Revisit of impedance measurements in KEKB - Updates

D. Zhou and K. Bane

Memo for discussion

Jun. 16, 2017

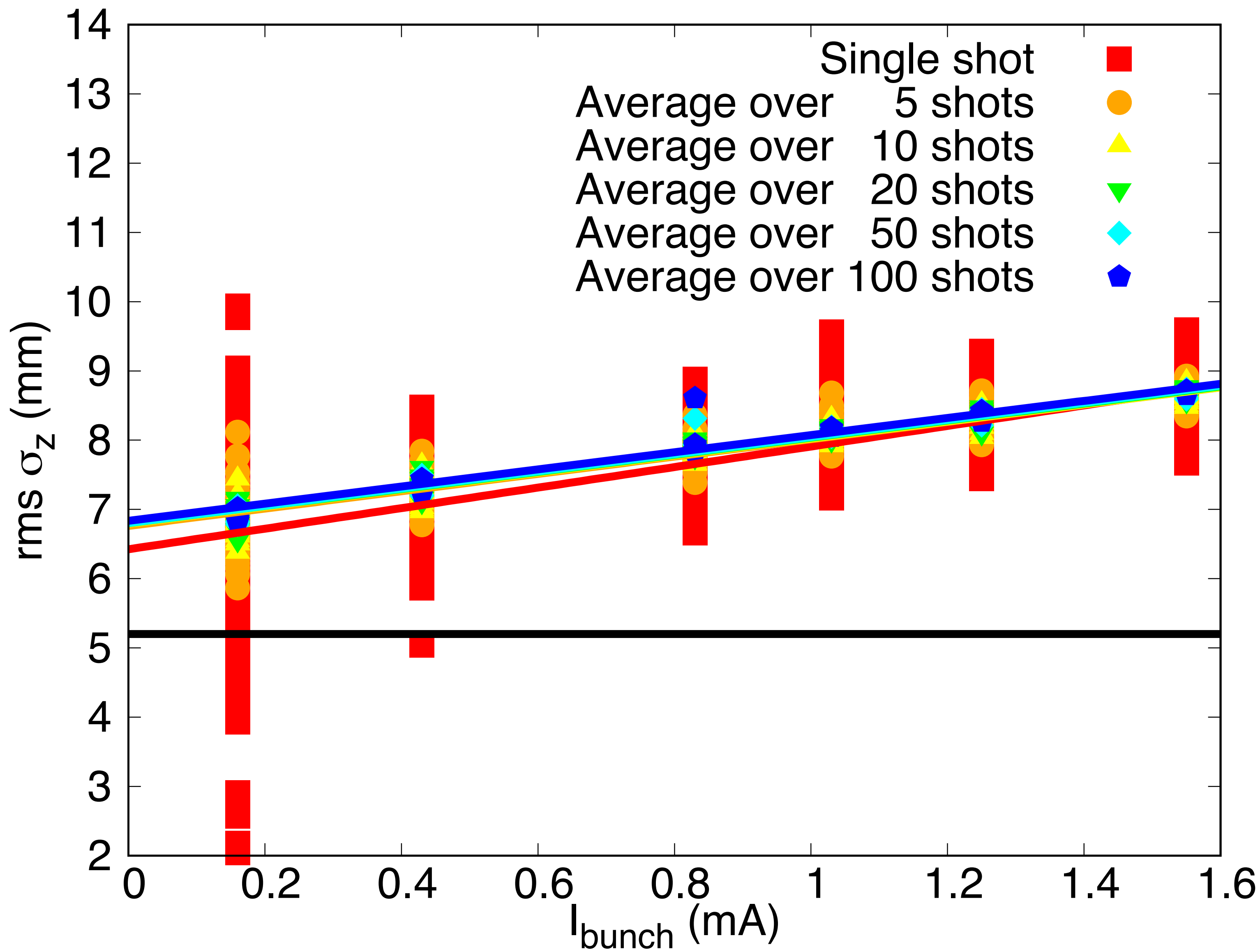
1. Streak camera measurements in KEKB

➤ **Conditions**

- **We did streak camera measurement for KEKB LER and HER on Oct. 26, 2009**
- **The streak cameras were installed with synchro scan system.**
- **Data were taken in single-shot mode (100 shots per bunch current for HER and 128 shots per bunch current for LER) by J. Flanagan**
- **The single-shot data can be summed up to get kind of average that reduces the background (or noise) if synchro-scan is good enough (that reduce timing jitter for streaking)**

1. Streak camera measurements in KEKB

- **HER (2009.10.26): nominal bunch length 5.2mm**
  - **Average over different number of shots: Converge to same results**
  - **Shot noise and timing jitter looked to be small**
  - **D.Z.: There were systematic errors in the SC system?**



$f_1(I_b)=6.42+1.48I_b$

$f_2(I_b)=6.76+1.25I_b$

$f_3(I_b)=6.79+1.23I_b$

$f_4(I_b)=6.80+1.24I_b$

$f_5(I_b)=6.81+1.24I_b$

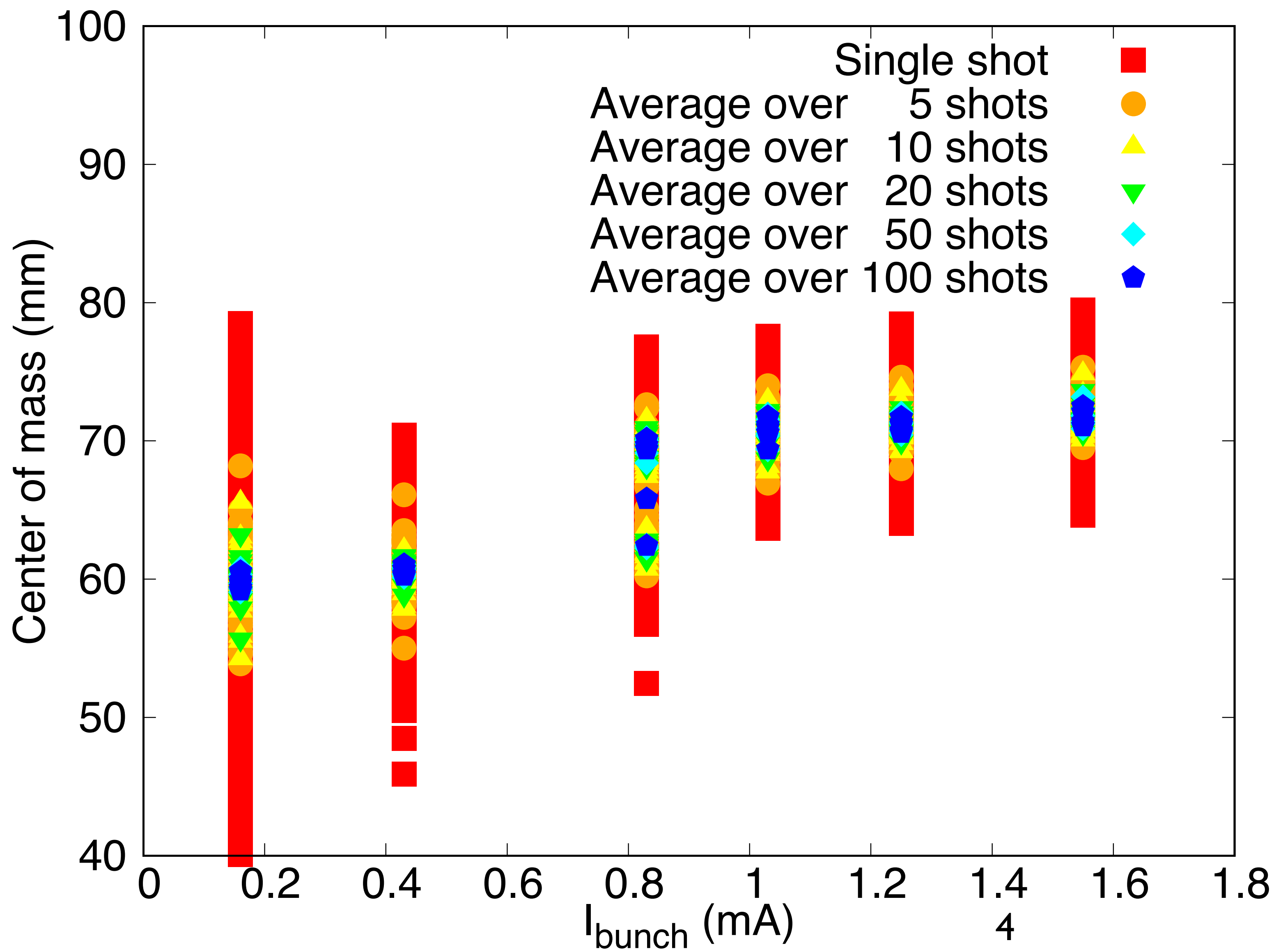
$f_6(I_b)=6.84+1.24I_b$

http://research.kek.jp/people/dmzhou/BeamPhysics/mwi/20160908_Bunch_Length_dmzhou.pdf

1. Streak camera measurements in KEKB

➤ HER (2009.10.26): nominal bunch length 5.2mm

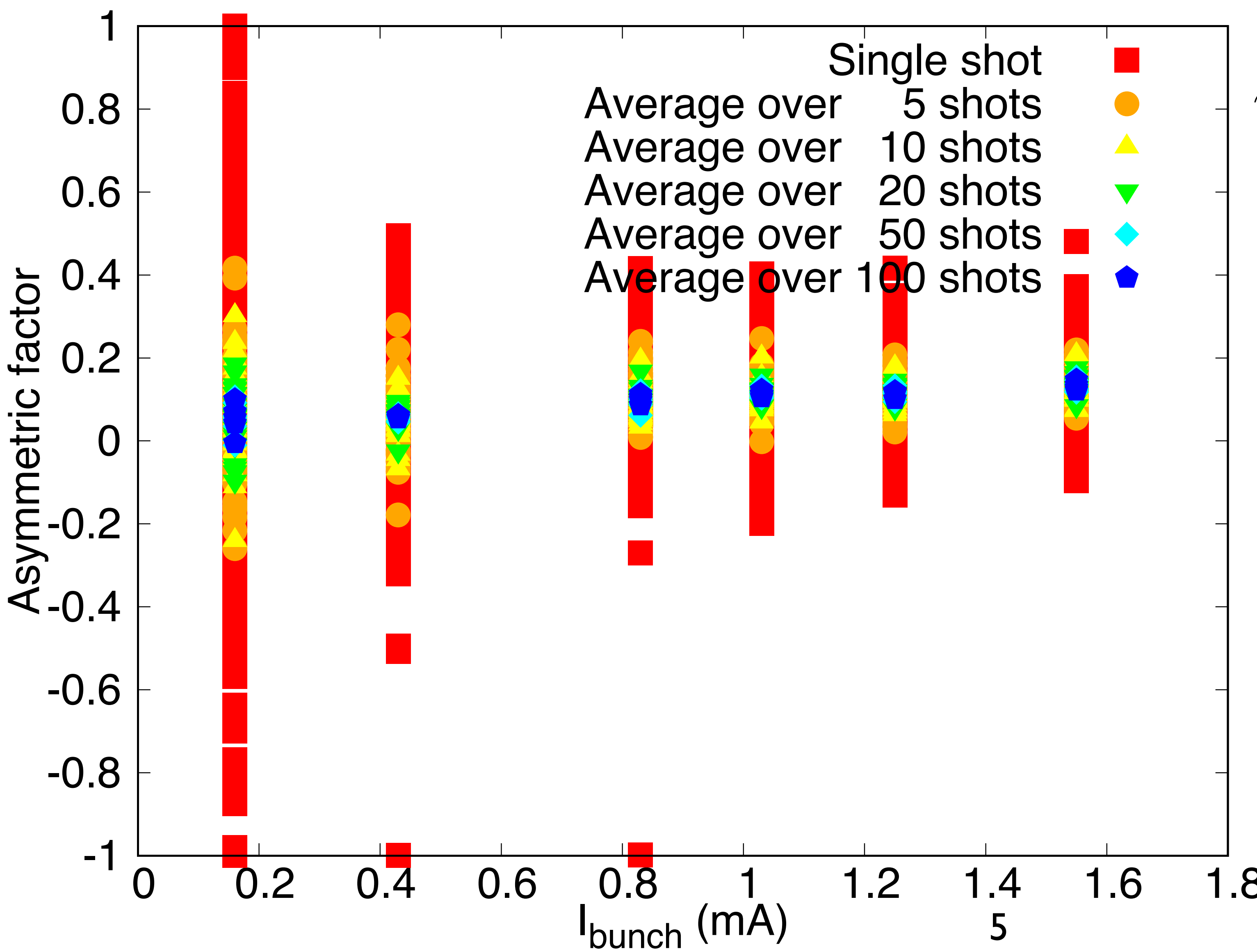
- Center of mass was calculated from fitted (asymmetric Gaussian fitting) bunch profile
- The rms center of mass from simulation was not available (Pseudo-Green wake for HER was not constructed)
- **D.Z.: Data looked strange at high bunch currents?**



1. Streak camera measurements in KEKB

➤ **HER (2009.10.26): nominal bunch length 5.2mm**

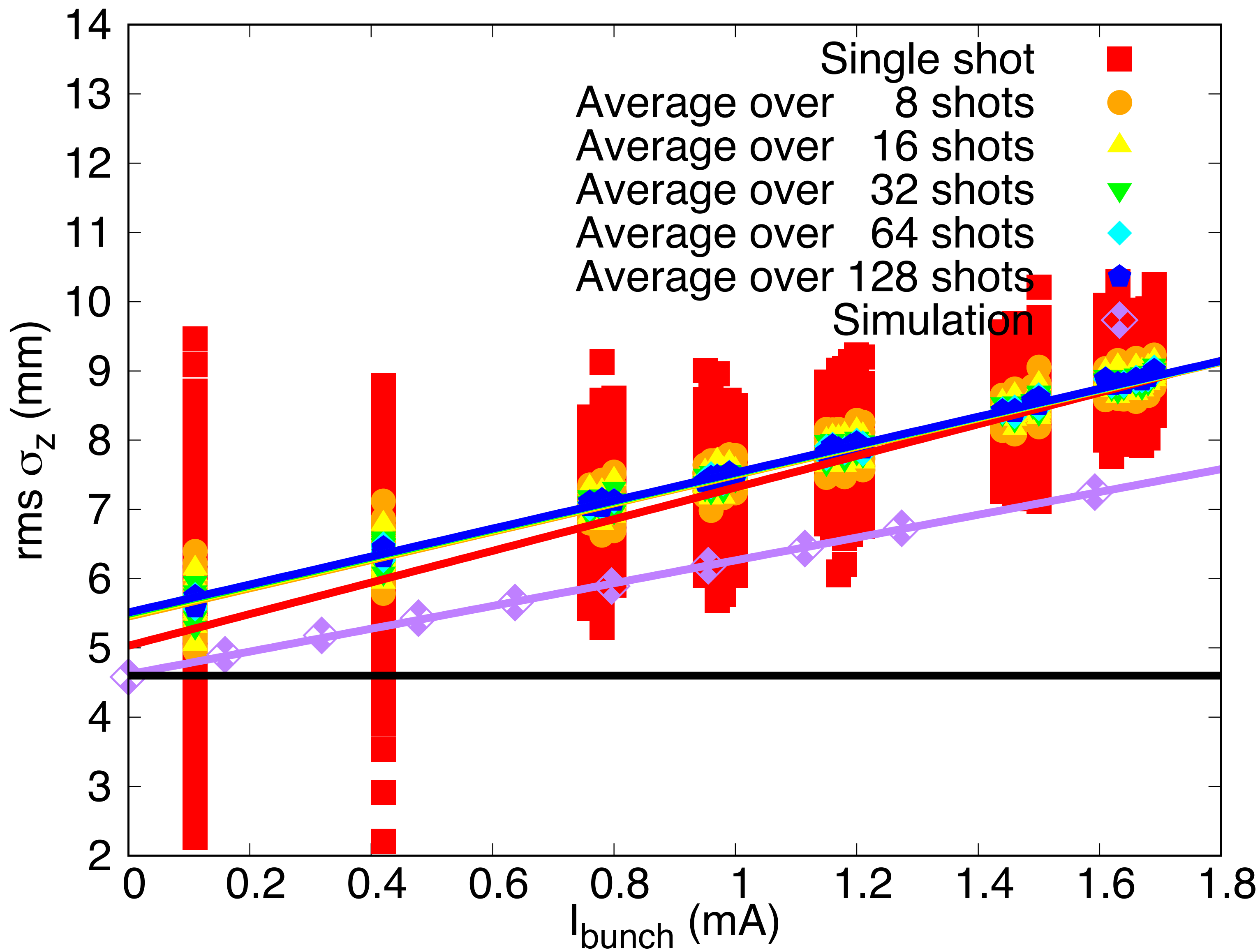
- **Asymmetric factor was calculated from asymmetric Gaussian fitting**
- **Average over streak data looks good?**
- **D.Z.: Data looked reasonable at high bunch currents?**



$$\psi(z) = I_0 * e^{-\frac{(z-\bar{z})^2}{2[1+\mathrm{sign}(z-\bar{z})A]^2\sigma^2}} + I_1$$

1. Streak camera measurements in KEKB

- ➤ **LER (2009.10.26): nominal bunch length 4.6mm**
  - **Single-shot measurement (128 shots per current) by J. Flanagan**
  - **Average over different number of shots: Converge to same results**
  - **Shot noise and timing jitter are small**
  - **D.Z.: There were systematic errors in the SC system?**



$f_1(I_b)=5.03+2.28I_b$

$f_2(I_b)=5.45+2.04I_b$

$f_3(I_b)=5.48+2.03I_b$

$f_4(I_b)=5.49+2.03I_b$

$f_5(I_b)=5.51+2.02I_b$

$f_6(I_b)=5.51+2.02I_b$

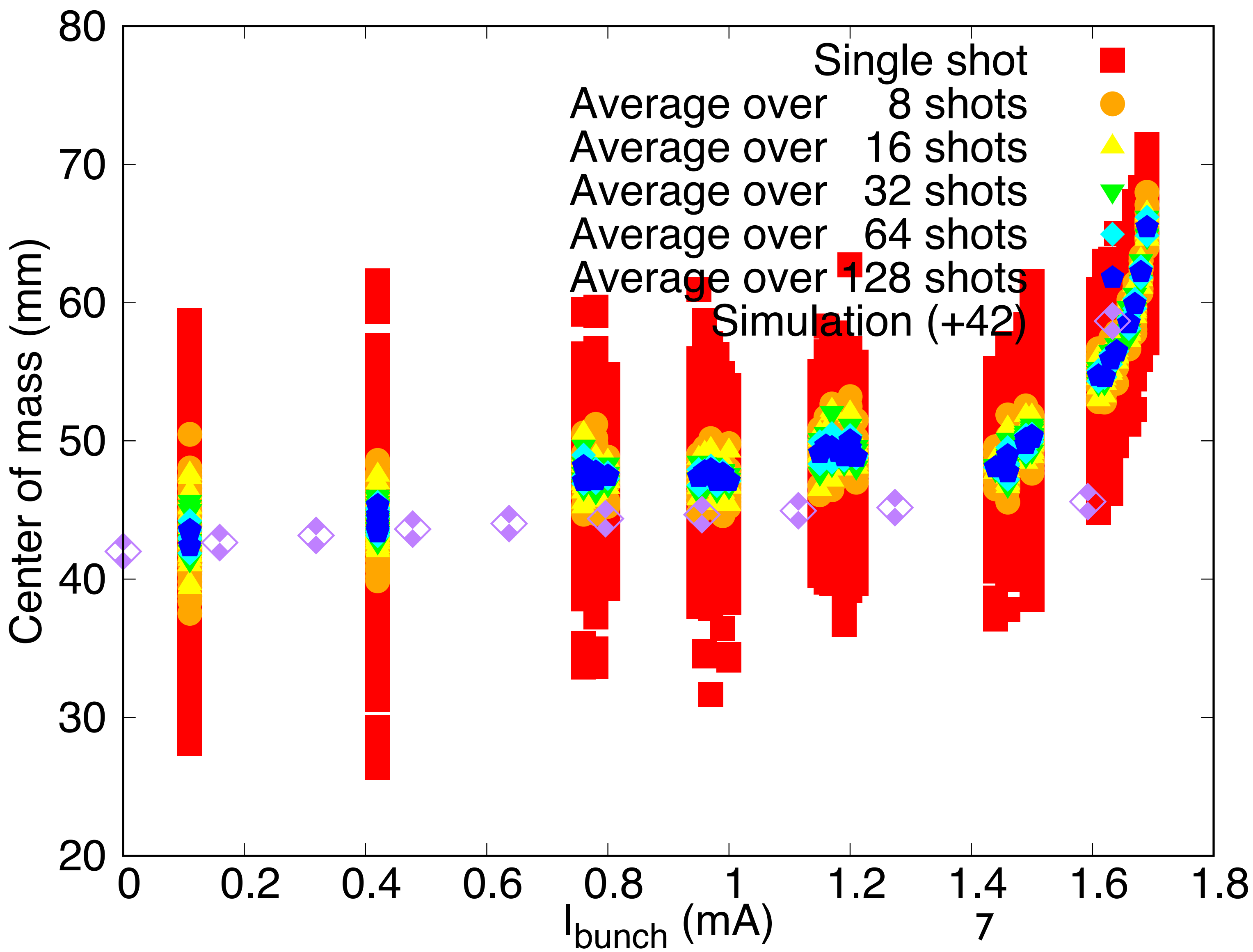
$f_7(I_b)=4.62+1.65I_b$

http://research.kek.jp/people/dmzhou/BeamPhysics/mwi/20160908_Bunch_Length_dmzhou.pdf

1. Streak camera measurements in KEKB

➤ LER (2009.10.26): nominal bunch length 4.6mm

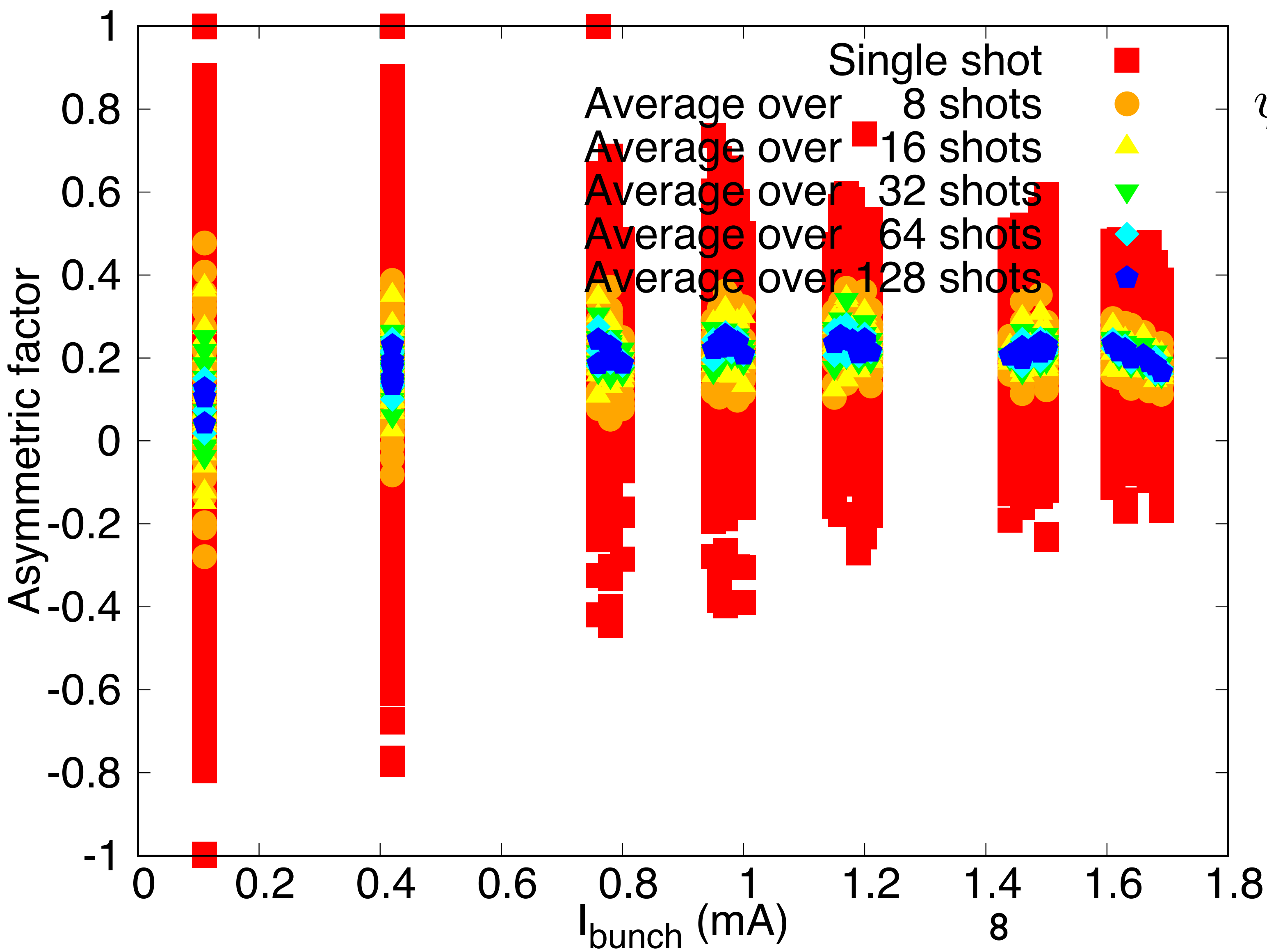
- Center of mass was calculated from fitted (asymmetric Gaussian fitting) bunch profile
- The rms center of mass from simulation (Solving Haissinski equation with impedance model) were also plotted (by shifting 42 mm for comparison)
- D.Z.: Data looked strange at high bunch current?



1. Streak camera measurements in KEKB

➤ **LER (2009.10.26): nominal bunch length 4.6mm**

- **Asymmetric factor was calculated from asymmetric Gaussian fitting**
- **Average over streak data looks good?**
- **D.Z.: Data looked strange at high bunch currents?**



$$\psi(z) = I_0 * e^{-\frac{(z-\bar{z})^2}{2[1+\mathrm{sign}(z-\bar{z})A]^2\sigma^2}} + I_1$$

2. Beam phase measurements in KEKB LER

➤ **Conditions**

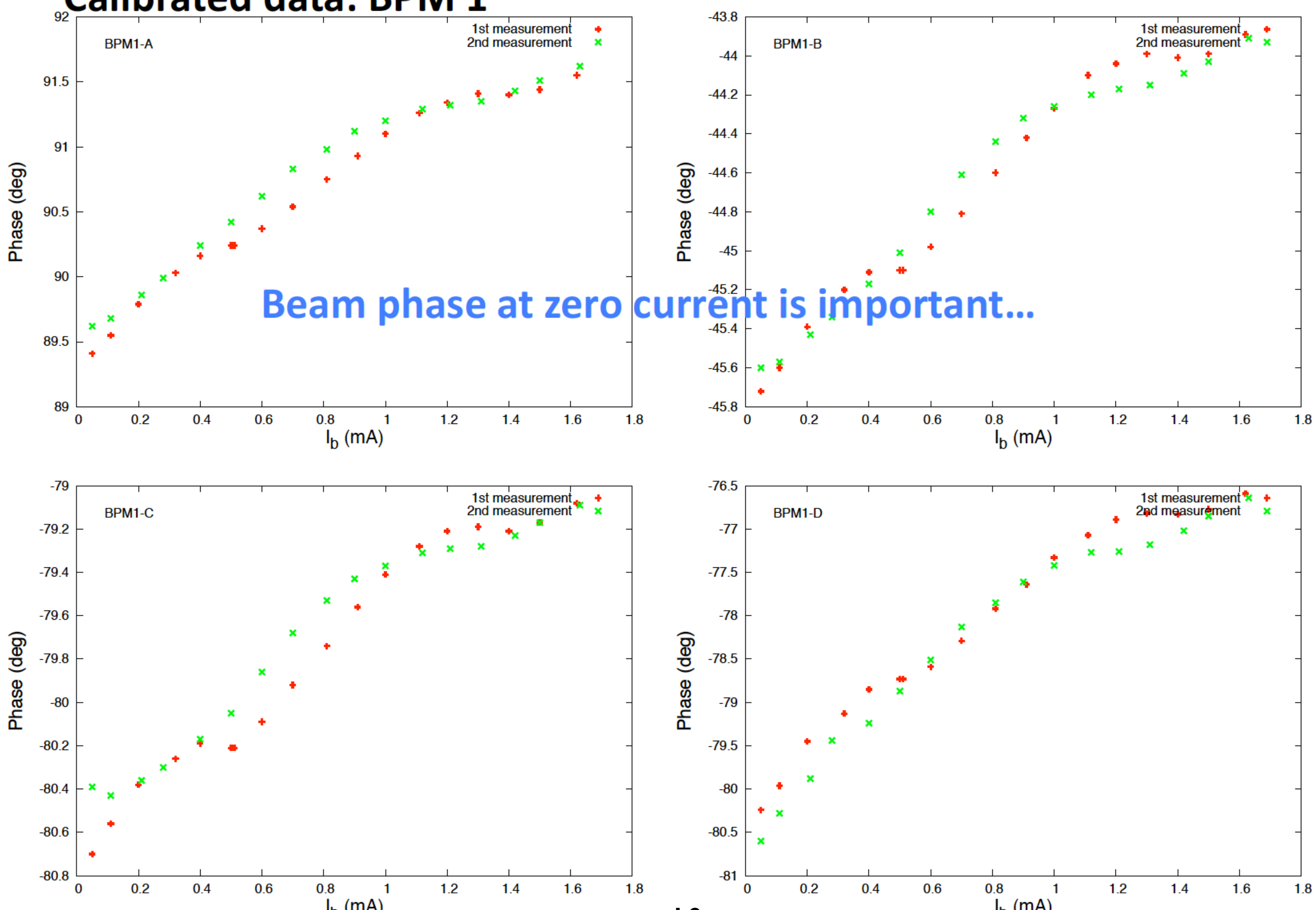
- **Beam energy: E=3.594074GeV**
- **Total RF voltage: Vrf=8MV**
- **Synchrotron radiation loss calculated from lattice file (use SAD code): U0=1.82MeV**
- **The method: Refer to T. Eeiri's paper "Measurement of longitudinal impedance at KEKB", the 14th Symposium on Accelerator Science and Technology, Japan, November, 2003**

2. Beam phase measurements in KEKB LER

➤ LER (2009.10.26): nominal bunch length 4.6mm

- The beam phase from BPM is relative phase. The zero-current phase has to be properly extracted from experiment data

Calibrated data: BPM 1

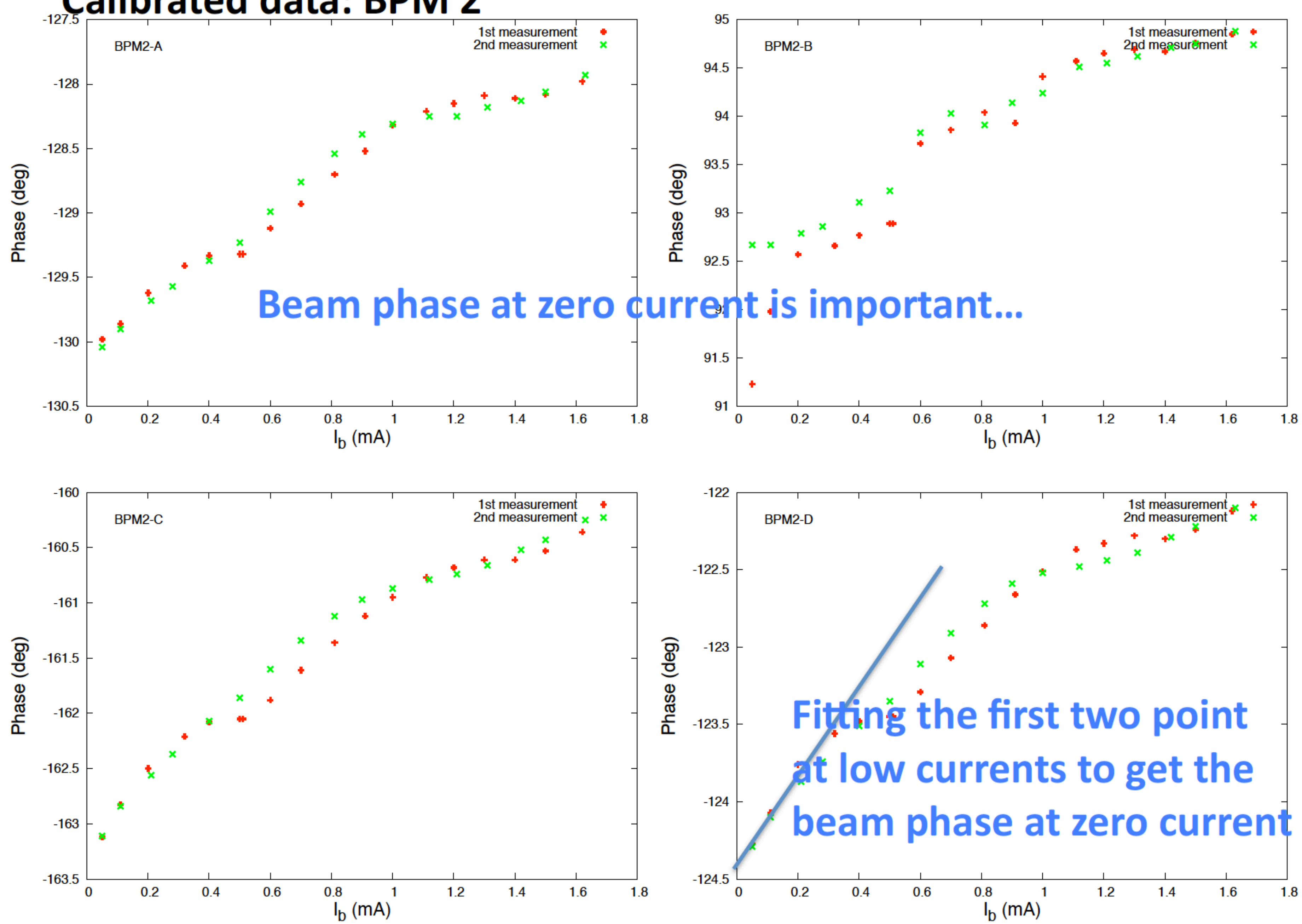


2. Beam phase measurements in KEKB LER

➤ LER (2009.10.26): nominal bunch length 4.6mm

- The beam phase from BPM is relative phase. The zero-current phase has to be properly extracted from experiment data

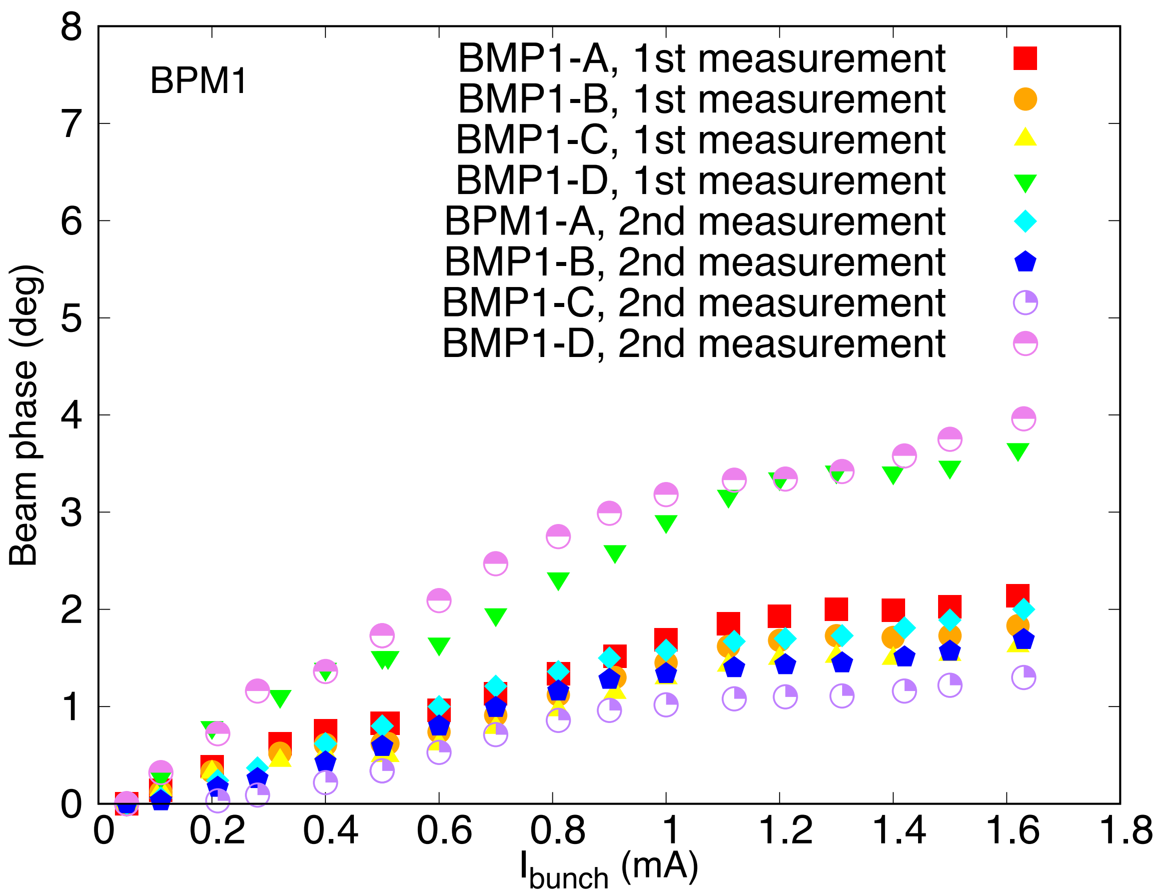
Calibrated data: BPM 2

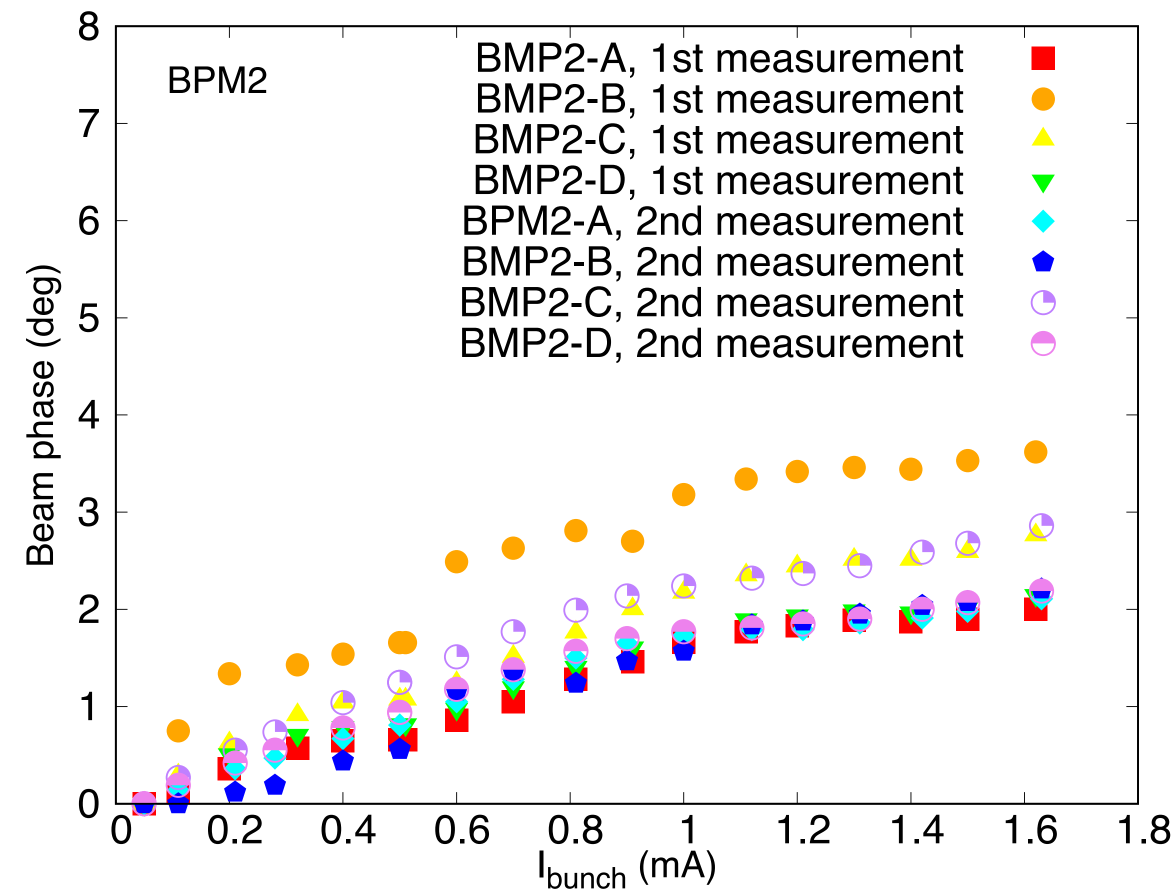


2. Beam phase measurements in KEKB LER

➤ LER (2009.10.26): nominal bunch length 4.6mm

- Assuming the bunch has the same RF phase at lowest current, then we have the following plots by subtracting the phase at the left-most for each BPM button. But in this case, there are large deviations at high bunch currents. This is not reasonable because at higher currents, the BPM signal is stronger, there should be less error in read-out of BPM.
- It's obvious to see that data of BPM1-D have something wrong and should be ignored.



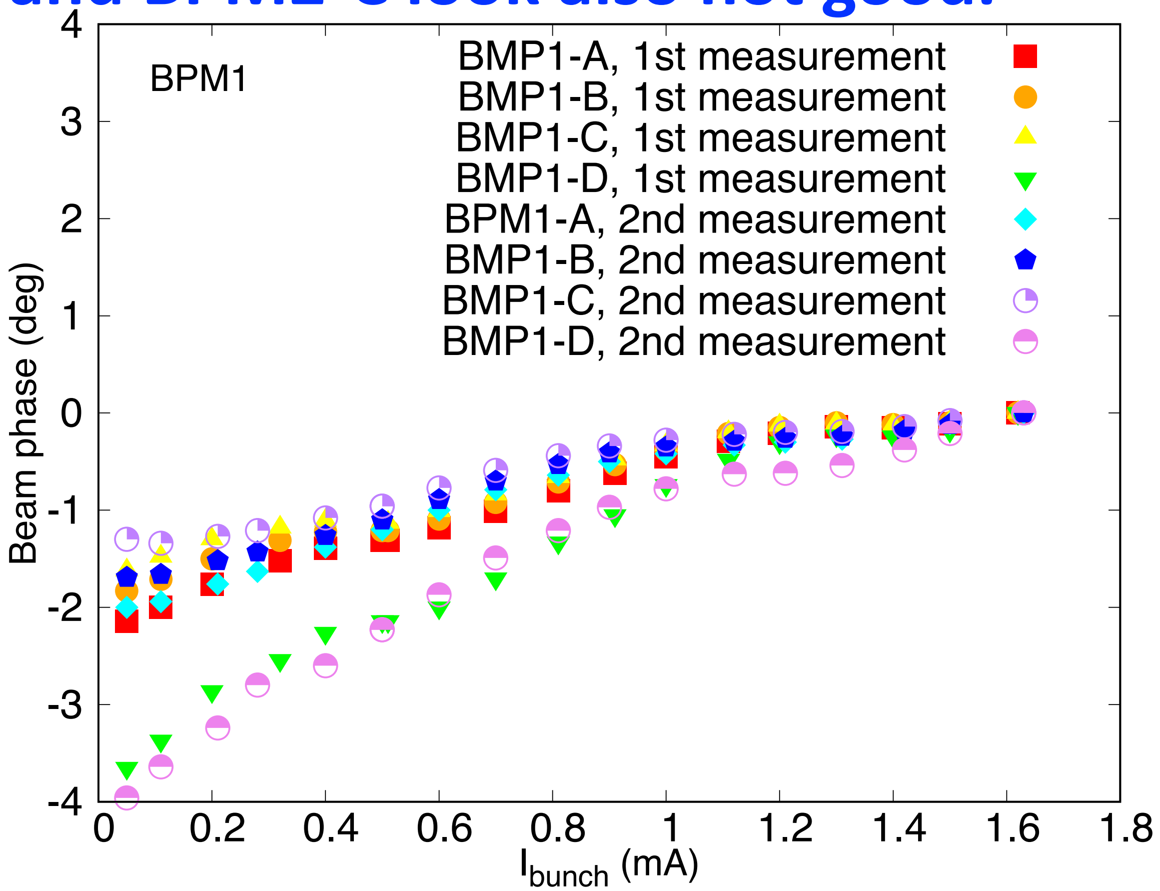


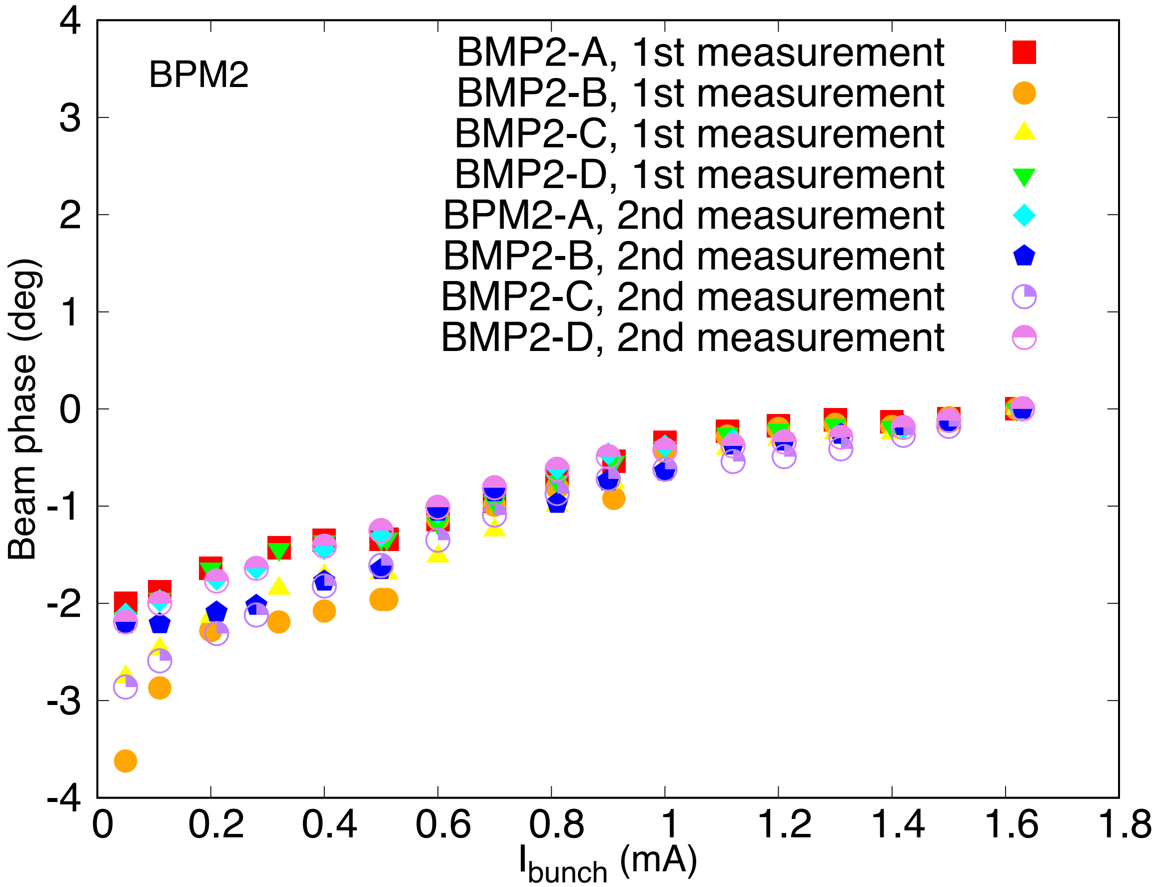
2. Beam phase measurements in KEKB LER

➤ LER (2009.10.26): nominal bunch length 4.6mm

● Then we assume that the bunch has the same RF phase at highest current, then we have the following plots by subtracting the phase at the right-most for each BPM button. In this case we accept that the deviations in beam phase scale as the bunch current. (I think) This is the most reasonable assumption we could make.

● Then we can tentatively ignore data with unreasonably large deviations: BPM1-D (1st & 2nd measurement), BPM2-B (1st & 2nd measurement). BPM1-C and BPM2-C look also not good.



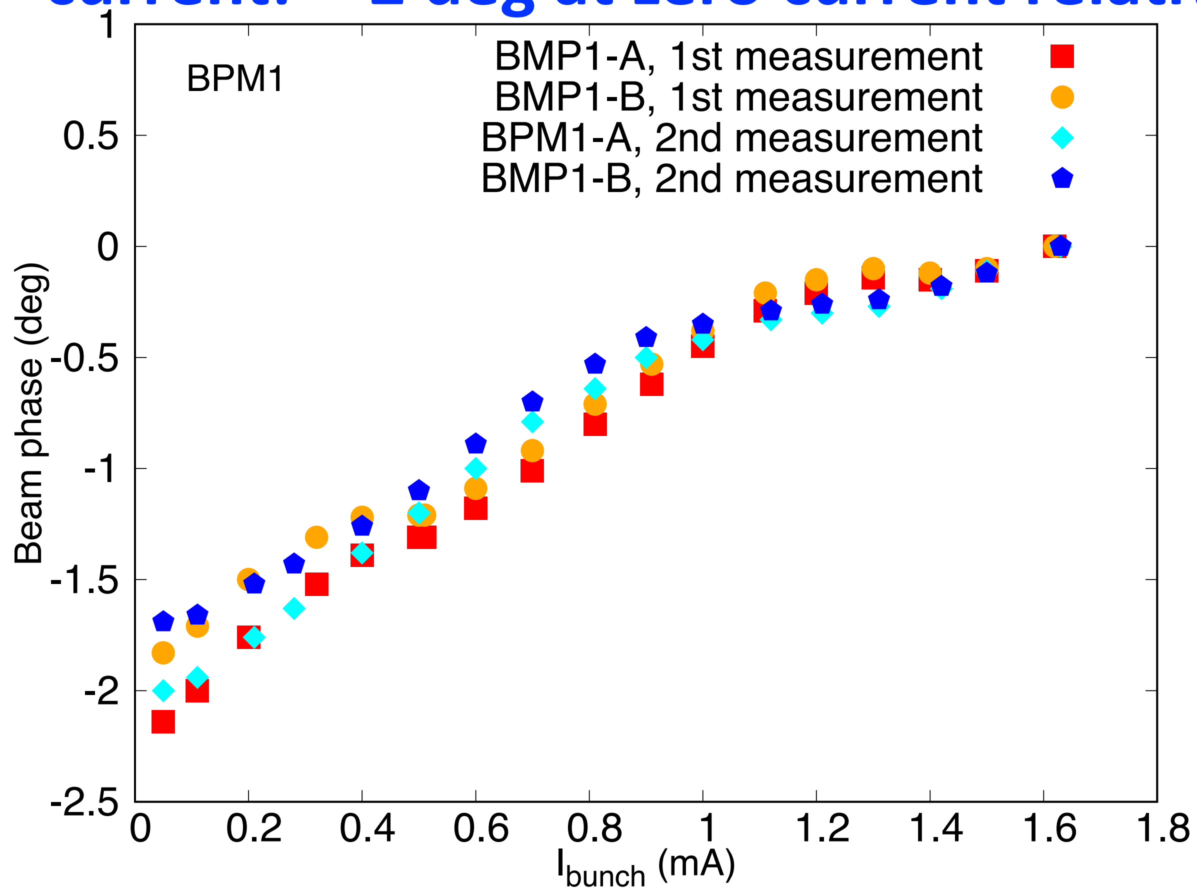


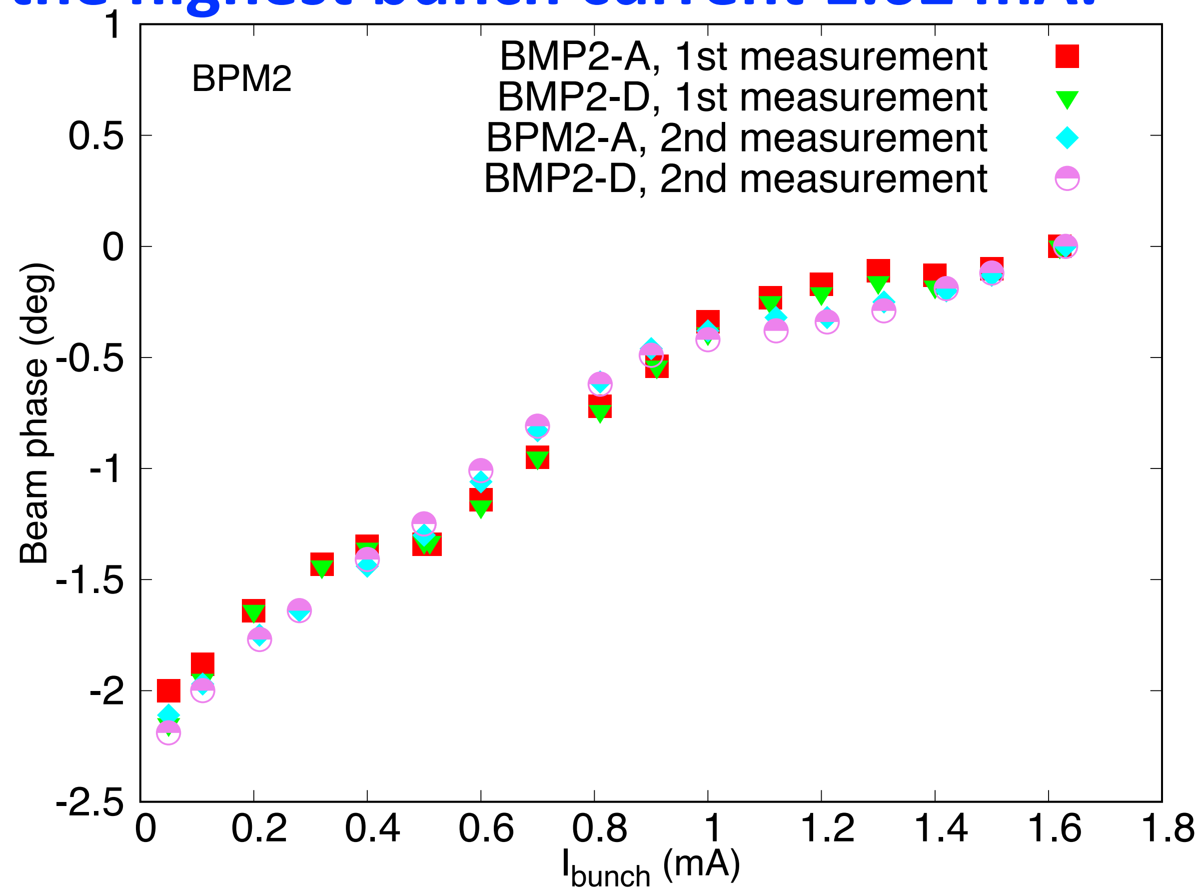
2. Beam phase measurements in KEKB LER

➤ LER (2009.10.26): nominal bunch length 4.6mm

● Now we have the "trustable" data as plotted in the following. The 8 sets of data look fairly consistent with each other(?).

● But the data are still doubtful in one point: there seems to be some saturation in the beam phase at currents higher than 1.2 mA. We might say it is from significant bunch lengthening. But there is also possibility of saturation in the BPM gain (The BPM gain might not be properly set for I_{bunch} >1.2 mA). Anyway, this does not influence our judgement of the beam phase at lowest current: ~-2 deg at zero current relative to the highest bunch current 1.62 mA.





2. Beam phase measurements in KEKB LER

➤ LER (2009.10.26): nominal bunch length 4.6mm

- **Source data: First measurement**

Ib	BPM1-A	BPM1-B	BPM1-C	BPM1-D	BPM2-A	BPM2-B	BPM2-C	BPM2-D
0.05	89.41	-45.72	-80.70	-80.24	-129.98	91.23	-163.12	-124.27
0.11	89.55	-45.6	-80.56	-79.96	-129.86	91.98	-162.83	-124.07
0.2	89.79	-45.39	-80.38	-79.45	-129.62	92.57	-162.5	-123.76
0.32	90.03	-45.20	-80.26	-79.13	-129.41	92.66	-162.21	-123.56
0.4	90.16	-45.11	-80.19	-78.85	-129.33	92.77	-162.08	-123.48
0.5	90.24	-45.1	-80.21	-78.73	-129.32	92.89	-162.05	-123.45
0.51	90.24	-45.1	-80.21	-78.73	-129.32	92.89	-162.05	-123.45
0.6	90.37	-44.98	-80.09	-78.59	-129.12	93.72	-161.88	-123.29
0.7	90.54	-44.81	-79.92	-78.29	-128.93	93.86	-161.61	-123.07
0.81	90.75	-44.6	-79.74	-77.92	-128.7	94.04	-161.36	-122.86
0.91	90.93	-44.42	-79.56	-77.64	-128.52	93.93	-161.12	-122.66
1.	91.1	-44.27	-79.41	-77.33	-128.32	94.41	-160.95	-122.51
1.11	91.26	-44.1	-79.28	-77.07	-128.21	94.57	-160.77	-122.37
1.2	91.34	-44.04	-79.21	-76.89	-128.15	94.65	-160.68	-122.33
1.3	91.41	-43.99	-79.19	-76.82	-128.09	94.69	-160.61	-122.28
1.4	91.4	-44.01	-79.21	-76.83	-128.11	94.67	-160.61	-122.3
1.5	91.44	-43.99	-79.17	-76.77	-128.08	94.76	-160.53	-122.24
1.62	91.55	-43.89	-79.08	-76.59	-127.98	94.85	-160.36	-122.12

2. Beam phase measurements in KEKB LER

➤ **LER (2009.10.26): nominal bunch length 4.6mm**

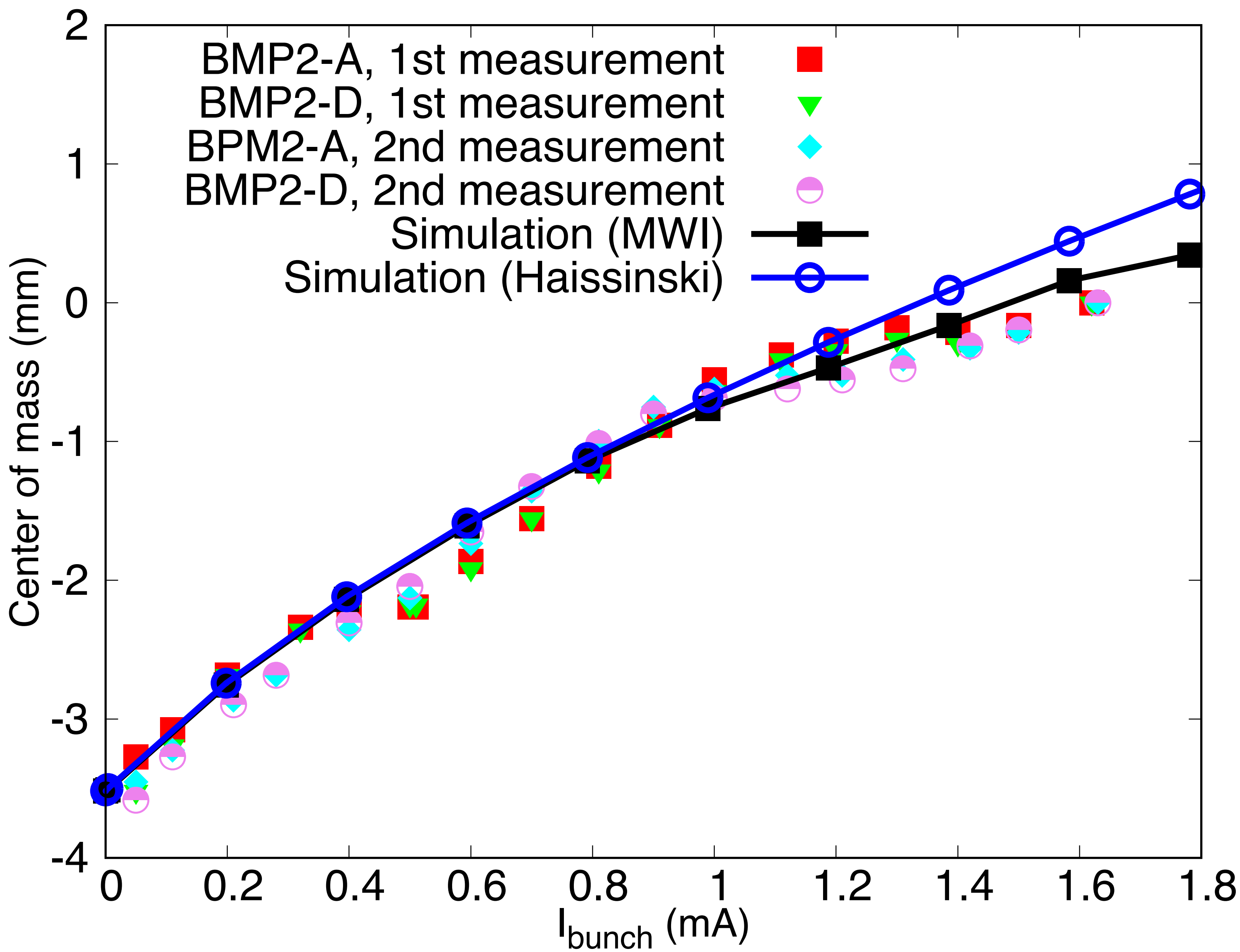
- Source data: Second measurement

Ib	BPM1-A	BPM1-B	BPM1-C	BPM1-D	BPM2-A	BPM2-B	BPM2-C	BPM2-D
0.05	89.62	-45.6	-80.39	-80.6	-130.04	92.67	-163.11	-124.29
0.11	89.68	-45.57	-80.43	-80.28	-129.90	92.67	-162.84	-124.1
0.21	89.86	-45.43	-80.36	-79.88	-129.68	92.79	-162.56	-123.87
0.28	89.99	-45.34	-80.3	-79.44	-129.57	92.86	-162.37	-123.74
0.4	90.24	-45.17	-80.17	-79.24	-129.37	93.11	-162.07	-123.51
0.5	90.42	-45.01	-80.05	-78.87	-129.23	93.23	-161.86	-123.35
0.5	90.42	-45.01	-80.05	-78.87	-129.23	93.23	-161.86	-123.35
0.6	90.62	-44.8	-79.86	-78.51	-128.99	93.83	-161.6	-123.11
0.7	90.83	-44.61	-79.68	-78.13	-128.76	94.03	-161.34	-122.91
0.81	90.98	-44.44	-79.53	-77.85	-128.54	93.91	-161.12	-122.72
0.9	91.12	-44.32	-79.43	-77.61	-128.39	94.14	-160.97	-122.59
1.	91.2	-44.26	-79.37	-77.42	-128.31	94.24	-160.87	-122.52
1.12	91.29	-44.2	-79.31	-77.27	-128.25	94.51	-160.79	-122.48
1.21	91.32	-44.17	-79.29	-77.26	-128.25	94.55	-160.74	-122.44
1.31	91.35	-44.15	-79.28	-77.18	-128.18	94.62	-160.66	-122.39
1.42	91.43	-44.09	-79.23	-77.02	-128.13	94.71	-160.52	-122.29
1.5	91.51	-44.03	-79.17	-76.85	-128.06	94.75	-160.43	-122.22
1.63	91.62	-43.91	-79.09	-76.64	-127.93	94.88	-160.25	-122.1

2. Beam phase measurements in KEKB LER

➤ **LER (2009.10.26): nominal bunch length 4.6mm**

- **Compare with MWI simulation (using Y. Cai's Vlasov solver)**
- **Beam phase at zero current taken as -2.15 deg (extracted from experimental data)**



3. HOM power in KEKB LER

➤ The 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@Vc=0.5 MV
- The calibration factor k for klystron is determined by $P_{beam}(I_{beam}=0)=0$

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

Note: Summation is done for all klystrons and RF cavities

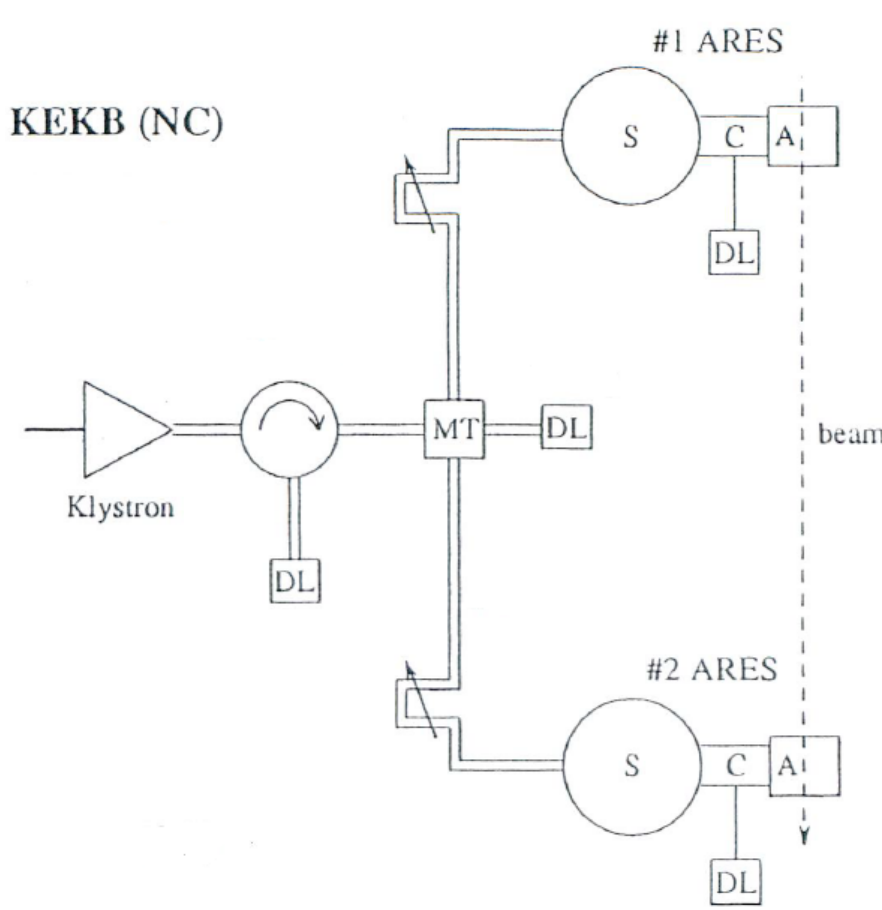
Logged data:

$P_{klystron}$: Klystron output power

$P_{reflection}$: Power reflected from RF cavity

$P_{coupling}$: Power to DL (dummy load?)

$P_{RFinput}$: Input power to RF cavity



K. Akai, KEKB ARC 1999

3. HOM power in KEKB LER

➤ The method

- Total beam power = P_{SR} (SR power) + P_{HOM} (HOM power) = V_{rf} Sin[ϕ_{rf}]
- P_{SR}=U_0 I_{beam} (U_0 can be calculated from lattice model)
- Loss factor can the extracted from P_{HOM} or ϕ_{rf}

KEKB LER:

$$U_0 = 1.6369316 MV \quad E_0 = 3.5 GeV$$

$$P_{beam} = P_{SR} + P_{HOM}$$

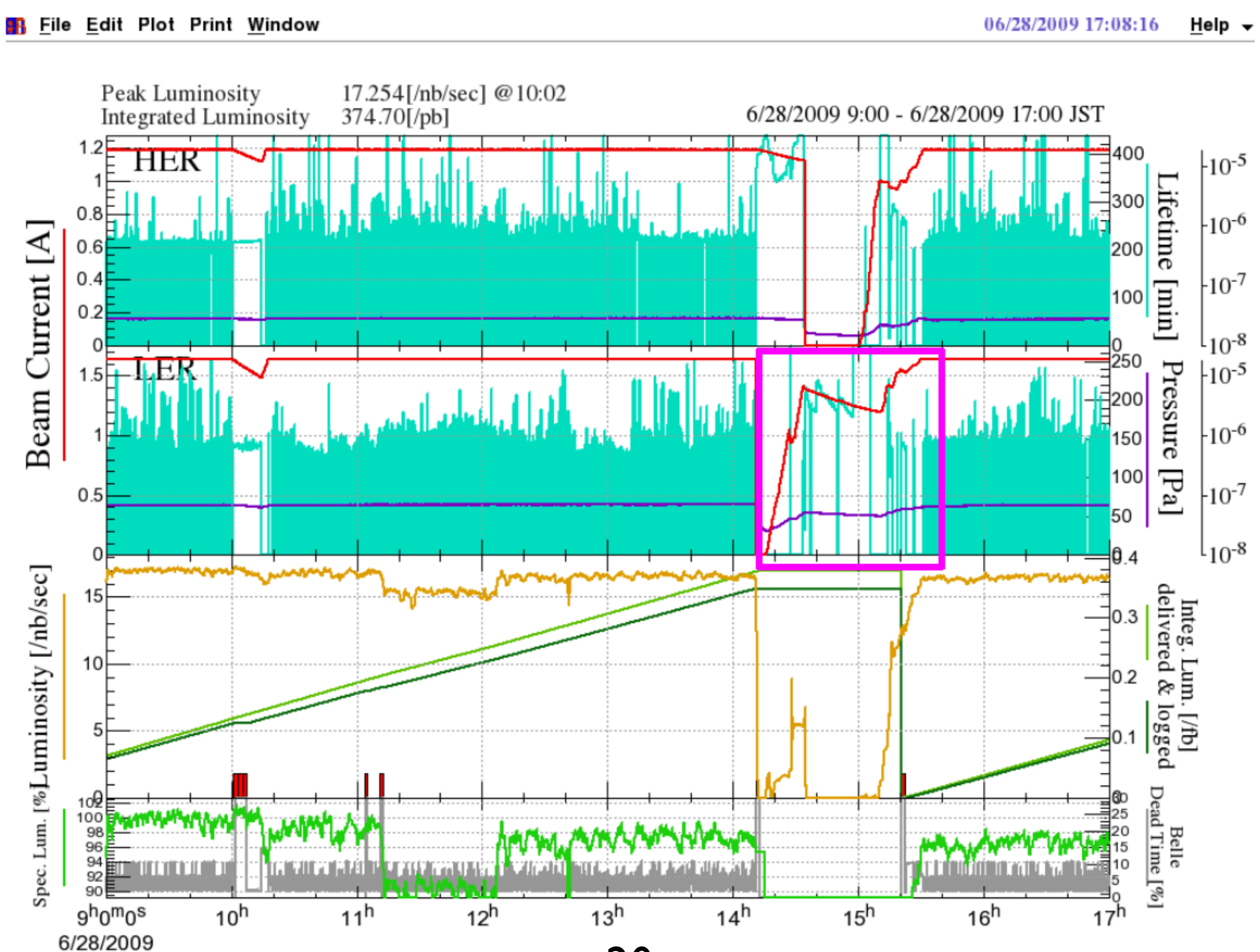
$$P_{SR}[kW] = U(E)[MV] \cdot I_{beam}[mA] = U_0[MV] \cdot \left(\frac{E}{E_0}\right)^4 \cdot I_{beam}[mA]$$

$$P_{HOM} = \kappa_{||}(\sigma_s) \cdot \frac{I_{beam}^2}{N_b} \cdot T_0$$

3. HOM power in KEKB LER

➤ The method

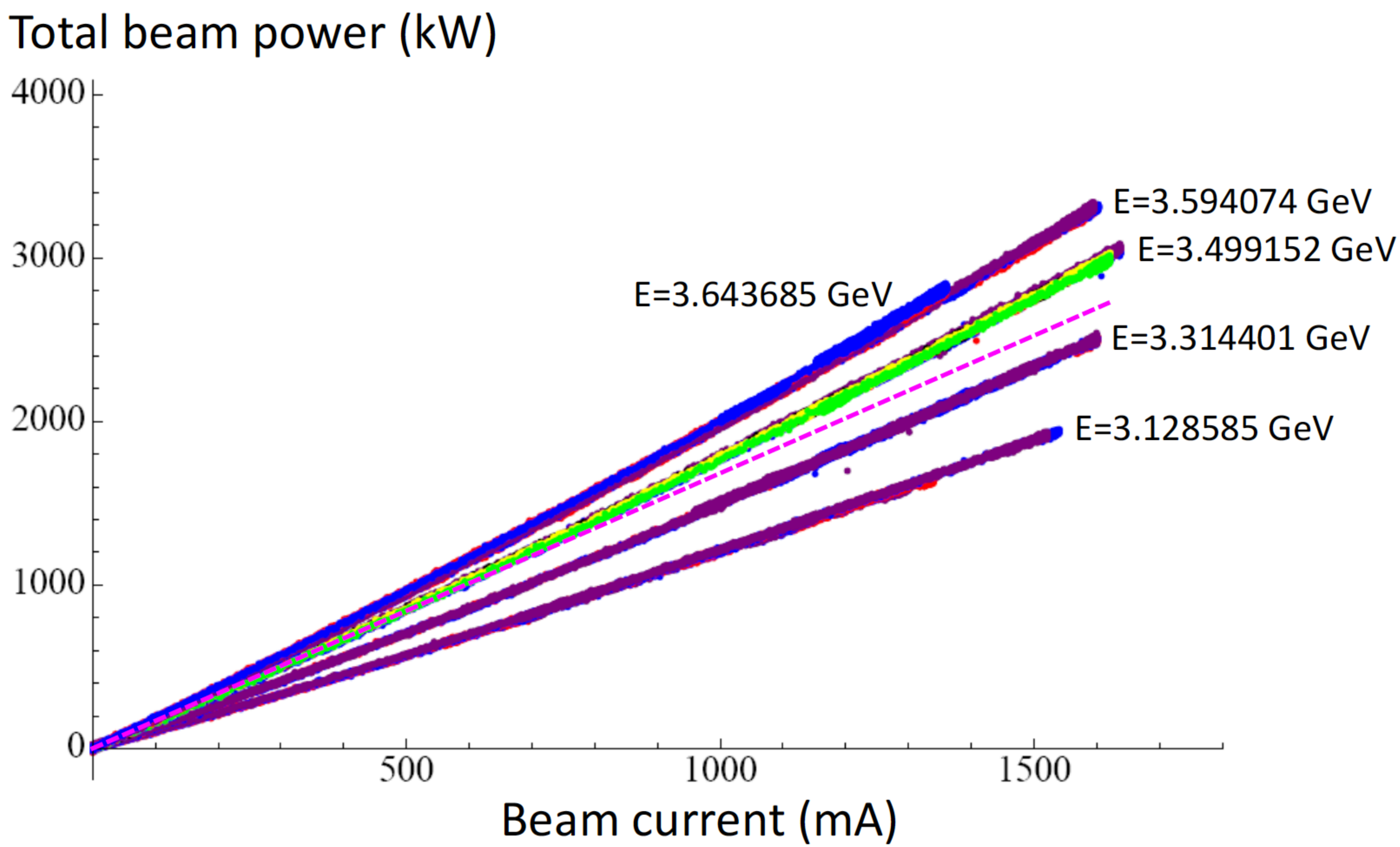
- Beam current dependent power can be found from beam injection to the rings (after beam abort)
- For physics run in 2008 and 2009 the typical number of bunches is N_{bunch}=1584+1 (one pilot bunch)
- We assume bunch current is uniform along the bunch train (this is true because of injection optimization
- Bunch spacing is ~3-4 RF bucket



3. HOM power in KEKB LER

➤ Beam power

- **Beam power depends on beam energy**
- **SR power linearly dependent on beam current**



3. HOM power in KEKB LER

➤ Scaling laws for machine parameters

$$U_0 = C_\gamma \frac{E^4}{\rho} \propto E^4$$

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

$$U_0 = V_{\rm rf}\sin\phi_s$$

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

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

3. HOM power in KEKB LER

➤ Scaled machine parameters of KEKB LER

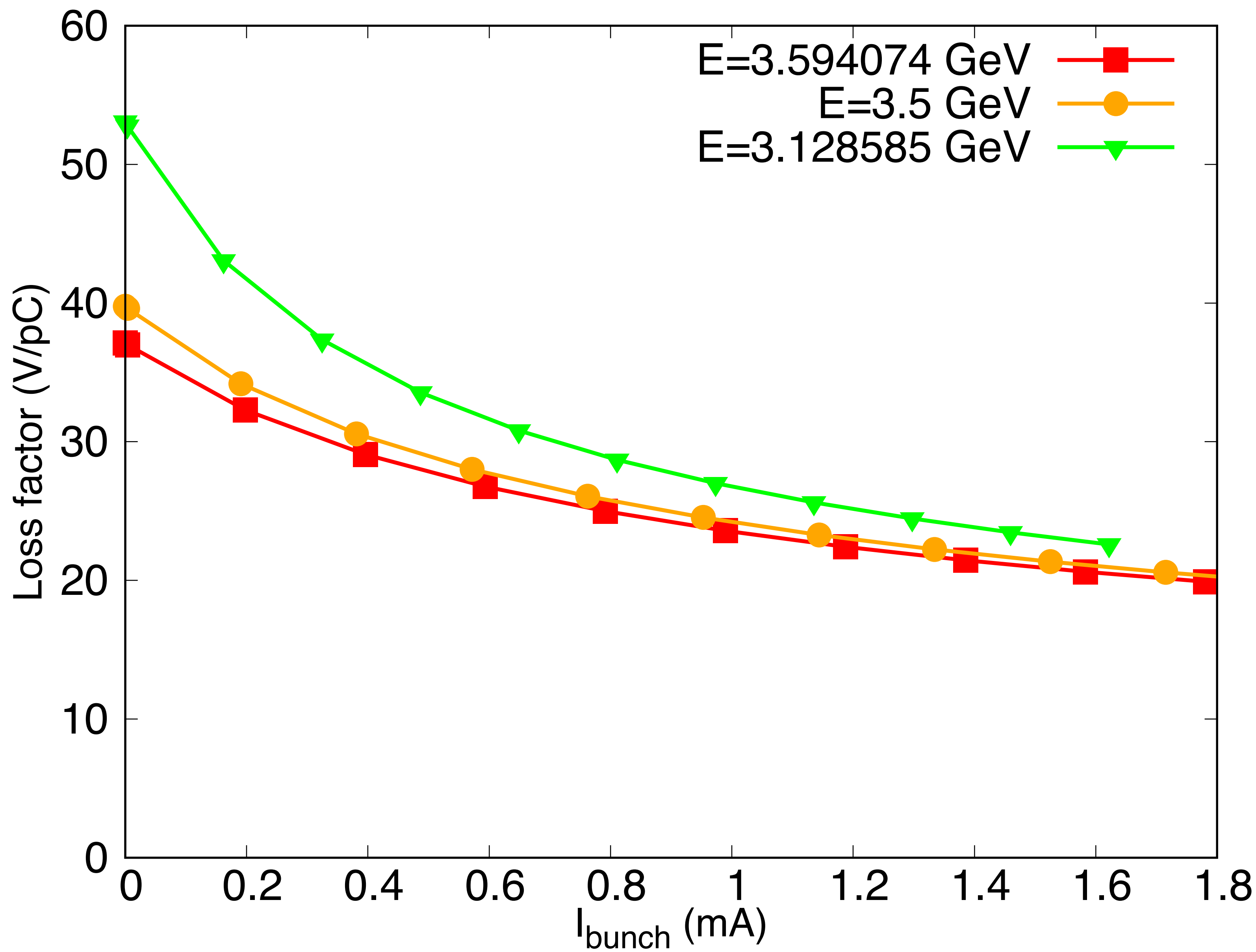
- Assume the KEKB operation followed the scaling laws over beam energy
- This assumption needs to be validated

Beam energy [GeV]	3.594074	3.5	3.314401	3.128585
RF voltage [MV]	8	8	8	8
SR loss [MeV/turn]	1.82015	1.636932	1.31637	1.04508
Nominal bunch length [mm]	4.78	4.58	4.20	3.85
Synch. tune	0.0236224	0.024	0.0247575	0.0255474
Energy spread [10^{-4}]	7.46541	7.27	6.88448	6.49852
Long. damping time [ms]	20.716	21.6	25.436	30.242
Circumference [m]	3016.25	3016.25	3016.25	3016.25
RF phase [deg]	13.15	11.81	9.47	7.51

3. HOM power in KEKB LER

➤ Expected loss factor vs. bunch current for KEKB LER

- Use the same Pseudo-Green function wake
- Use Y. Cai's VFP solver for simulation
- Loss factor calculated from simulated bunch profile (Haissinski solution)

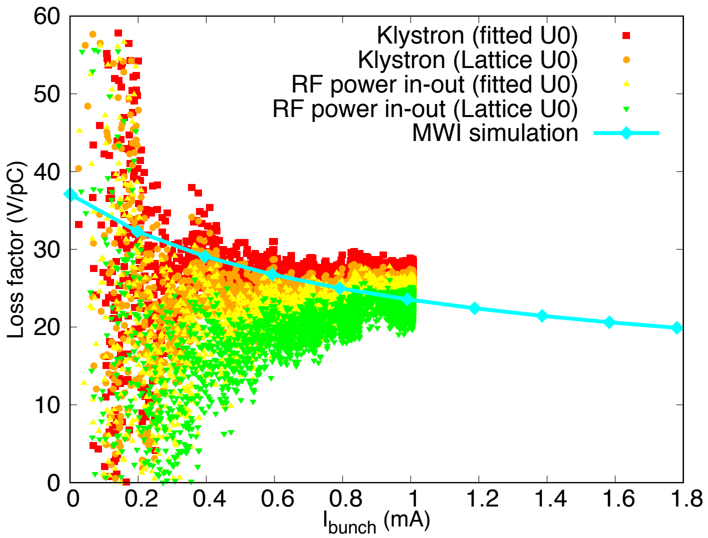


3. HOM power in KEKB LER

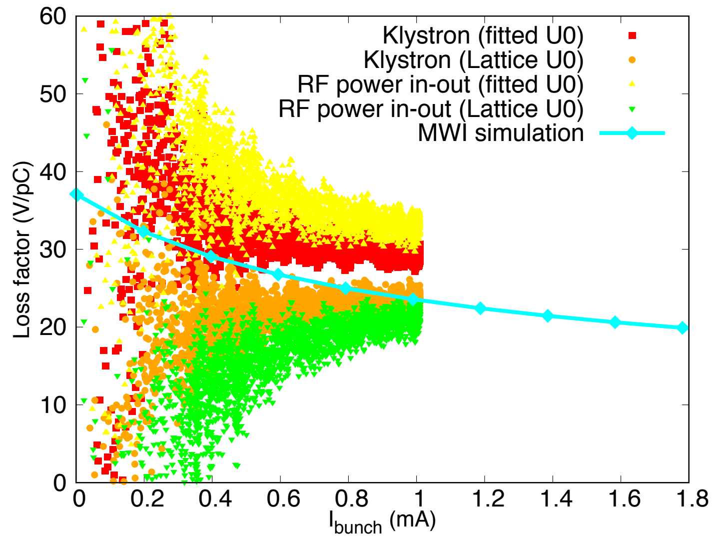
➤ HOM power (E=3.594074 GeV)

- **Extracting the SR power using polynomial fitting (taking the linear part) is not a good idea**
- **On the other hand, using U_0 given by lattice model looks much better (better reproducibility)**

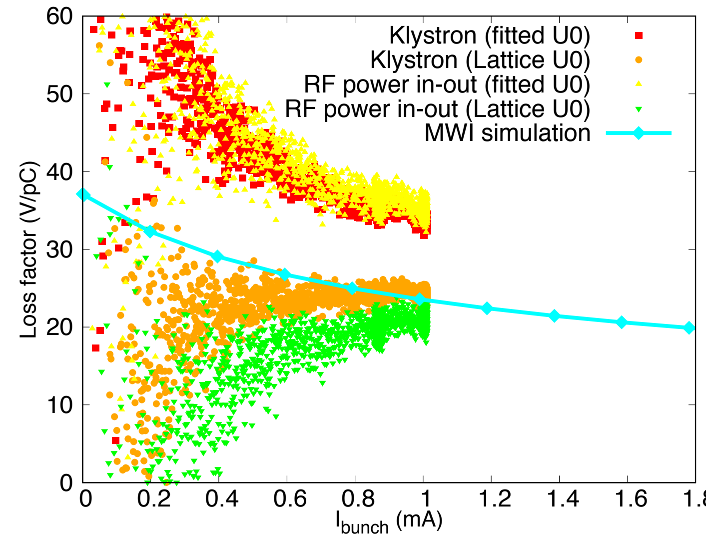
2009.05.01



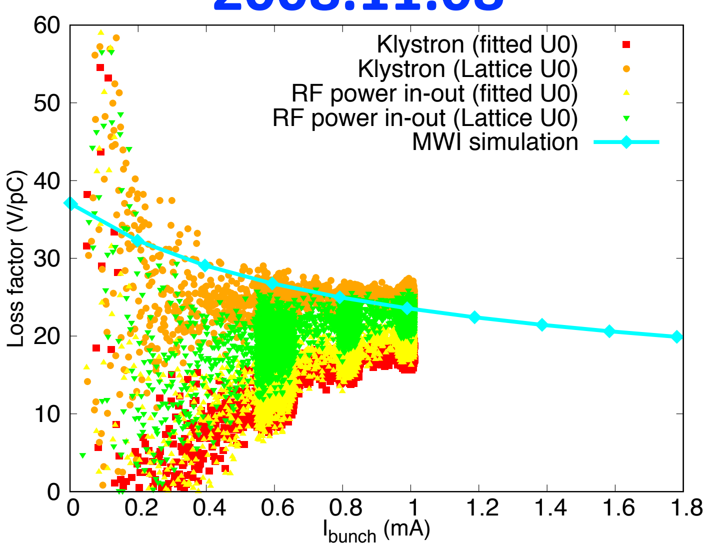
2009.05.24



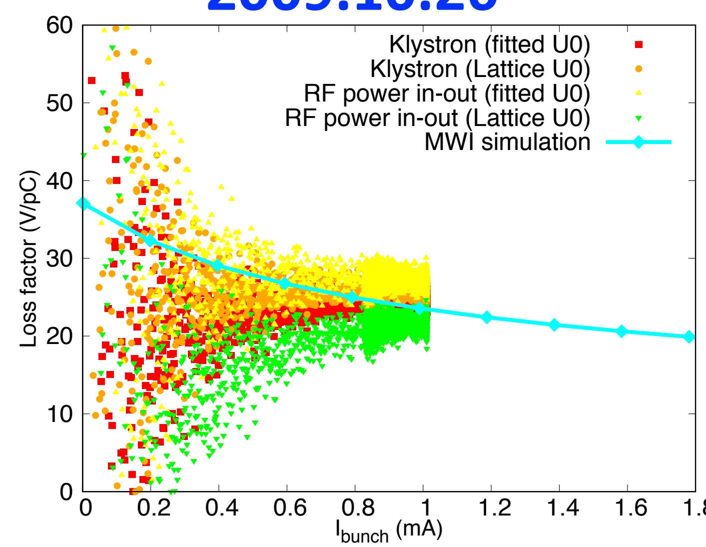
2009.06.15



2008.11.08



2009.10.26



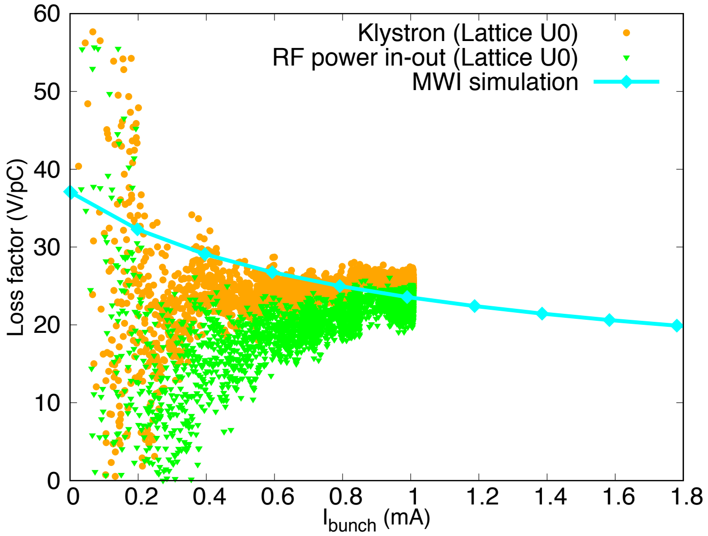
3. HOM power in KEKB LER

➤ HOM power (E=3.594074 GeV)

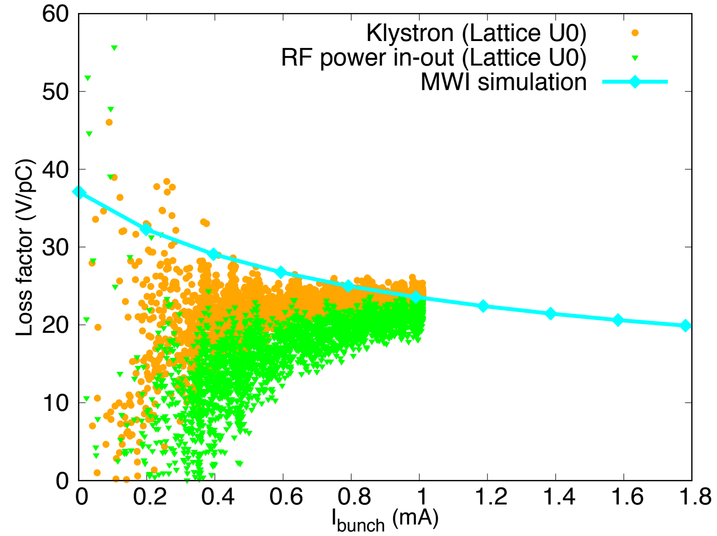
- The reproducibility of the HOM power vs. beam current is good
- But data from Klystron and RF input power are not consistent (reasons?)
- There might be systematic errors not identified => Possible candidates: 1)

Klystron calibration factor k; 2) SR radiation U_0; 3) Others?

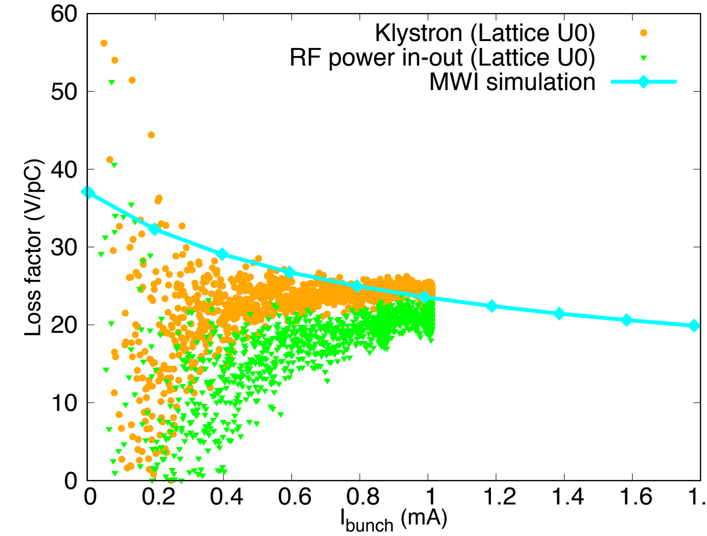
2009.05.01



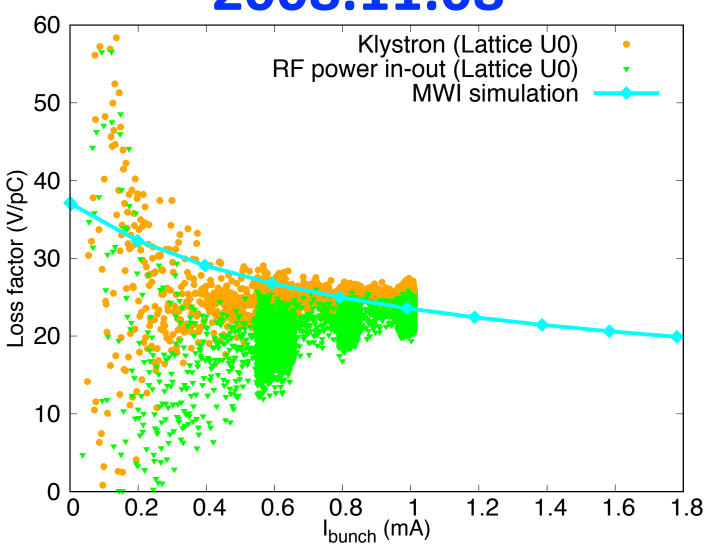
2009.05.24



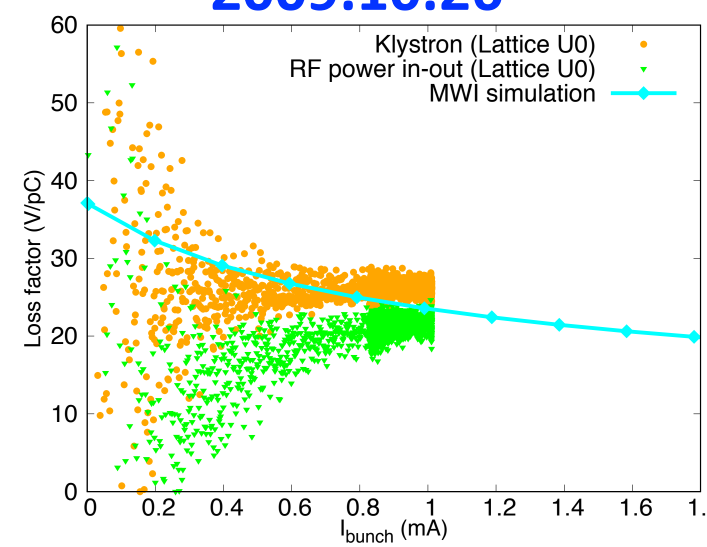
2009.06.15



2008.11.08



2009.10.26

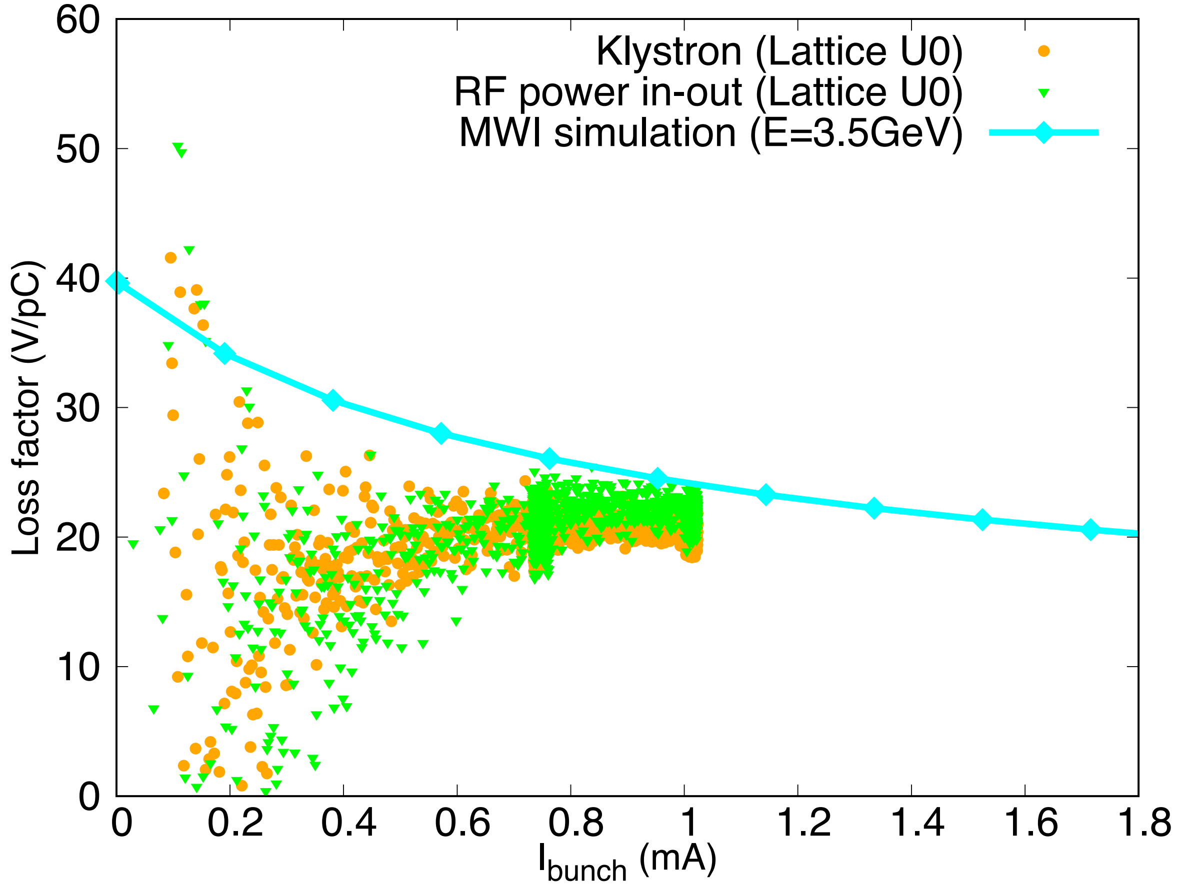


3. HOM power in KEKB LER

➤ HOM power (E=3.498821 GeV)

- **How to understand the slope of HOM power data?**
- **Total voltage to be checked**

2008.05.02

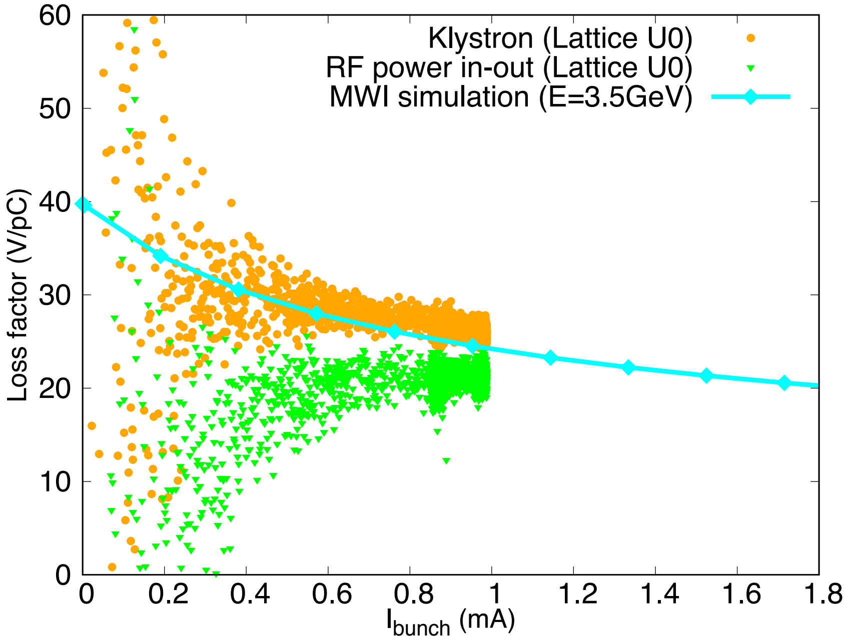


3. HOM power in KEKB LER

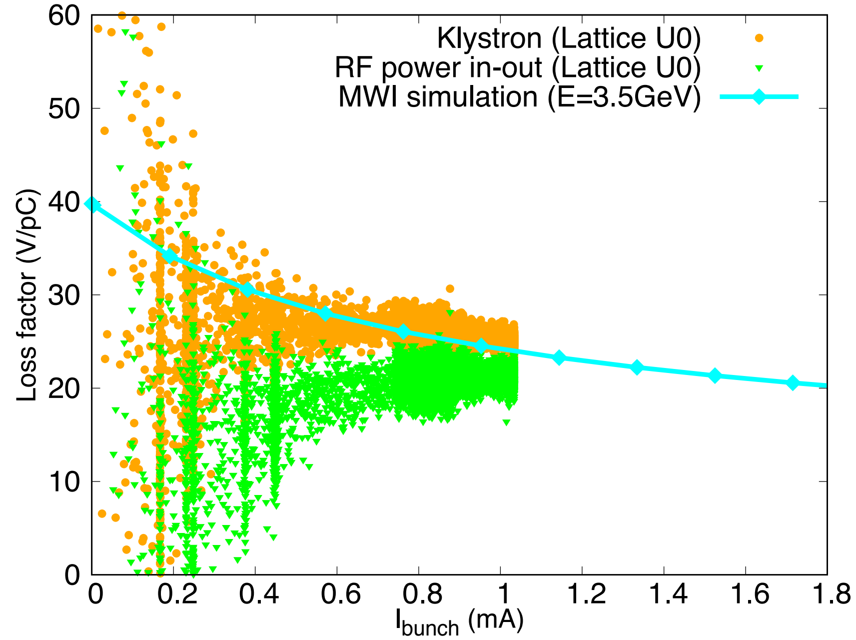
➤ HOM power (E=3.478613 GeV)

- **HOM power agree with expectation of impedance model?**
- **Total voltage to be checked**

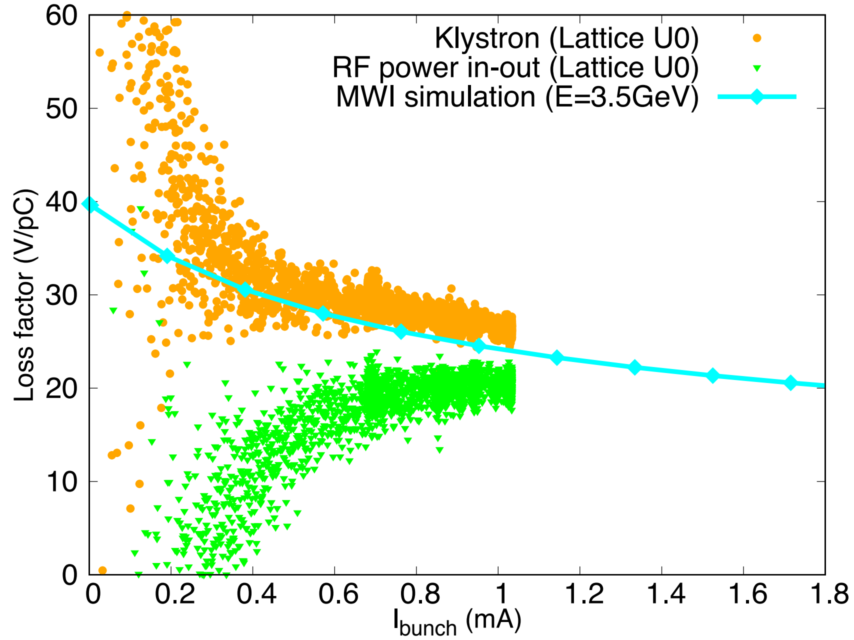
2009.06.27



2009.06.27 (22PM)



2009.06.28

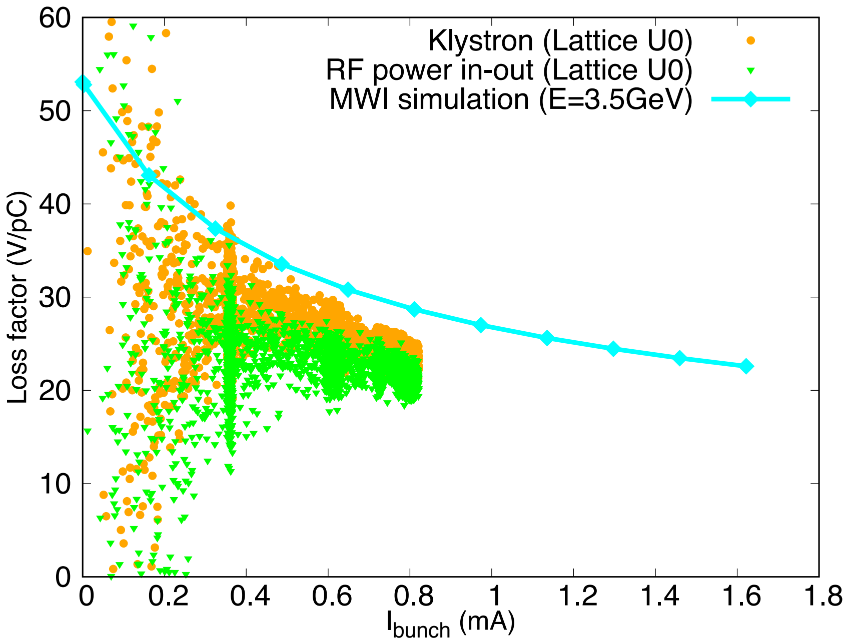


3. HOM power in KEKB LER

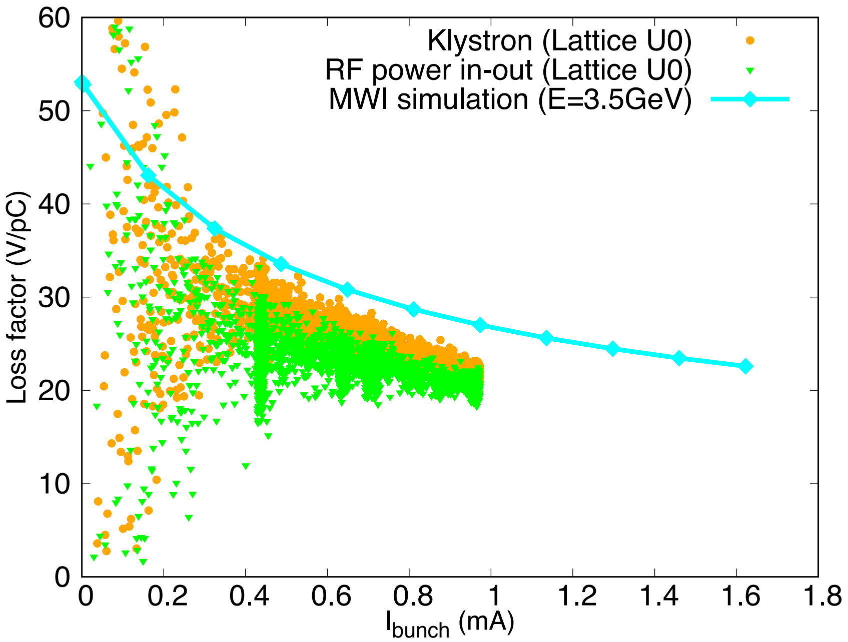
➤ HOM power (E=3.128585 GeV)

- HOM power agree with expectation of impedance model?
- Total voltage to be checked

2008.06.16



2009.06.29



2009.06.30