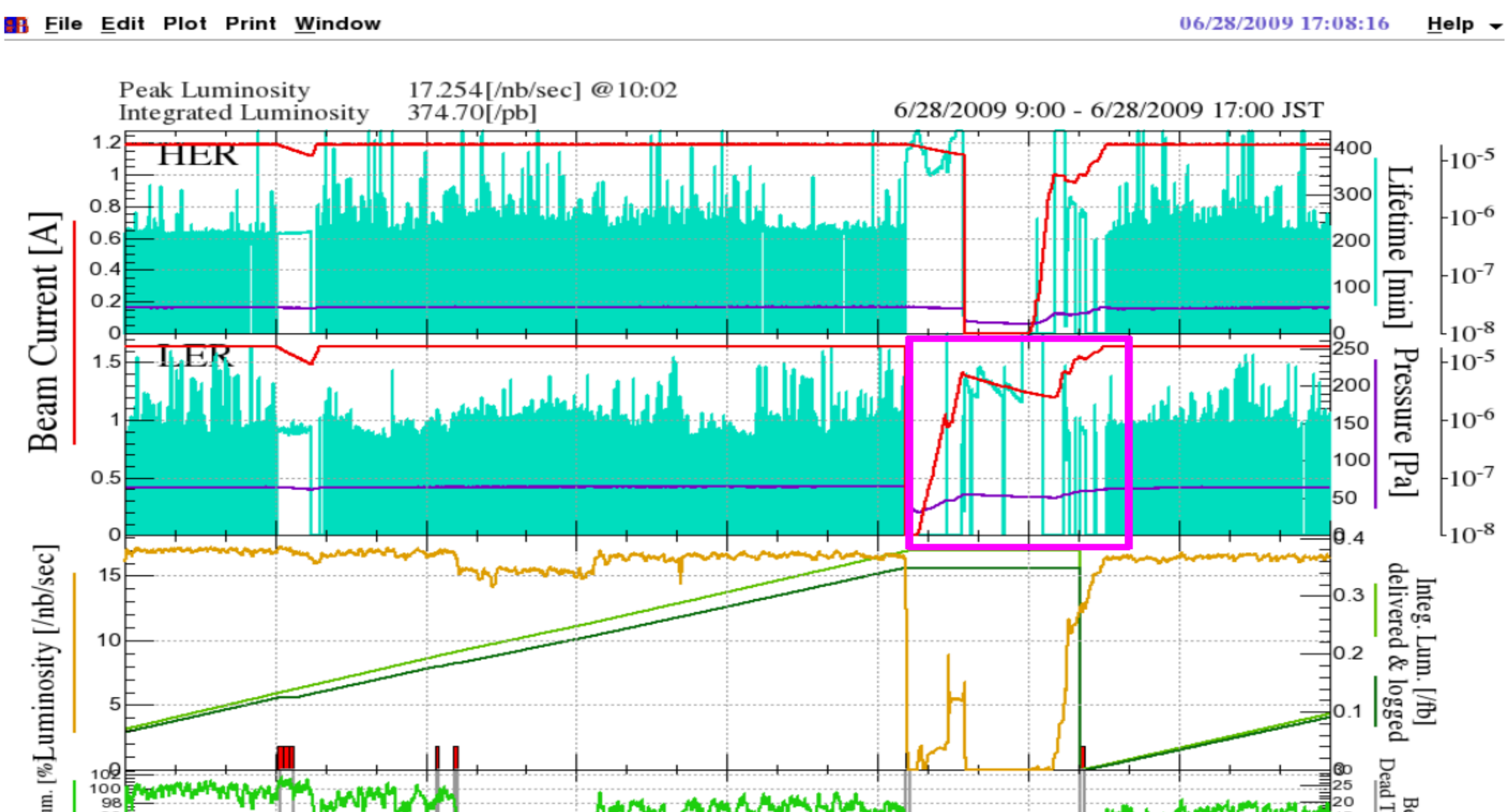
he method

eam current dependent power can be found from beam injection to
after beam abort)

or physics run in 2008 and 2009 the typical number of bunches is
=1584+1 (one pilot bunch)

ssumed bunch current is uniform along the bunch train (this is true
se of injection optimization

unch spacing is ~3-4 RF bucket

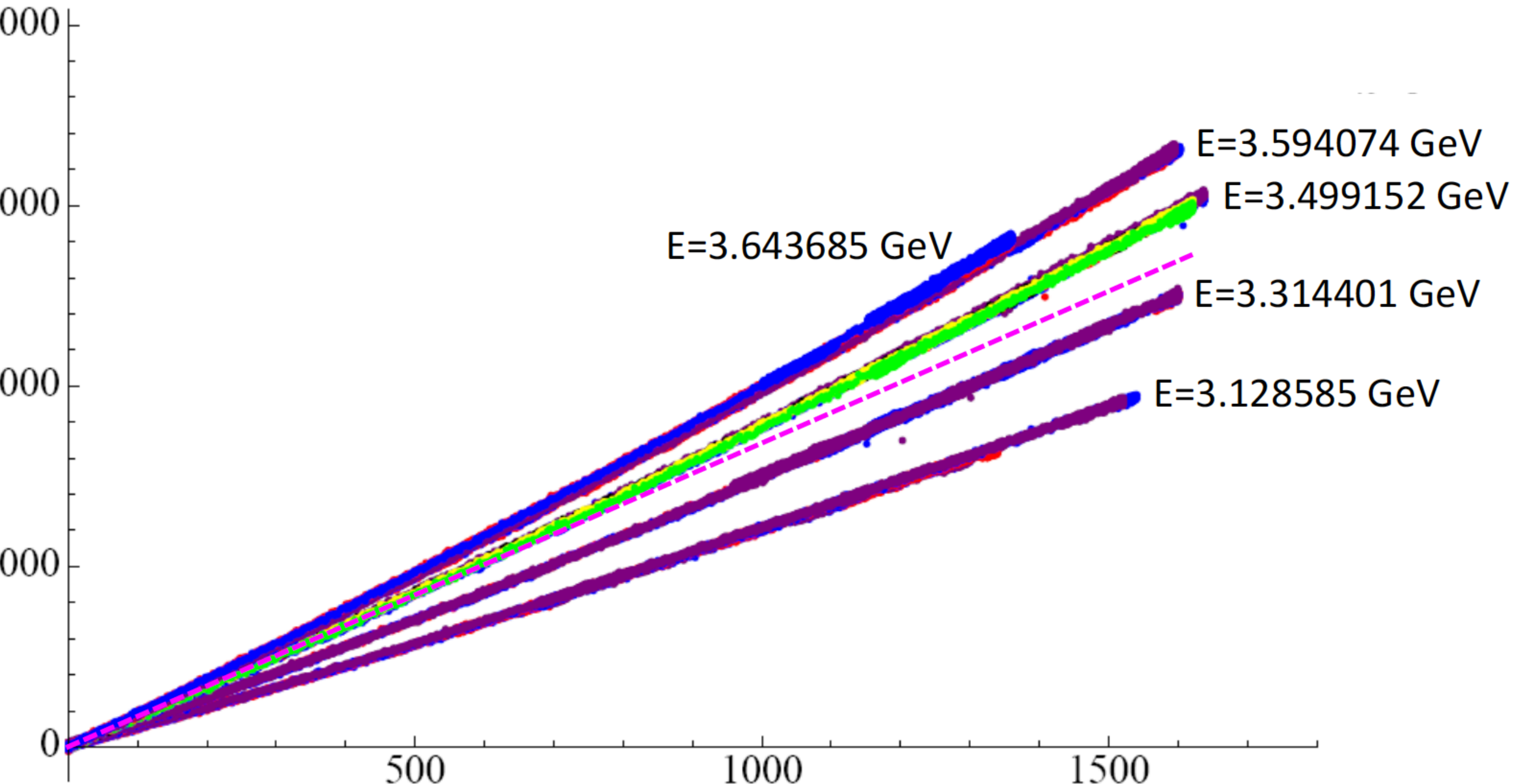


eam power

Beam power depends on beam energy

SR power linearly depends on beam current

Total beam power (kW)



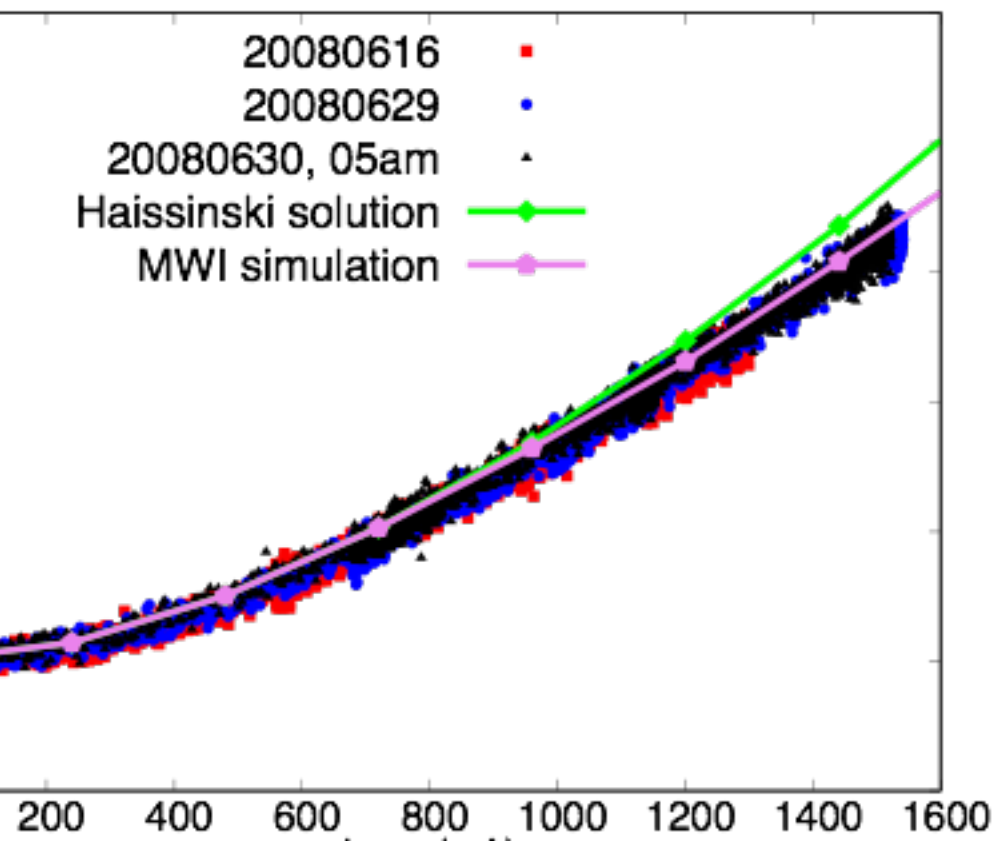
OM power (E=3.128585 GeV, Vrf=7 MV)

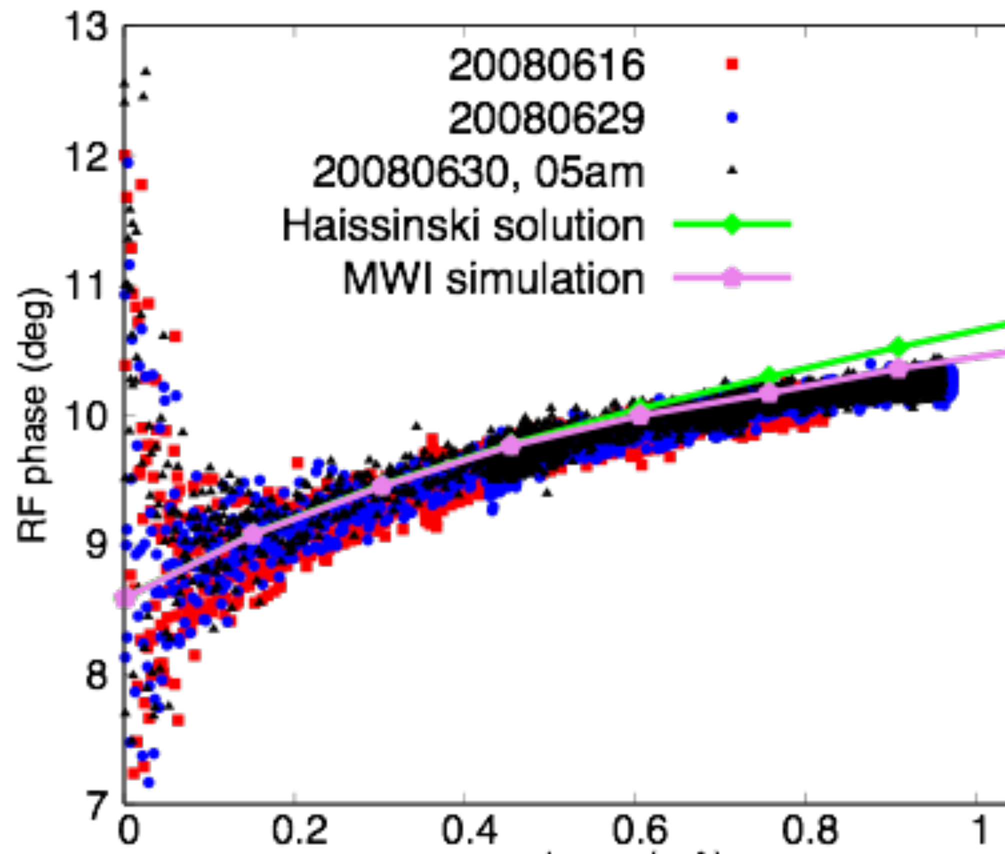
SR power calculated from lattice model

Good reproducibility in beam power data

Above MWI threshold: Additional drop in HOM power and R

e due to energy spread increase





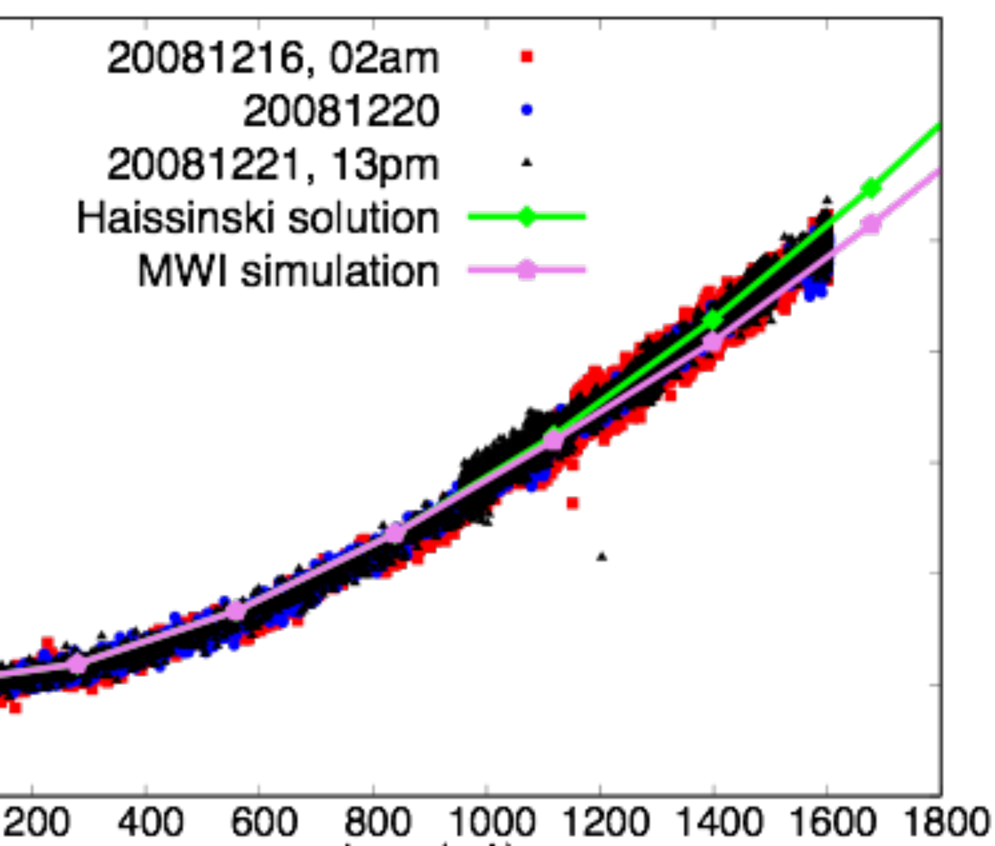
OM power (E=3.314401 GeV, Vrf=8 MV)

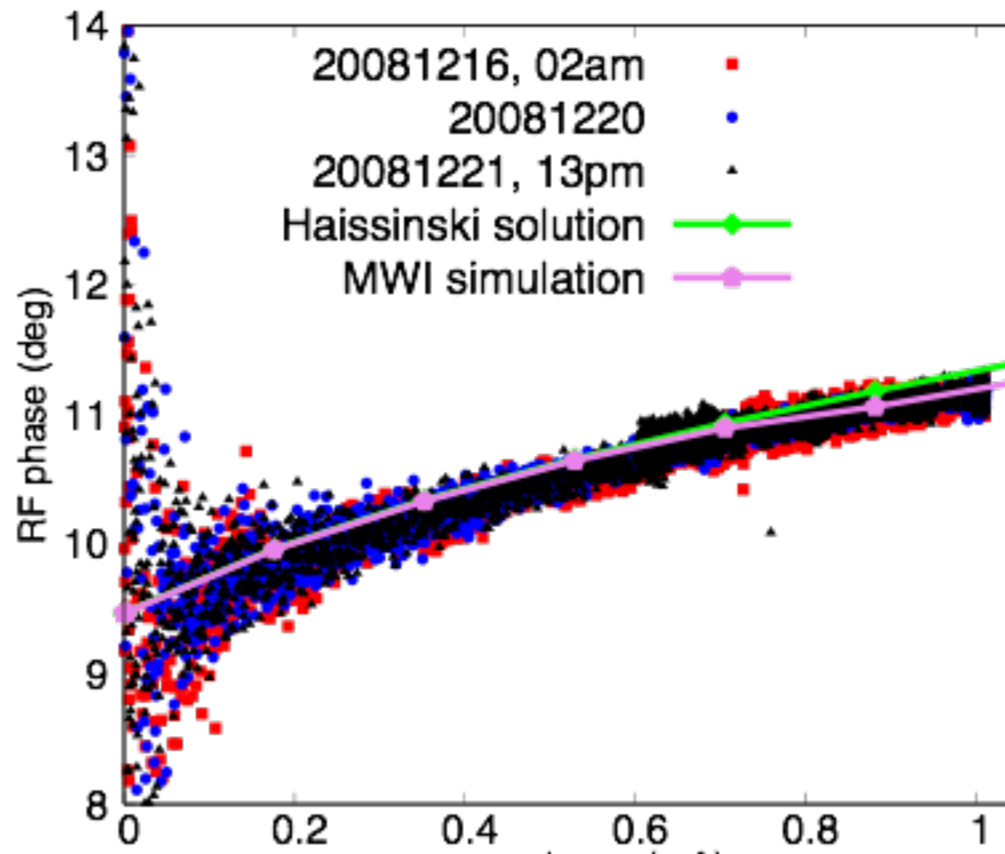
SR power calculated from lattice model

Good reproducibility in beam power data

Above MWI threshold: Additional drop in HOM power and R

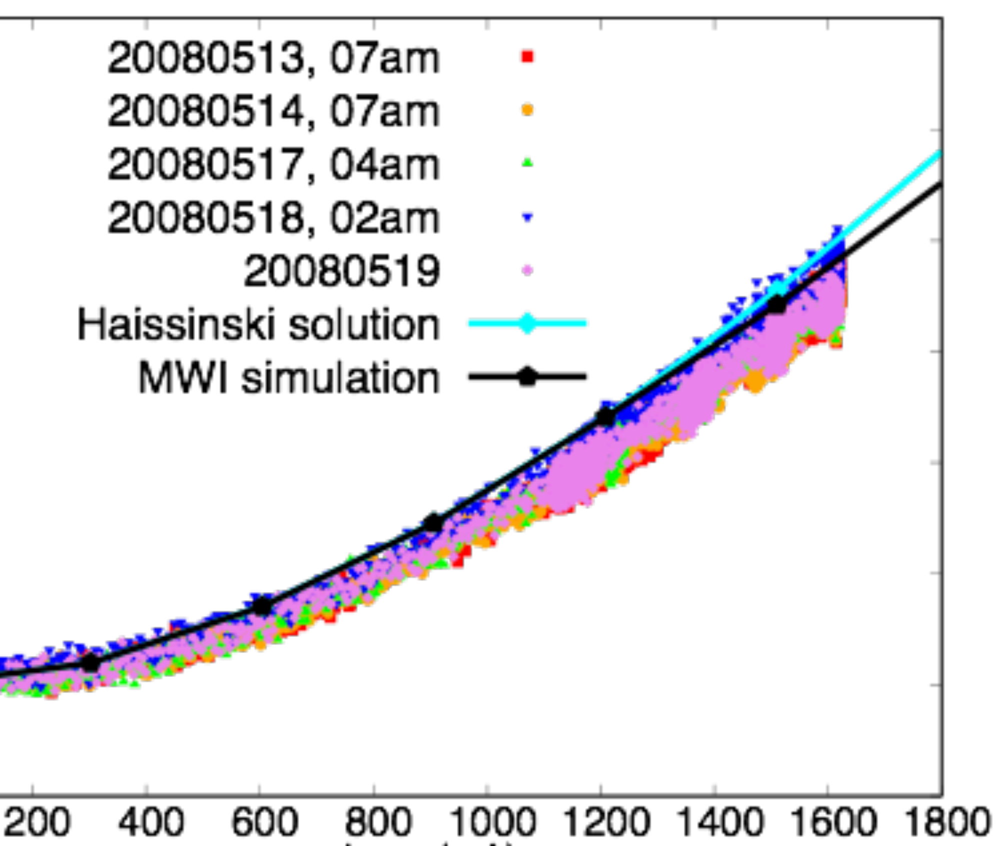
e due to energy spread increase

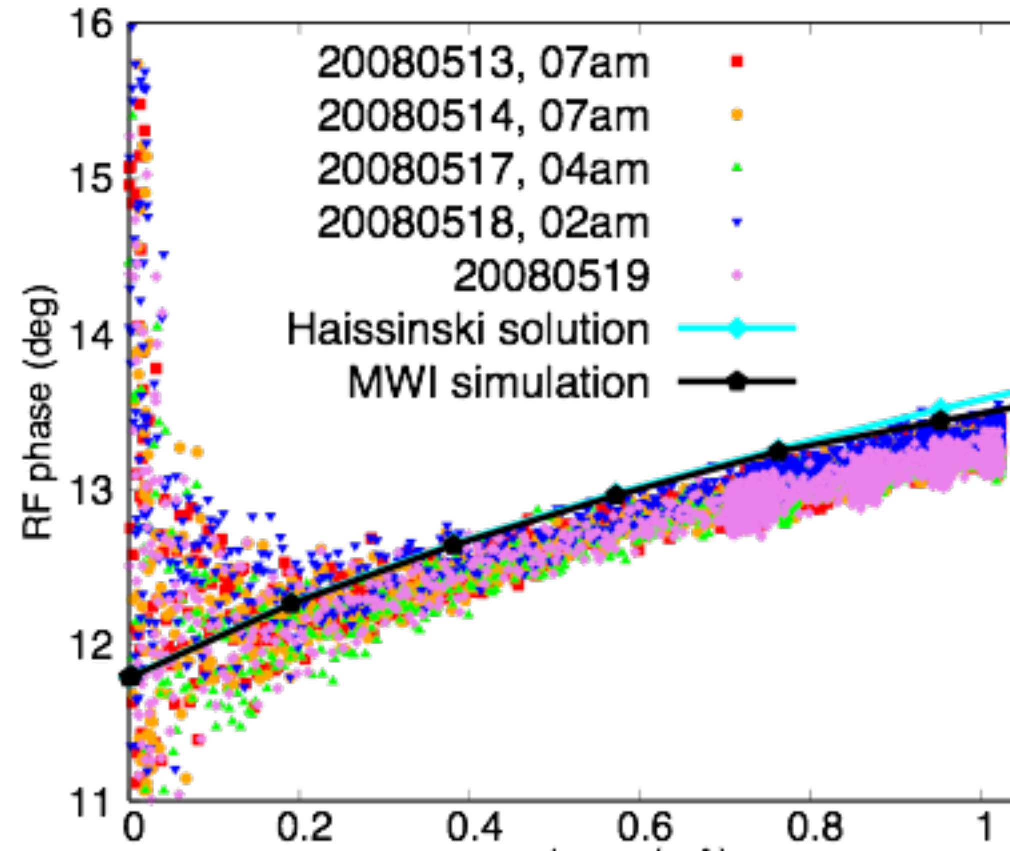




OM power (E=3.499152 GeV, Vrf=8 MV)

- SR power calculated from lattice model
- Good reproducibility in beam power data
- Above MWI threshold: Additional drop in HOM power and R
e due to energy spread increase
- As beam energy increase, the MWI threshold moves higher
- Overestimate on SR power?





OM power (E=3.594074 GeV, Vrf=8 MV)

SR power calculated from lattice model

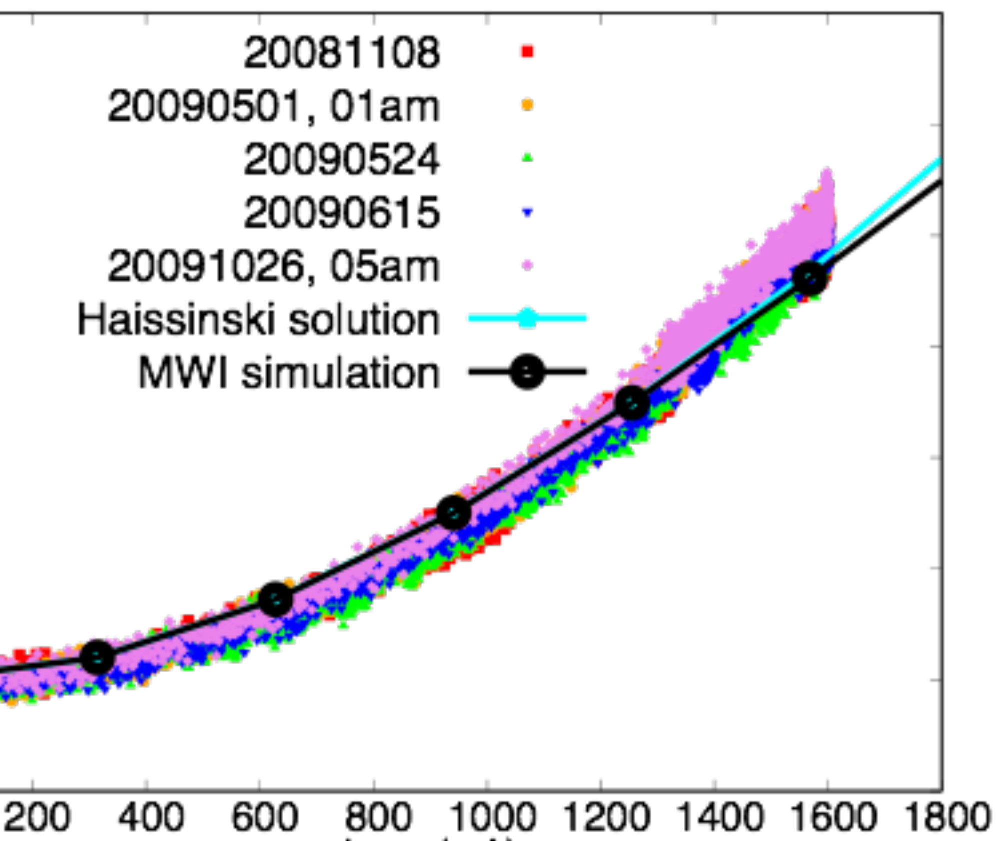
Good reproducibility in beam power data

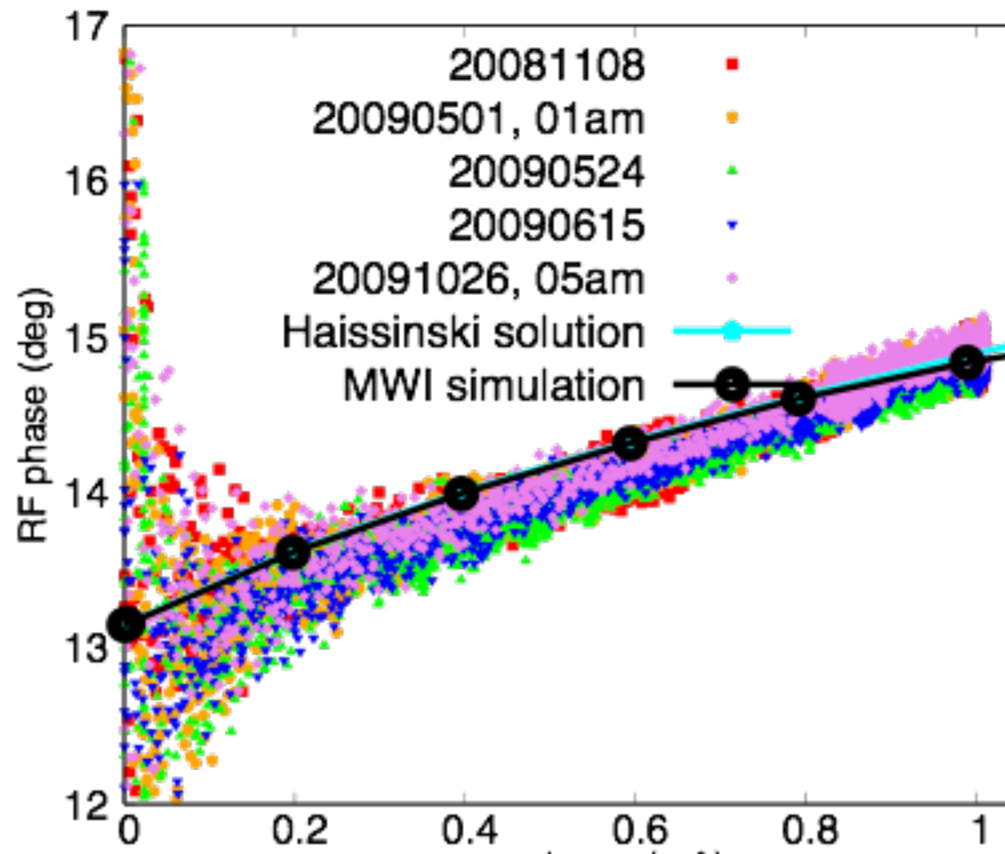
Above MWI threshold: Additional drop in HOM power and R

e due to energy spread increase

As beam energy increase, the MWI threshold moves higher

Overestimate on SR power?





Ve have shown that for KEKB LER, beam phase vs *I* measurements of 2 gree well with theoretical calculations

rom klystron power measurements, we find good agreement to the ph easurements and the calculations, except at high beam energies—the eason is not presently understood. We believe at the moment that this roblem of us not completely understanding the rf feedback system

he theoretical calculations were "bottom-up" wake calculations, where umerically obtain the wakes for a short Gaussian bunch for the differen acuum chamber objects in the ring beginning with the chamber drawing nd including CSR. There are no fitting parameters.

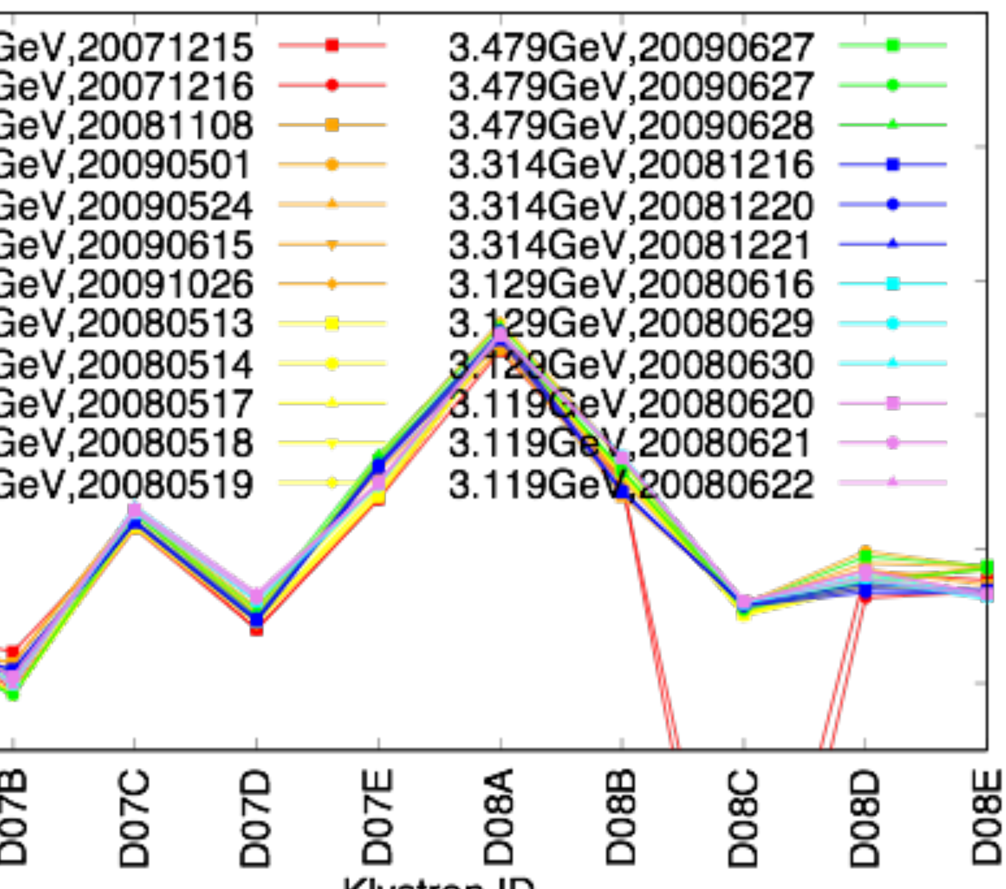
SR is a significant contributor to the pseudo-Green function, with the eam pipe shape being important—the parallel plate model yields a diffe hreshold and bunch length variation with current, and the difference in hase vs *I* curve is also significant.

he fact that there is good agreement between the phase calculations a
easurements suggests that the ring broad-band impedance is well
nderstood. This in spite of the complicated 3D nature of many objects

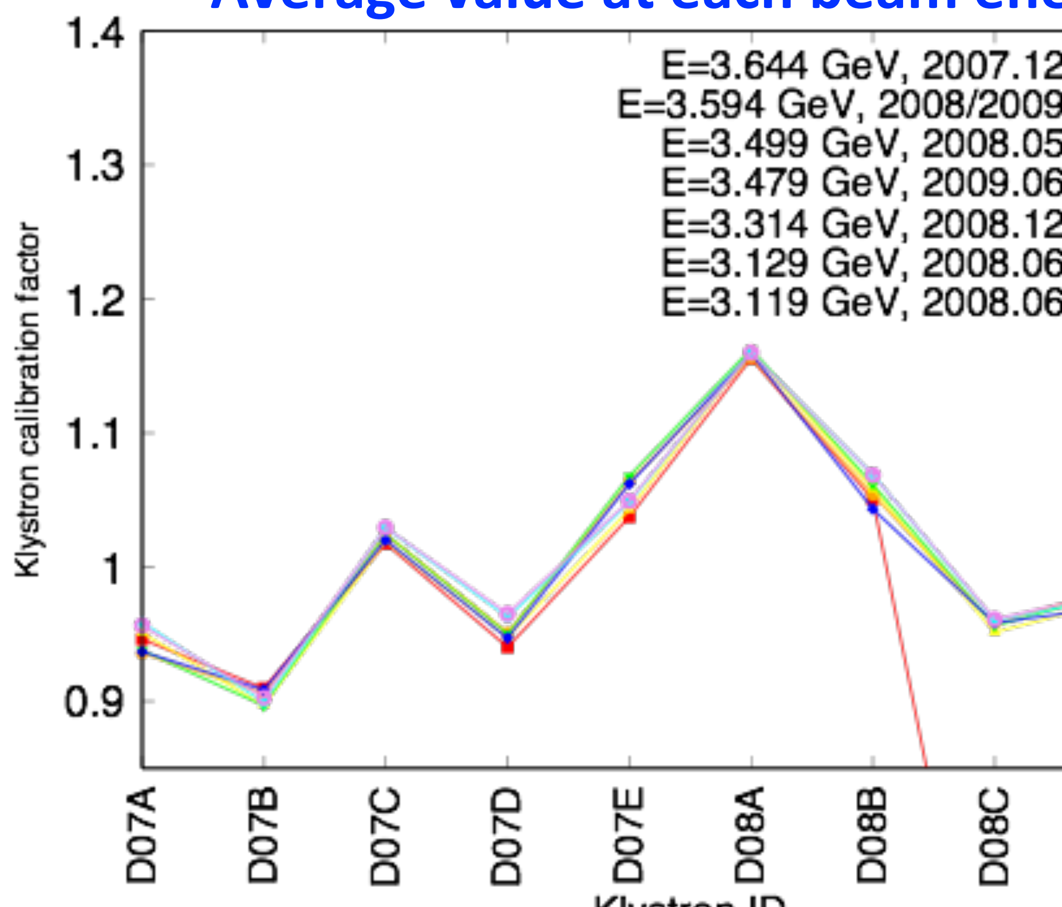
he calculated KEKB LER ring impedance is resistive in character, which
so indicated by the relative large slope in phase vs *I* measurements. Th
esults disagree with earlier streak camera measurements that indicatec
ery inductive impedance (large bunch lengthening and small phase shift
. We suspect that there were systematic errors in the streak camera
easurements. We will try to resolve this discrepancy—which also exis
or measurements on the (similar) SuperKEKB rings—once SuperKEKB
estarts next year

alibration factor for klystron output power

- Calculated from the power balance at zero beam current
- Vary by klystrons
- Larger than 1 for some klystrons
- Vary over time for each klystron?

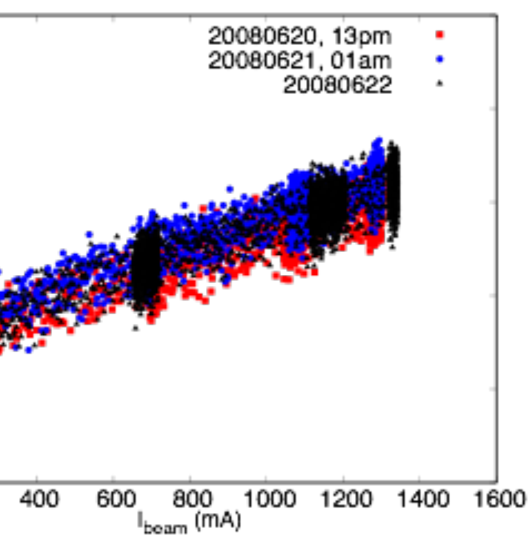


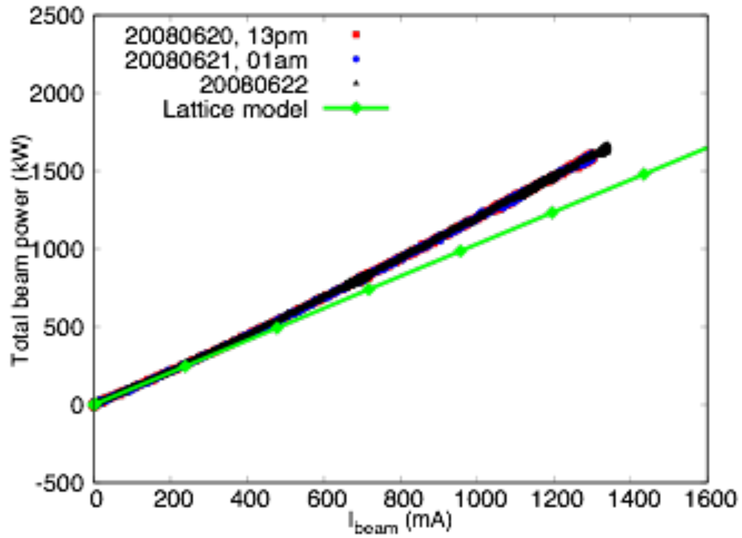
Average value at each beam ene

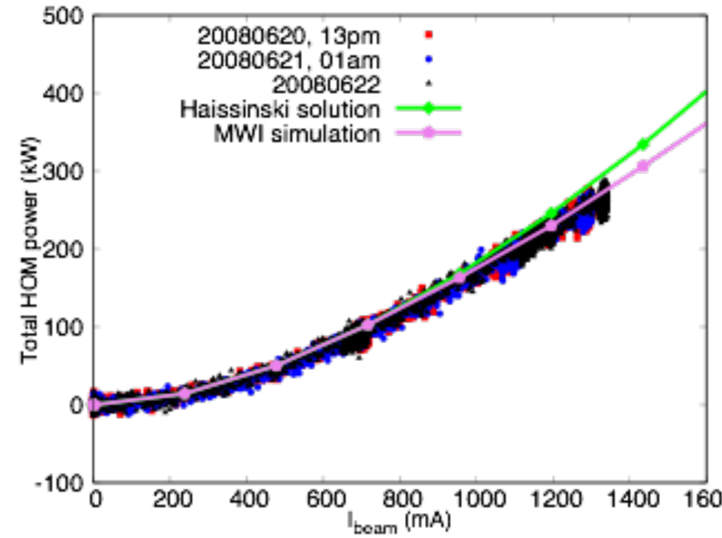


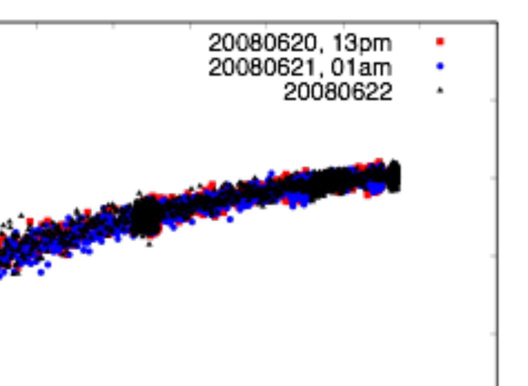
OM power (E=3.118663 GeV, Vrf=7 MV)

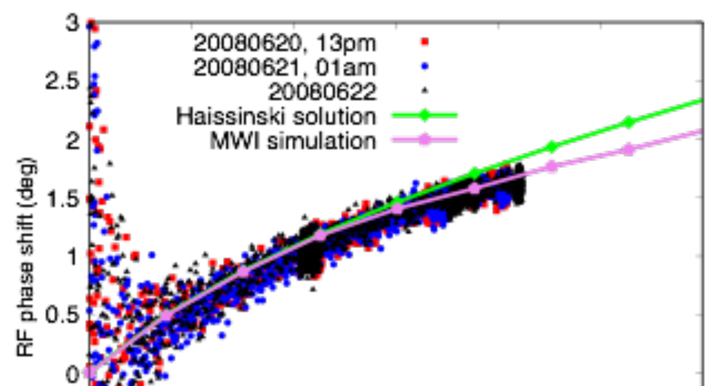
R power calculated from lattice model
ood reproducibility in beam power data
bove MWI threshold: Additional drop in HOM power and RF phase d
y spread increase

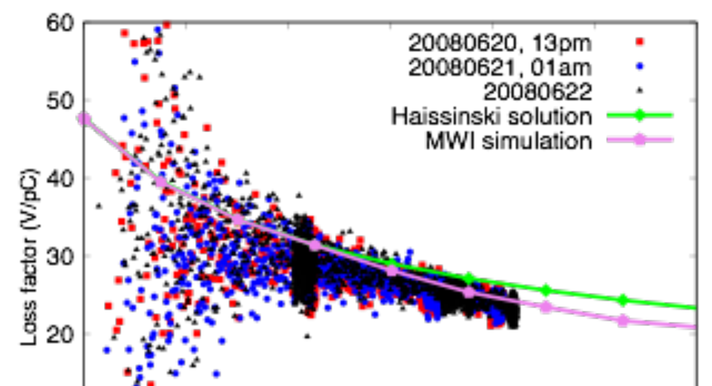












OM power (E=3.478613 GeV, Vrf=8 MV)

R power calculated from lattice model

ood reproducibility in beam power data

bove MWI threshold: Additional drop in HOM power and RF phase d

y spread increase