Wakefield effect in ATF2

Kiyoshi Kubo

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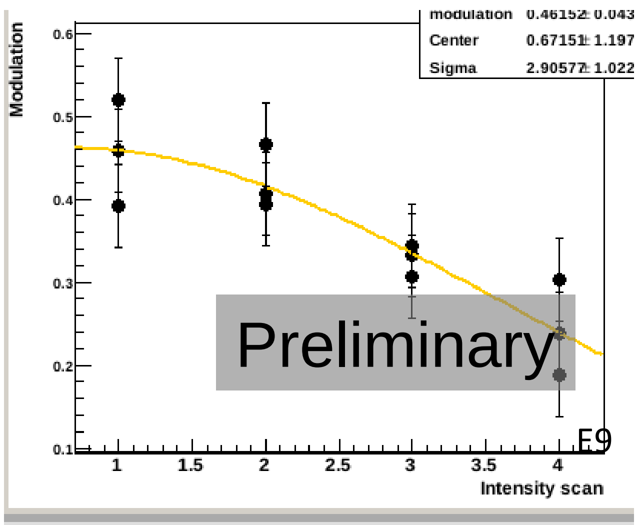
Why discuss wakefield in ATF2?

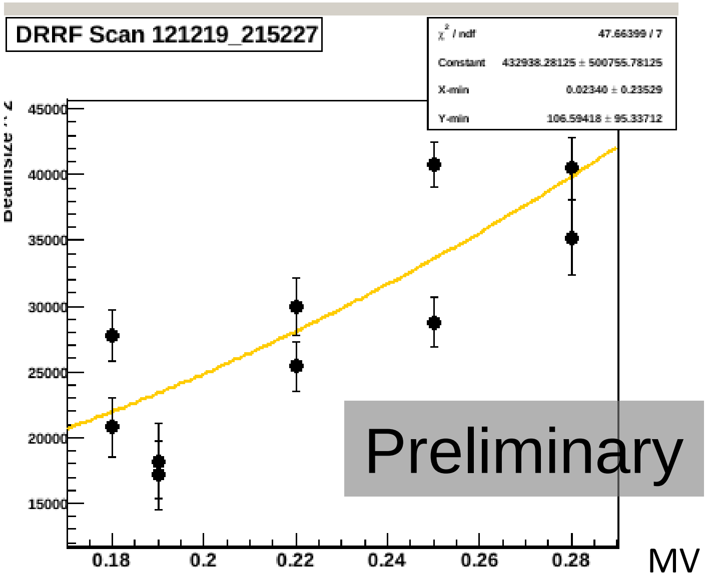
- We observed ~70 nm beam size last December, but only at very low intensity.
- There was strong intensity dependence of beam size.

Intensity dependence measured in Dec. 2012

IPBSM modulation (30 deg.)
vs. bunch intensity



beamsize^2 (IPBSM 30 deg.)
vs. DR RF voltage (bunch length)



Beam size depended on bunch charge and
bunch length (which may mean longitudinal charge density)

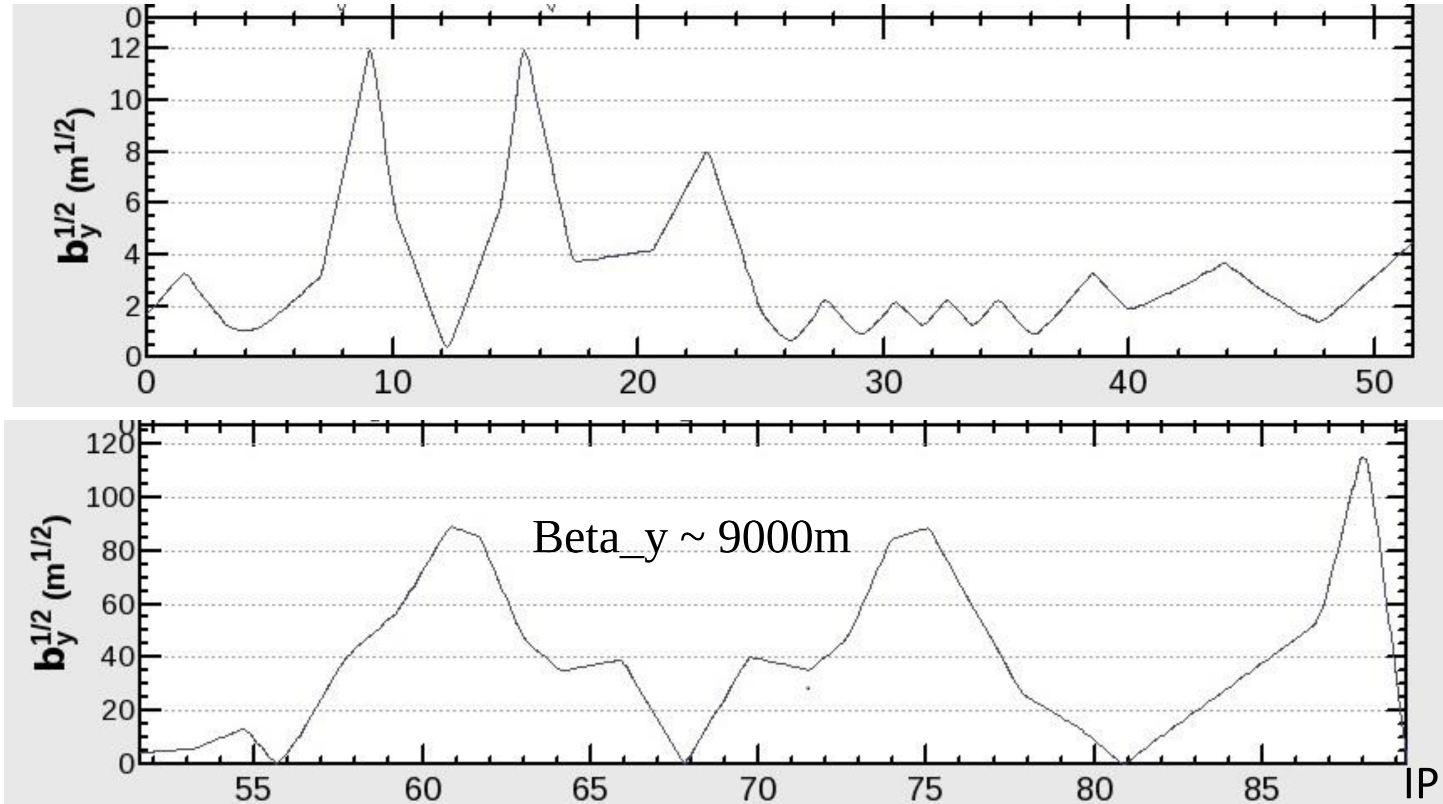
$$M = \cos(30°)\exp\left(-\frac{2\pi^2\sigma_y^2}{(\lambda/2\sin(15°))^2}\right)$$

(Assuming perfect monitor)

Contents of this report

- Possible wakefield sources in large beta region
- Works in last December
- Tracking simulation with wakefield of Cavity BPMs + Bellows
  - Effect of misalignment
  - Correction by on mover Reference Cavity
  - Effect of orbit distortion
  - Effect of measured beam – Cavity BPM offset
- Experimental observations and comparison with simulations
- Comparison with ILC-BDS
- Future studies

Vertical Beta-function in Extraction and Final Focus Line



Beta_y of the upstream part is much smaller than downstream part.

$$\text{Effect of wakefield} \sim (\text{kick angle})/\sigma_{y'} \propto \Delta y\sqrt{\beta_y} \propto \begin{cases} \sqrt{\beta_y} & (\text{for same } \Delta y) \\ \beta_y & (\text{if } \Delta y \propto \sigma_y \propto \sqrt{\beta_y}) \end{cases}$$

(Transverse kick by dipole mode wakefield)

Possible significant wakefield sources In large beta region in FF line

- Cavity BPM
  - Dipole cavity at every Quadrupole (and sextupole) magnet
  - Reference cavities
- Bellows
  - At both sides of every Quadrupole (and sextupole) magnet
- Vacuum ports, etc.

(Beam pipe inner diameter 24 mm,

Aperture of Dipole cavity 20 mm, Reference cavity 16 mm)

- We removed some of these.
- Experiments and simulations were performed.

Tried to Remove (reduce) possible wakefield sources in high beta region in Dec. 2012

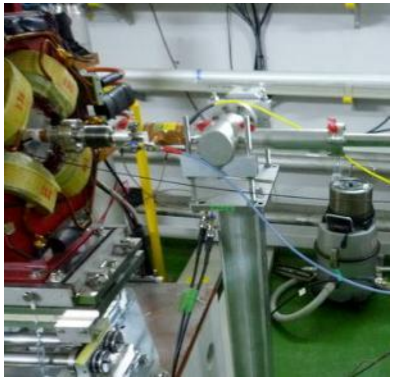
Vacuum ports: replaced by ones with better vertical symmetries

Beam pipe 24 mm (diameter)

Removal of not used 3 Cavity-BPM reference cavities

Cavity aperture 16 mm
(diameter)

Gate valve and S-band Reference cavity : Moved from high beta region to lower beta region

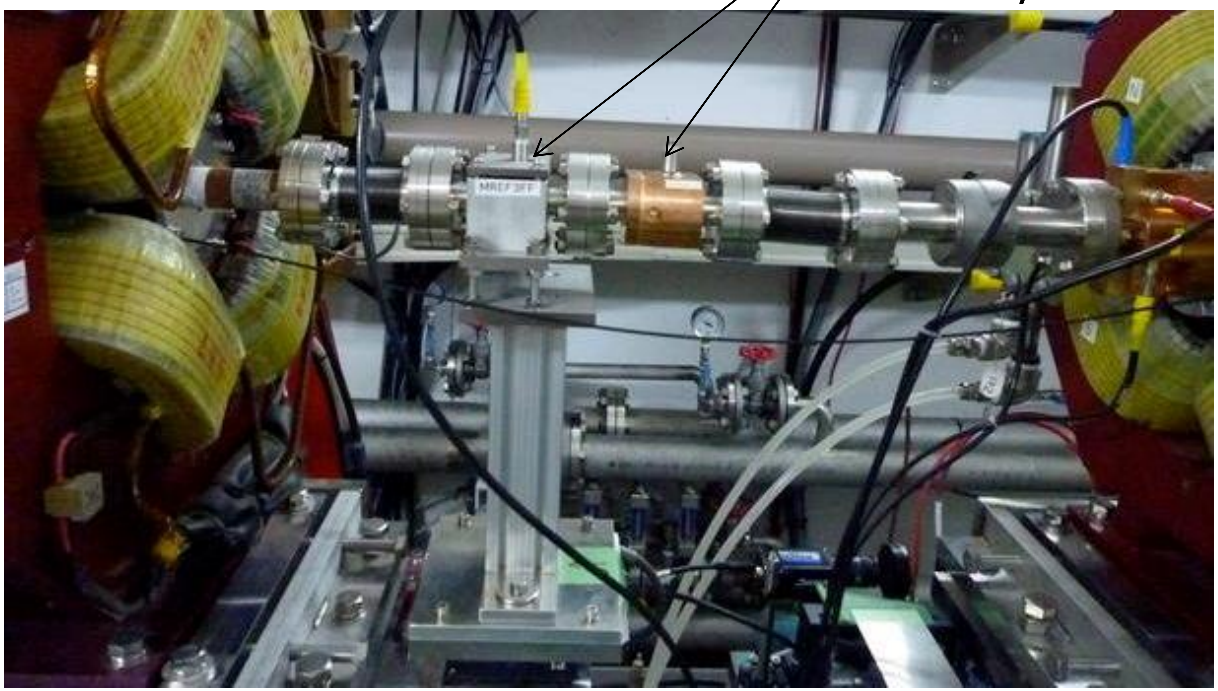


Install Cavity BPM reference cavities on a mover

For investigating effect of Cavity BPM wakefield

Expecting cancellation of wakefield of other locations

C-band reference cavities
(aperture16 mm diameter)
Vertically movable



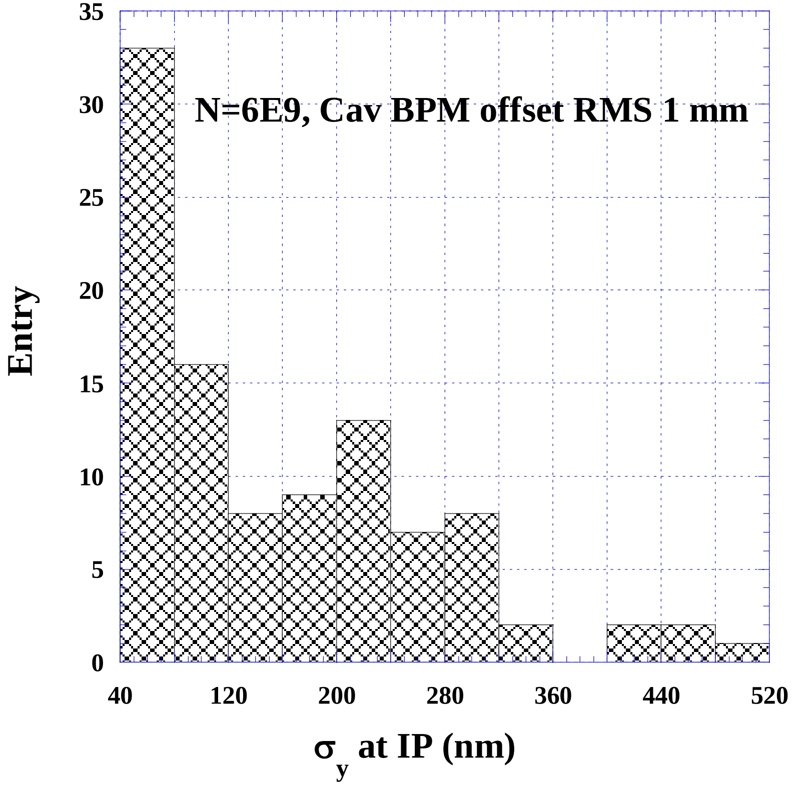
Simulation and experiments of wakefield effect

- Simulation (particle tracking using code SAD)
  - Using wakepotential given by A. Lyapin et.al. (assume bunch length 7 mm)
  - Beam size with random offset of BPMs + bellows
  - Correction by scanning reference cavity on mover
  - Effect of IPBPMs
  - Beam size with orbit distortion
  - Beam size assuming measured beam – Cavity BPM offset
- Experiment: beam size vs. bunch intensity
- Simulation and experiment: response to offset change of the reference cavity on mover
  - Orbit change
  - Beam size at IP

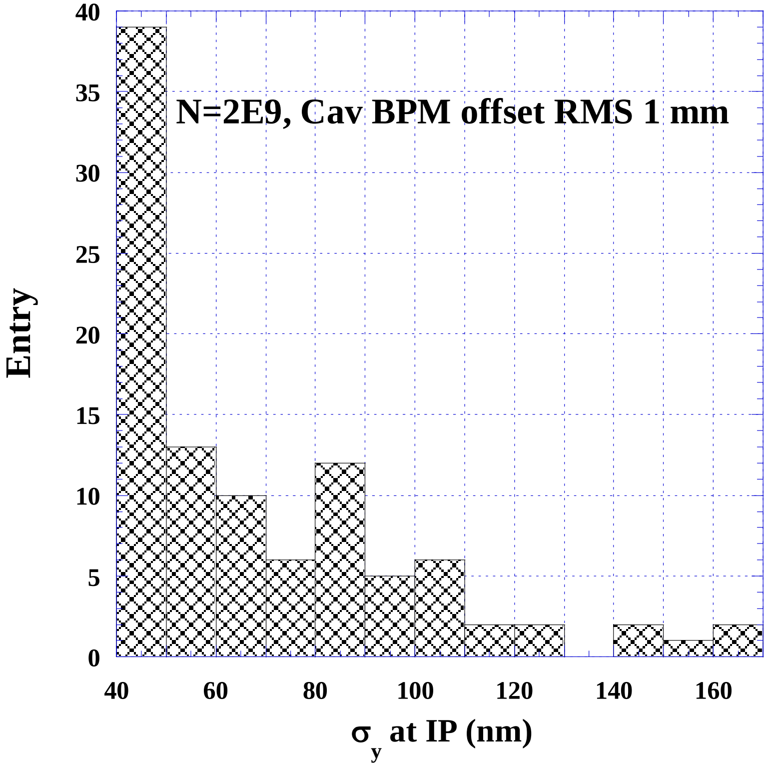
Simulations
(next 8 slides)

Beam size with random offset of cavity BPM + bellows

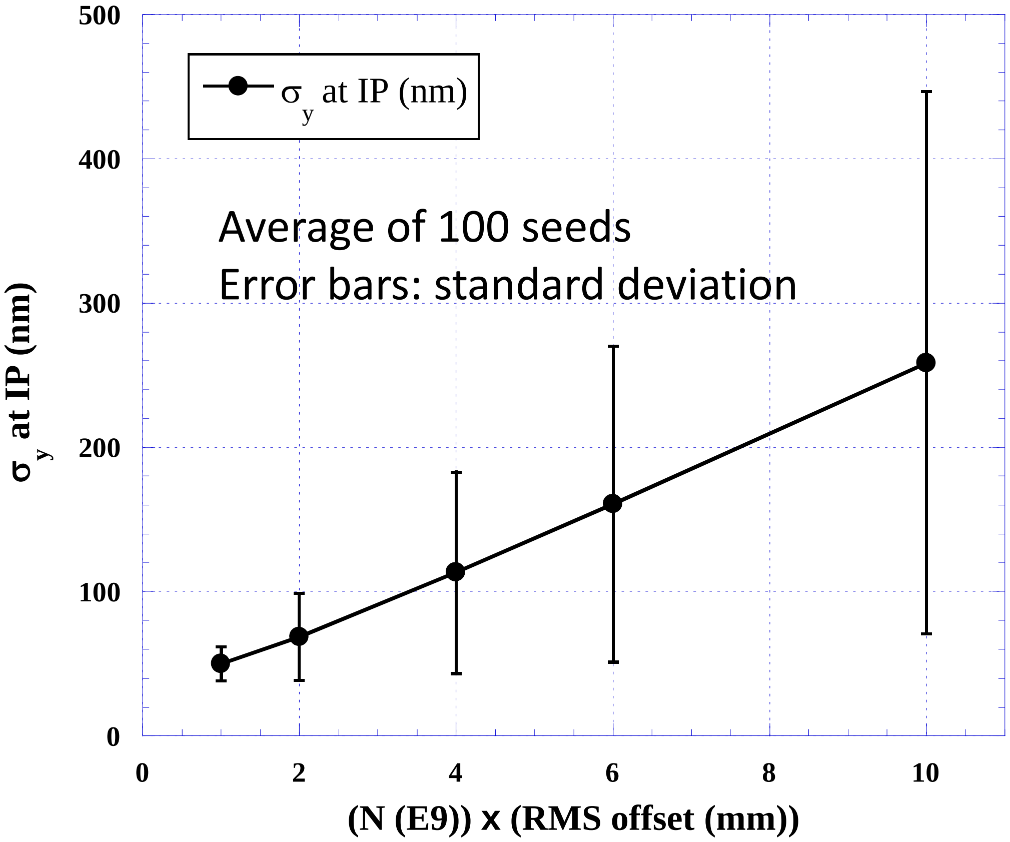
Random Offset RMS 1 mm, N=6E9, 100 random seed



Random Offset RMS 1 mm, N=2E9, 100 random seed

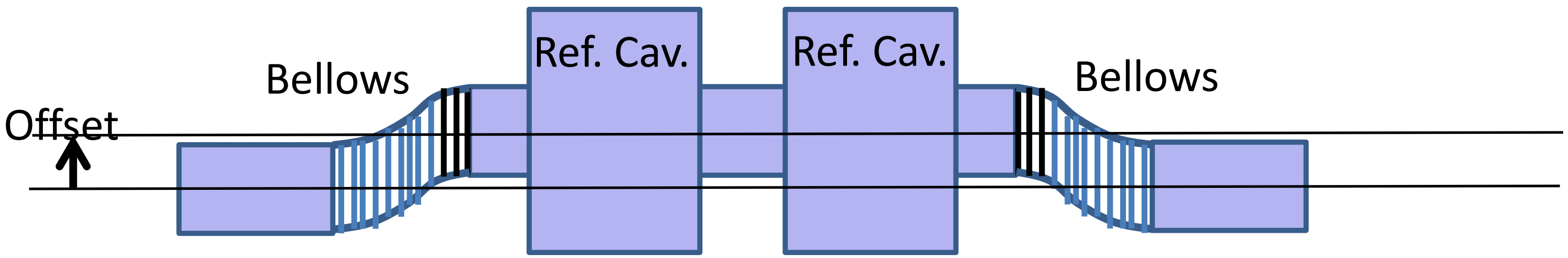


Beam size vs. intensity - simulation
with random offset of cavity BPM + bellows



Reference cavity position scan

Two reference cavities on a vertical mover



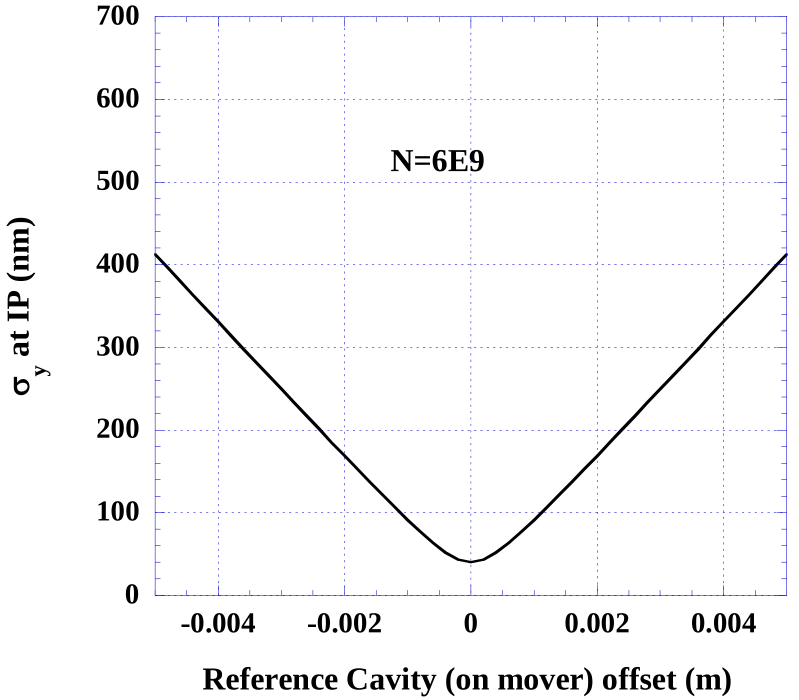
Simulation: Took wakefield of 2 cavities + 1 (half+half) bellows

Wakepotential of cavity BPM, reference cavity and bellows are all approximately resistive (for ATF bunch length).
→ compensation can be expected. (Not perfectly)

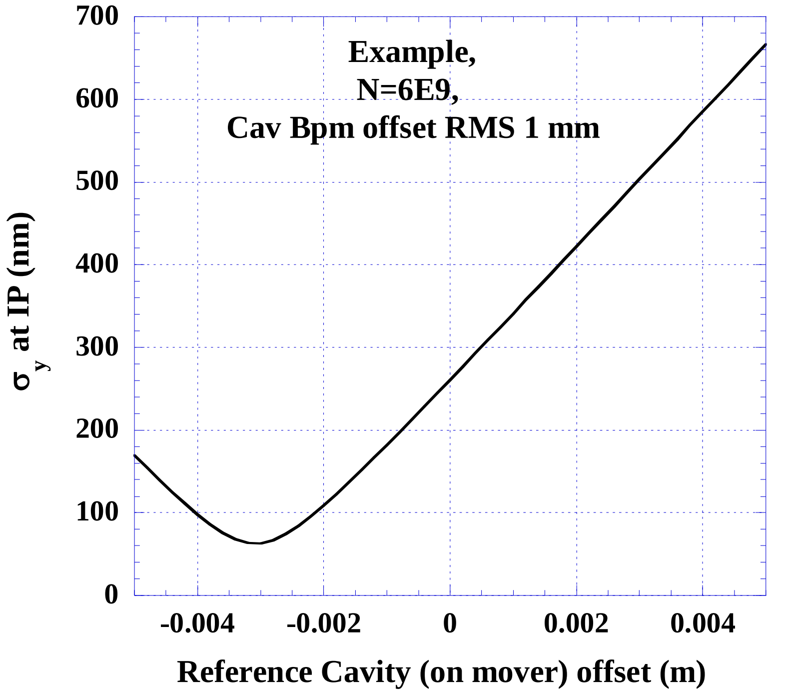
Dependence on reference cavity position

Scan position of a set of 2 C-band reference cavities and one bellows

No other errors



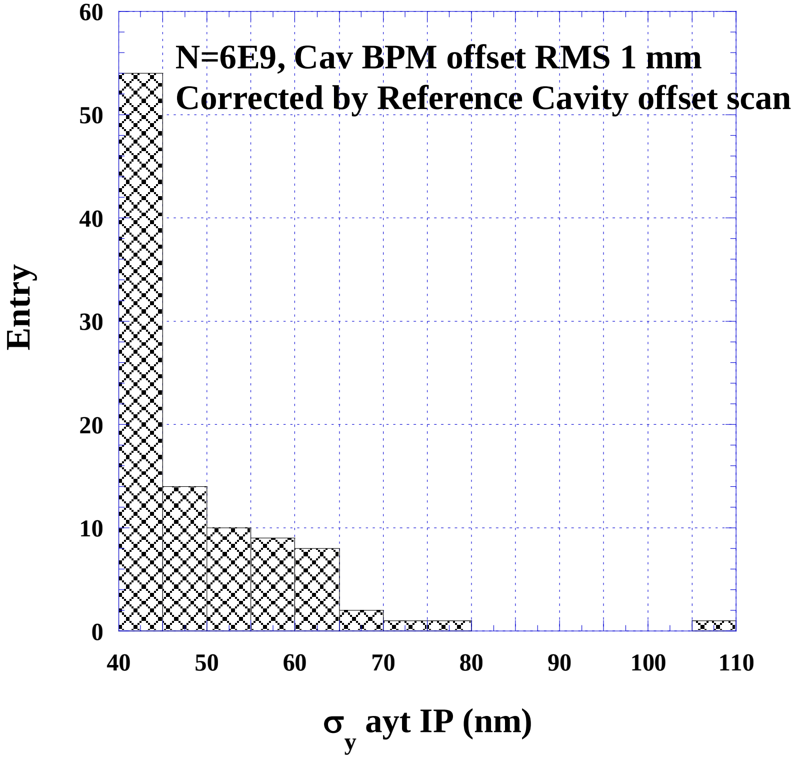
With offset of other cavity BPMs



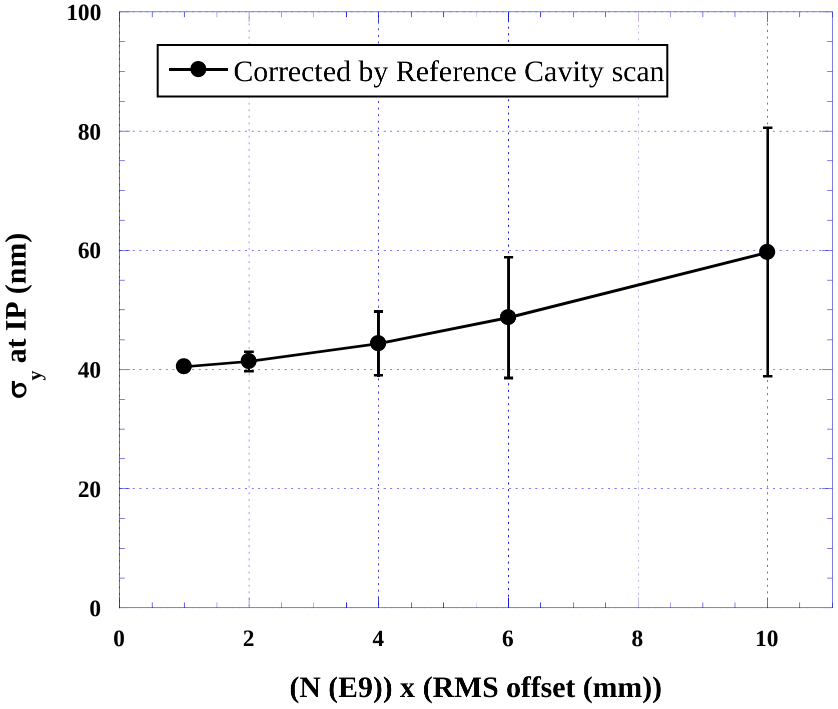
Beam size change ~ 400 nm with 5 mm at N=6E9 → 13 nm/mm/N(E9)

Correction by scanning reference cavity position

Random Offset RMS 1 mm,
N=6E9



Average and standard dev.



Effect of static offset should be mostly corrected.
Even assuming very large misalignment of Cavity BPMs

Beam size at IP vs. orbit distortion, simulation

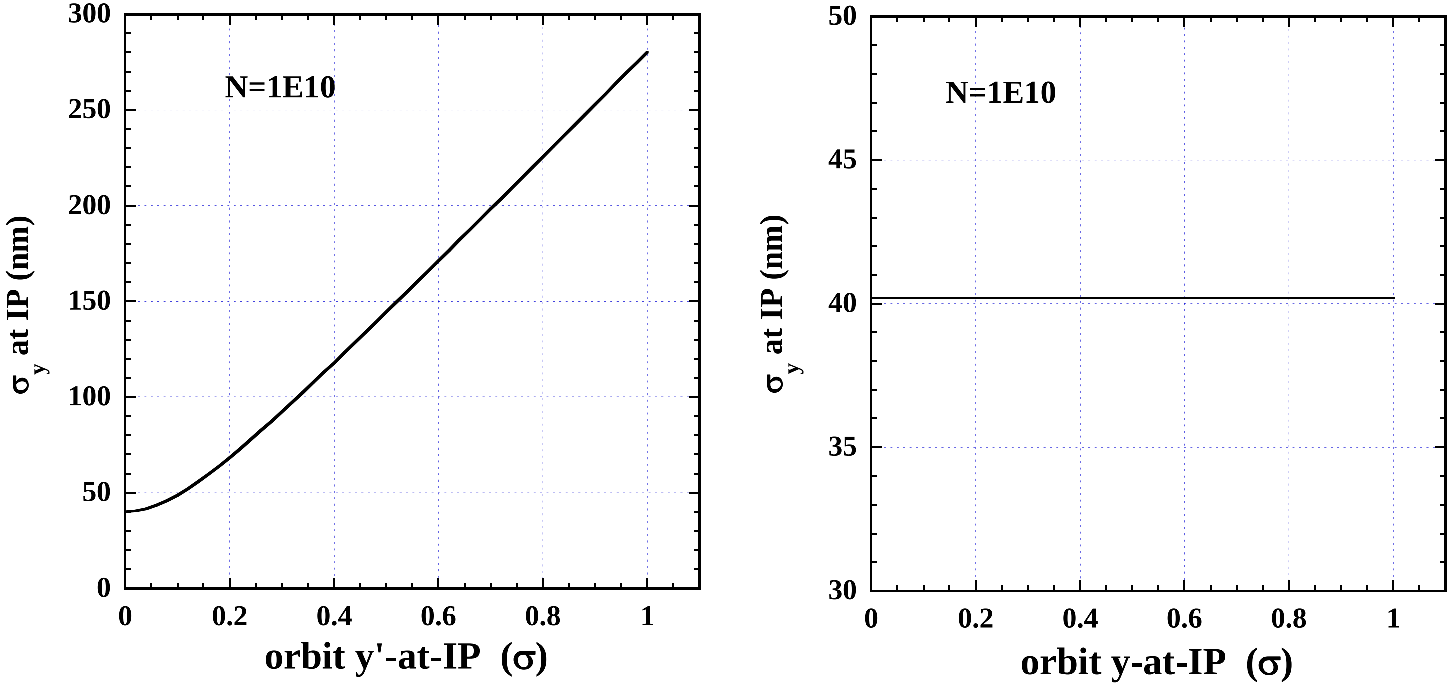
All wakefield sources affects the beam with the same phase.

Two orthogonal orbit modes (“y’ at IP” and “y at IP”)

Phase advance from all components at high beta_y to IP ~(n+1/2)π

→ Only “y’ at IP” orbit is important

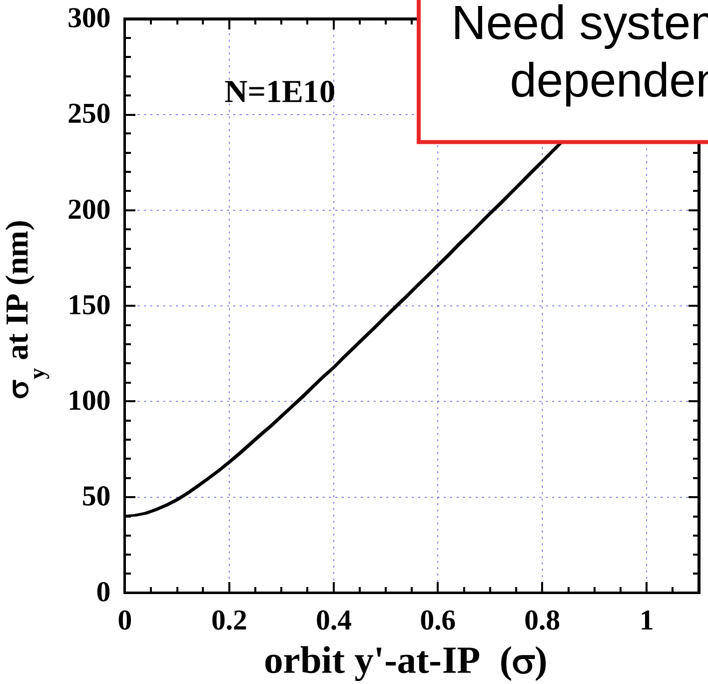
emittance_y=12 pm

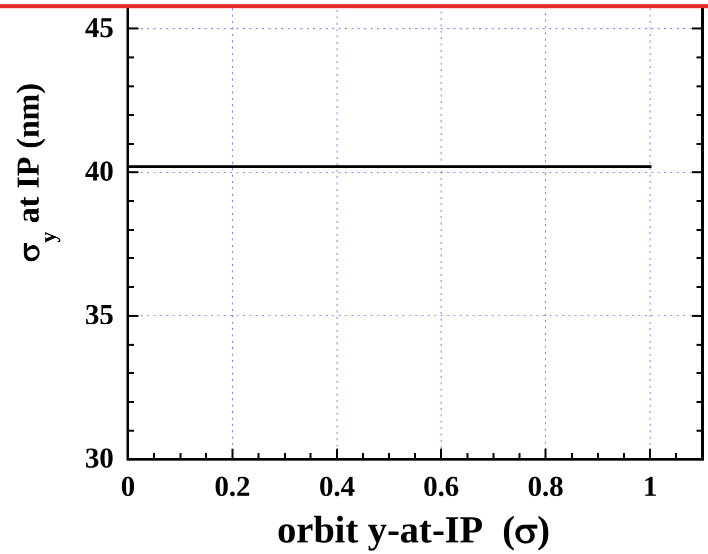


Beam size at IP vs. orbit distortion, simulation

- Orbit distortion 1-sigma in y'-at-IP phase has similar effect as random cavity offset, RMS 1mm
- Orbit jitter of ATF2 < 0.3 sigma.
  - No significant effect to low intensity beam.
  - But may be problem for high intensity, N ~1E10

Need systematic experimental data of beam size dependence on orbit. (will be taken in April)

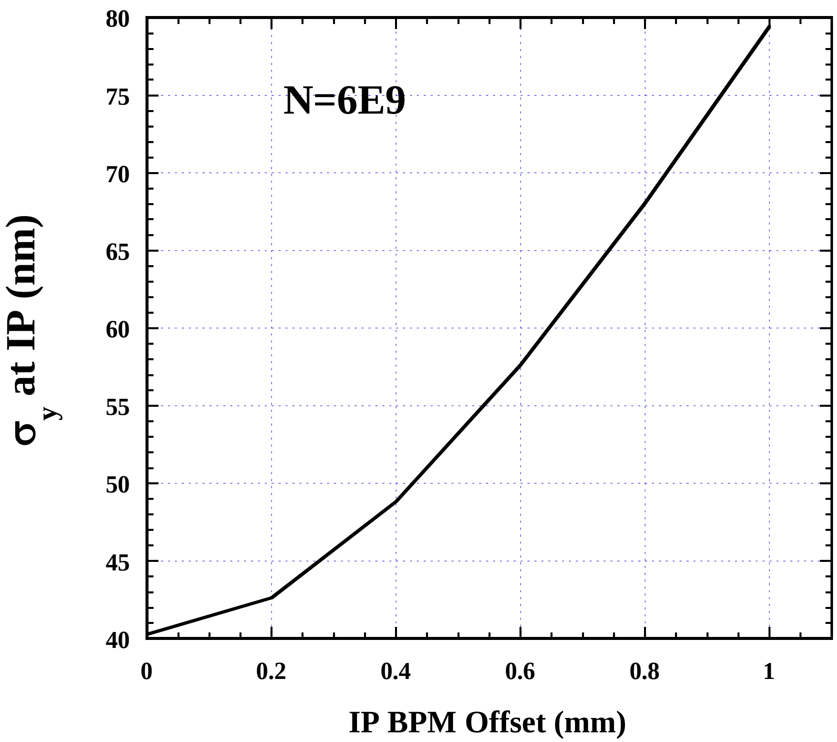




Effect of IPBPM wakefield, simulation

Two special Cavity BPMs near IP (IPBPMA and IPBPMB)

- Small aperture and ~x10 stronger wakepotential than other C-band BPMs. But,
- Close to IP (15 cm and 7 cm) and beam-cavity offset should be very small (being monitored), then, effect should be small.

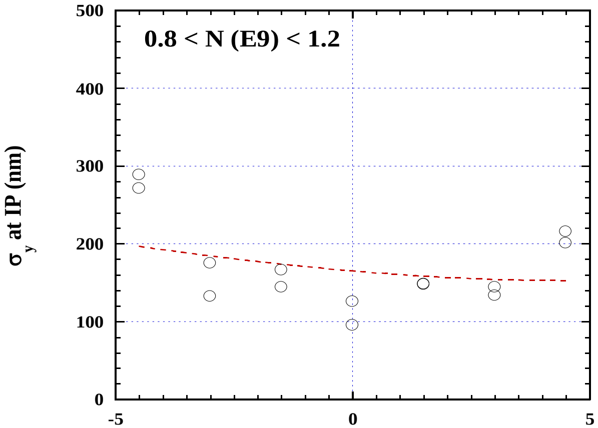


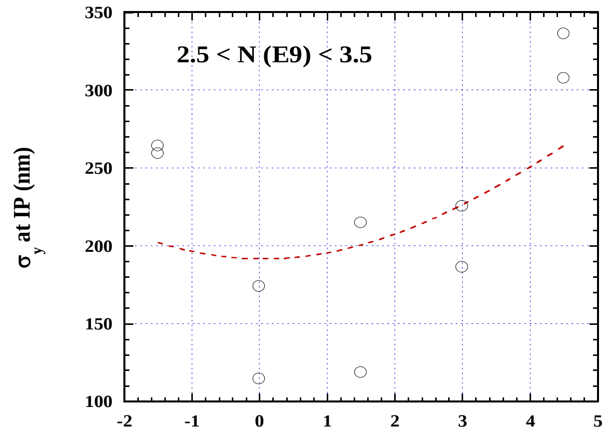
Same offset for two BPMS assumed

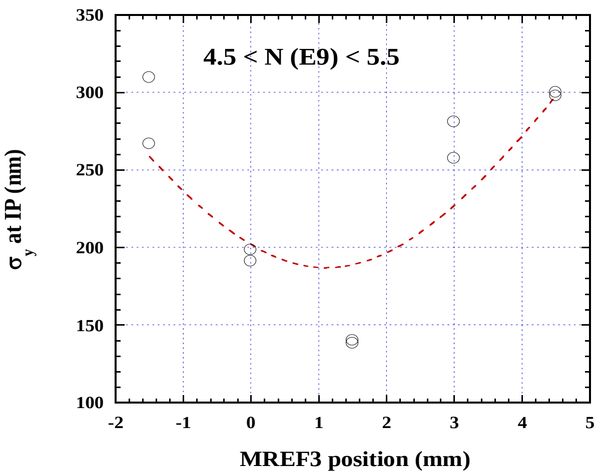
Experimental data compared with Simulations (next 6 slides)

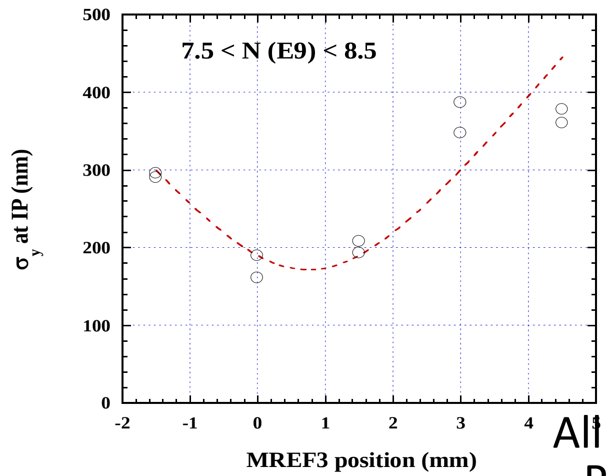
Beam size vs. reference cavity offset, experiment

Beam size vs. mover position









Lines are from fitting

$$\sigma = \sqrt{\sigma_0^2 + [aN(y - y_0)]^2}$$

y : position of ref. cav.

σ_0, y_0 : free parameters

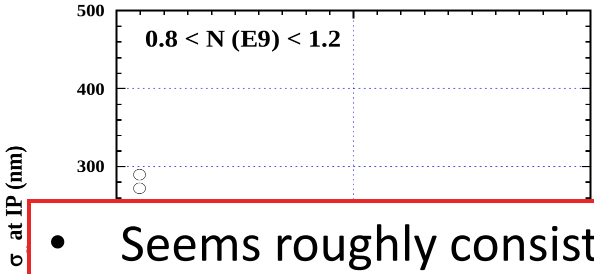
a : 13 nm/mm/N(E9)

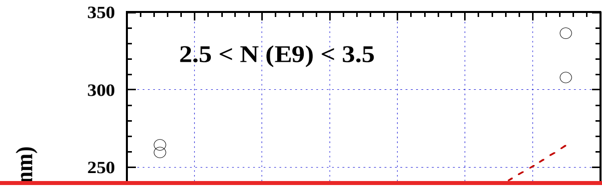
Measured beam sizes shown are evaluated assuming the monitor is perfect.

All data taken on Feb. 21
Preliminary

Beam size vs. reference cavity offset, experiment

Beam size vs. mover position



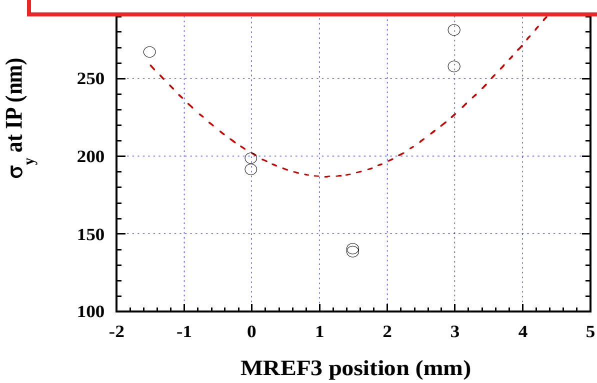


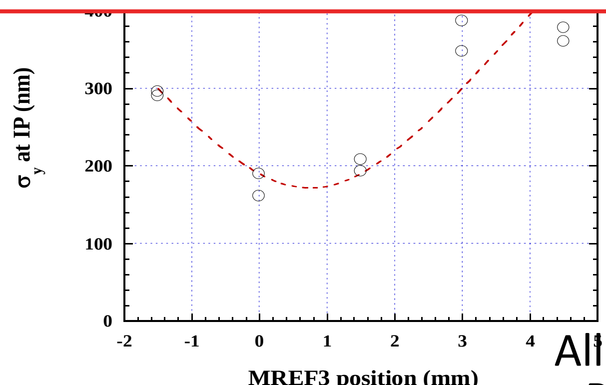
Lines are from fitting

$$\sigma = \sqrt{\sigma_0^2 + [aN(y - y_0)]^2}$$

y : position of ref. cav.

- Seems roughly consistent with simulation for high intensity.
- Stronger dependence than simulation for low intensity and large offset?
  - Effect of higher order wakefield ? (calculation assumed dipole wake)
  - Or, other effect than wakefield ?
- More systematic experiment will be performed in April.





is perfect.

All data taken on Feb. 21

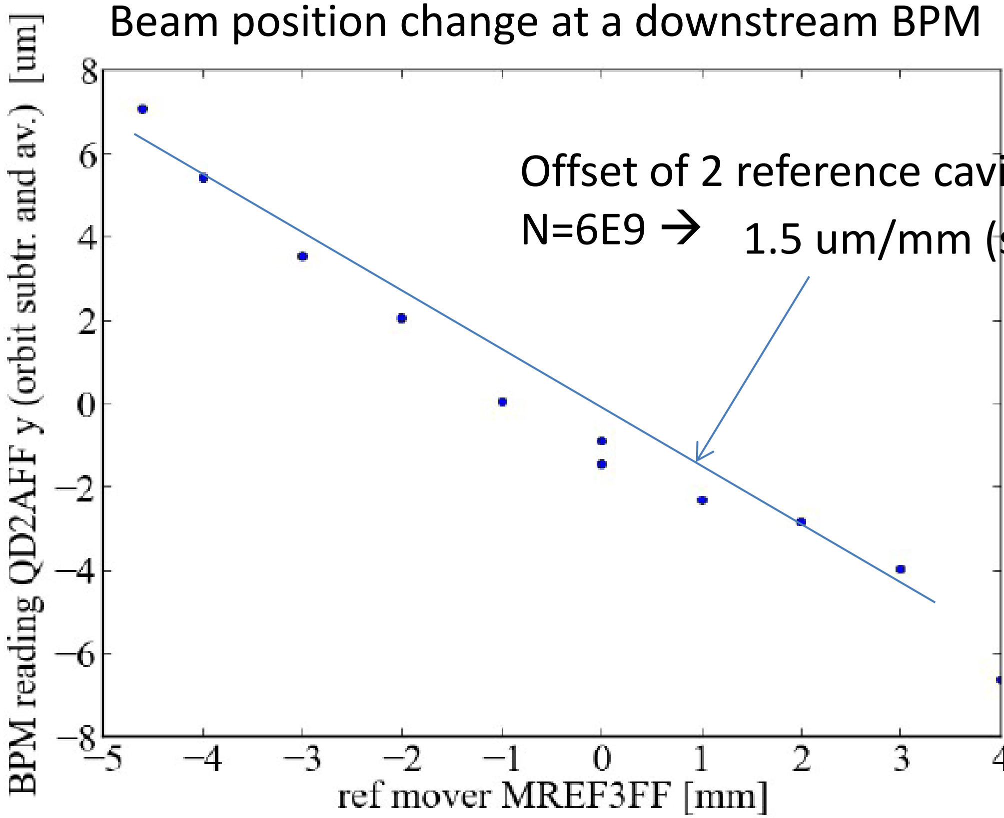
Preliminary

Note on measured beam size data presented in this report

- Measured beam sizes shown here are calculated from Modulation of IPBSM without considering any errors.
- And real beam size may be smaller than these apparent beam sizes. (Discussed in later reports.)
- In this report, please look at relative beam size change. Do not look at absolute values.

Orbit response to reference cavity position
Experiment and simulation

Beam position change at a downstream BPM

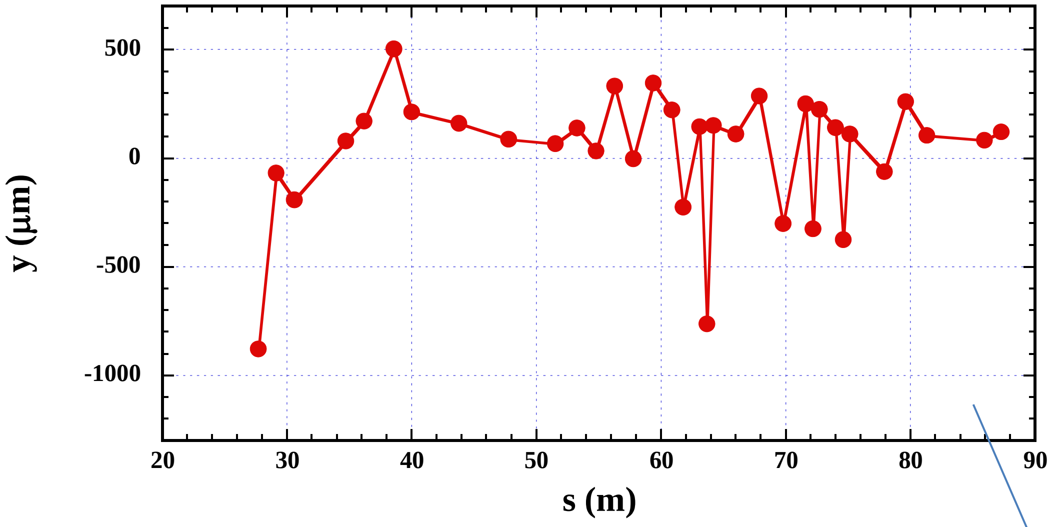


Offset of 2 reference cavities (MREF3FF) + 1 bellows
N=6E9 → 1.5 um/mm (simulation)

Data from Jochem Snuverink, et.al. ,20121207 ATF operation meeting

Roughly consistent with calculation.
More systematic experiment will be performed in April.

Measured beam-CavBPM offset and beam size simulation

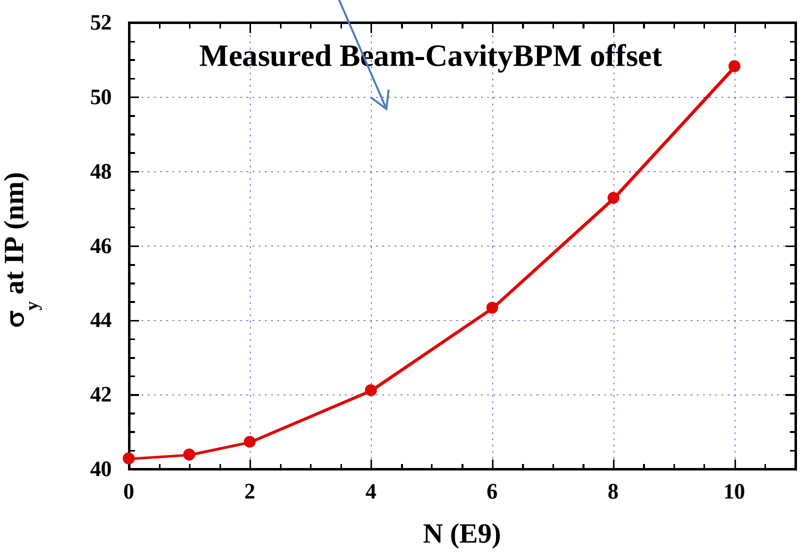


Measured beam-cavity BPM offset (example)

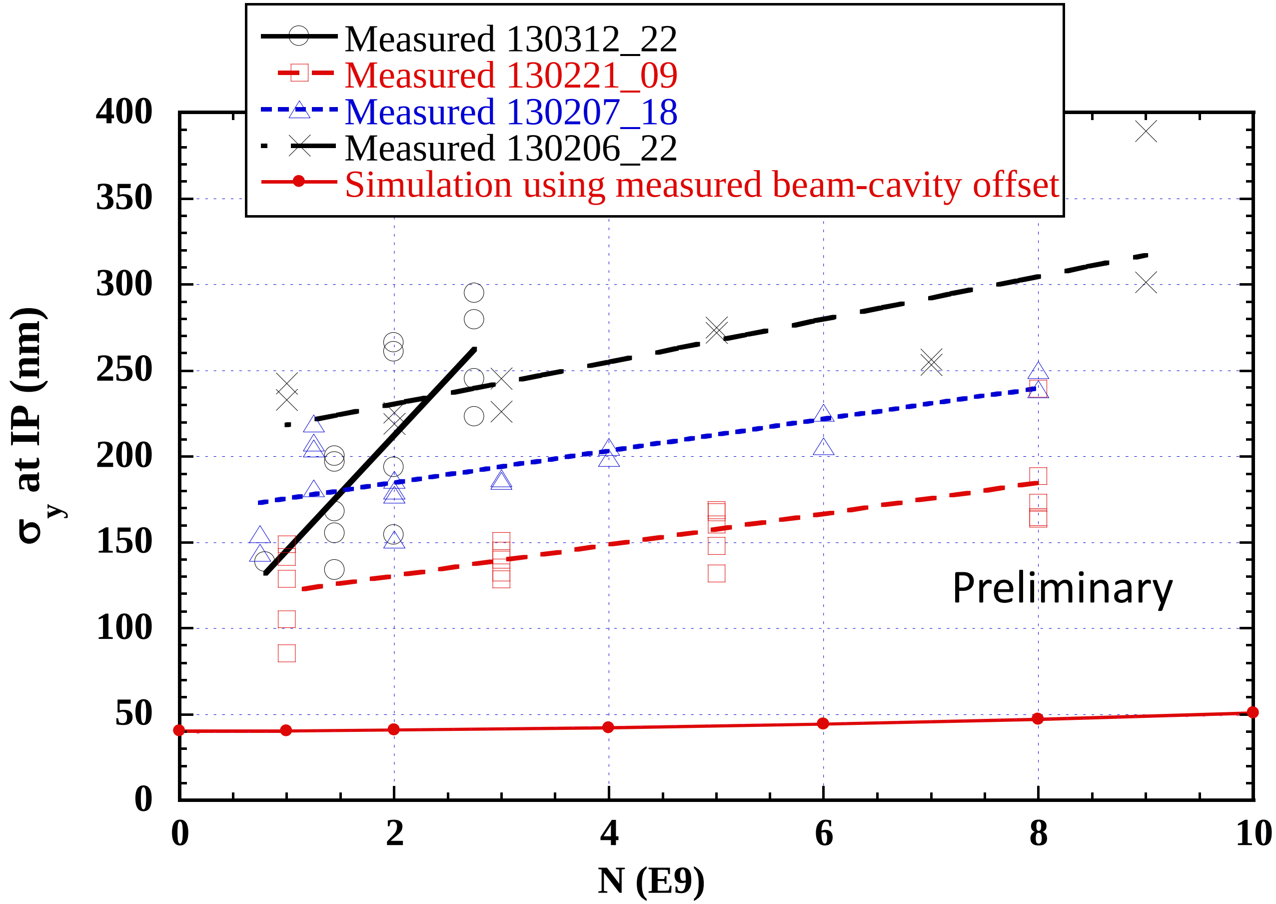
(Beam orbit + BPM offset)

Simulated beam size at IP assuming these offsets vs. bunch population

Wakefield of Cavity BPM and Bellows.
Same offset for BPM and corresponding Bellows



Beam size vs. bunch intensity



Measured beam sizes shown are evaluated assuming the monitor is perfect.
Effects of errors should be different for different days.

Measured data show much stronger intensity dependence than simulation assuming measured beam-Cavity BPM offset.

Other possible wakefield sources

- In septum region (just after extraction kicker)
  - Very narrow chamber (aperture 8 mm) with some steps. But,
  - Beta-function is small (<10 m, compared with max. beta ~10,000 m in FF) and effect should be small, unless beam offset is very large.
  - Can be checked in the EXT line diagnostics region. (no conclusion now. to be performed near future)

- Vacuum ports, Gate valve, aperture steps in FF
  - Wakepotential calculations show these effects are small.

Comparison between experiment and simulations SUMMARY

- Response to position change of reference cavity on mover
  - Orbit response: consistent
  - Results of beam size response: not very clear.
  - Further systematic experiment will be in April
- Intensity dependence of beam size
  - Dependence was very strong
    - Can not be explained by measured beam-Cavity BPM offset and wake of Cavity BPM
    - Significant sources other than Cavity BPM
    - No conclusion. Need more data.

Wakefeild effect in ILC BDS and RTML

- Roughly compare effect with ATF2

For Wakefeild Effect comparison in ILC BDS and RTML beta_y at magnets

ILC BDS

Number of Q-magnets ~85

$$\sum_{\text{Q-mag.}} \sqrt{\beta_y} = 2{,}939 \text{ m}^{1/2}$$

$$\sum_{\text{Q-mag.}} \beta_y = 347{,}216\text{m}$$

$$\int ds \sqrt{\beta_y} \sim 89{,}000 \text{ m}^{3/2}$$

$$\int ds \beta_y \sim 8{,}900{,}000 \text{ m}^2$$

ATF2

Number of Q-magnets =46

$$\sum_{\text{Q-mag.}} \sqrt{\beta_y} = 1{,}024 \text{ m}^{1/2}$$

$$\sum_{\text{Q-mag.}} \beta_y = 62{,}660\text{m}$$

$$\int ds \sqrt{\beta_y} \sim 4{,}000 \text{ m}^{3/2}$$

$$\int ds \beta_y \sim 1{,}100{,}000 \text{ m}^2$$

ILC RTL (long return line in RTML)

Number of Q-magnets ~800
Beta ~ 100 m,
Beam energy 5 GeV,
Bunch length ~ 6 mm,

Wake effect comparison.

Assume Same wake source at every Q-magnet. Same bunch charge.

Same beam – wake source offset (misalignment of components)

	ILC BDS	ILC RTL	ATF EXT/FF
1/E_beam (1/GeV)	1/250	1/5	1/1.3
Effect of bunch length	0.3 (?)	1	1
$1/\sqrt{\varepsilon_y}$ (m^(-1/2))	$1/\sqrt{8\times10^{-14}}$	$1/\sqrt{2\times10^{-12}}$	$1/\sqrt{1.2\times10^{-11}}$
$\sum_{\text{Q-mag.}}\sqrt{\beta_y}$ (m^(1/2))	3,000	8,000	1,000
Total (Relative to ATF)	**0.057 (?)**	**5.1**	**1**

Beam – wake source offset scale as beam size (beam orbit distortion)

	ILC BDS	ILC RTL	ATF EXT/FF
1/E_beam (1/GeV)	1/250	1/5	1/1.3
Effect of bunch length	0.3 (?)	1	1
$\sum_{\text{Q-mag.}}\beta_y$ (m)	350,000	80,000	63,000
Total (Relative to ATF)	**0.0087 (?)**	**0.33**	**1**

Wake effect comparison.
Assume Same wake source at every Q-magnet. Same bunch charge.

Same beam – wake source offset (misalignment of components)

ILC RTL will not need small aperture cavity BPMs at every quad.
So, this calculation is not really relevant for RTL.
ILC BDS has loser tolerance than ATF2. But not confirmed factor 0.3 (effect of bunch length difference) was assumed.

1/E_bea			
Effect o			
$1/\sqrt{\ }$			
$\sum_{\text{Q-mag.}} \sqrt{\beta_y}$ (m^(1/2))	3,000	8,000	1,000
Total (Relative to ATF)	**0.057 (?)**	**5.1**	**1**

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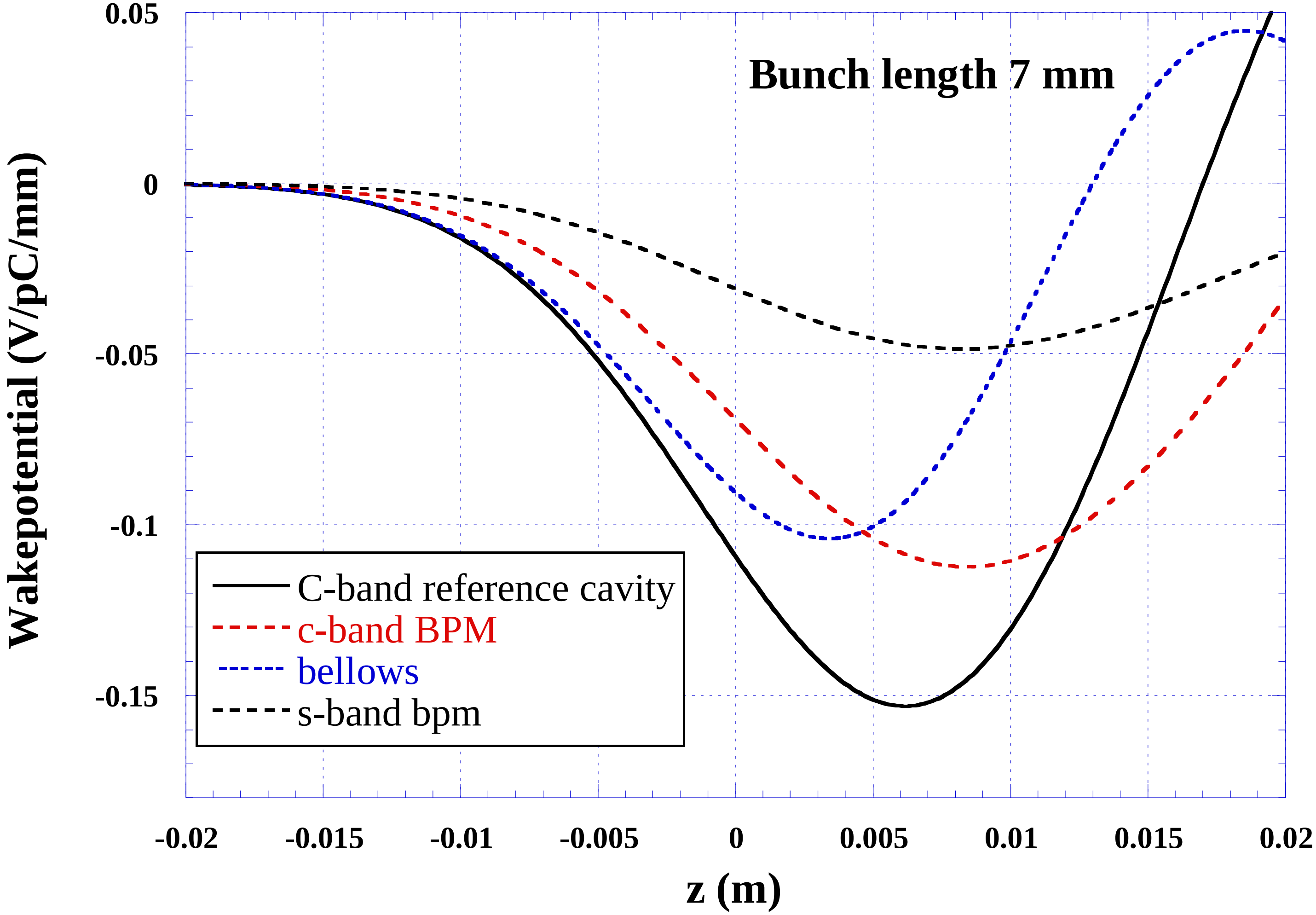
Total (Relative to ATF)	**0.0087 (?)**	**0.33**	**1**

Future plans

- Further experiment. (mostly in April)
  - More systematic experiment moving reference cavities.
  - Put bellows on another mover for checking wakefiled of bellows (?)
  - More systematic experiment of intensity dependence
    - Including IPBSM 174 deg. mode
  - May change optics (larger beta* or lower beta at Cavity-BPMs) and see intensity dependence
  - Study emittance growth in the beginning of EXT line
- Possible reduction of wakefield (not decided yet)
  - Some cavity BPMs can be removed or replaced by strip line BPMs (or swapped with strip line BPM at low beta region)
  - Modify vacuum chamber (insert shields in bellows)
  - More alignment, if effective.

Back up slides



Calc. by A. Lyapin

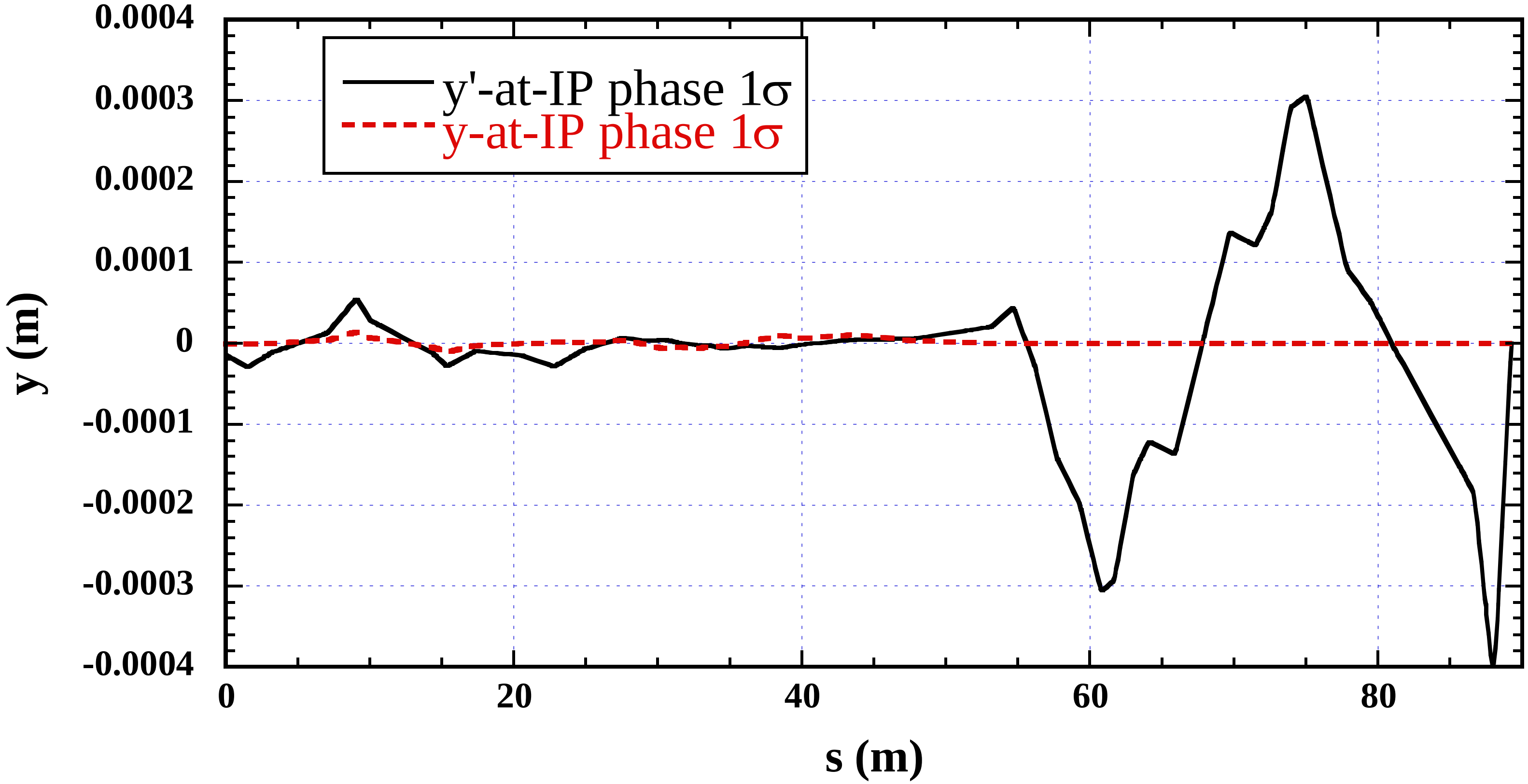
Beam size at IP affected by orbit distortion

- Beam size at IP vs. vertical orbit distortion in FF is simulated

- Transverse wakefield of all cavities affects the beam with the same phase.
- Offset at each cavity BPM is proportional to sqrt(beta_y)
- Phase advance from all BPM at high beta_y to IP ~$(n+1/2)\pi$
  - Only “y’ at IP phase” orbit is important

1-sigma orbit in y-phase and y'-phase

Emittance_y=12 pm



Effect of y-at-IP phase orbit should be small