ATF2 Wakefield (Beam size Intensity dependence) Studies

ALCWS2018, 201805

K.Kubo

Wakefield effects to beam size at IP

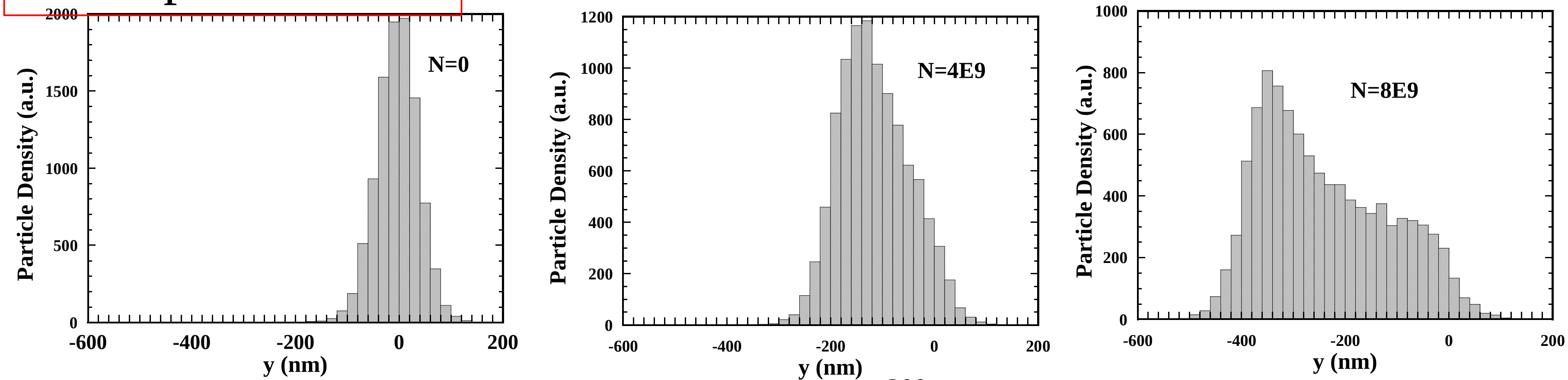
- Static Wakefield effect
  - Misalignment and distorted orbit.
  - Can be (partly) compensated by wake source on mover.

- Dynamic Wakefield effect
  - Angle at IP phase orbit jitter is important

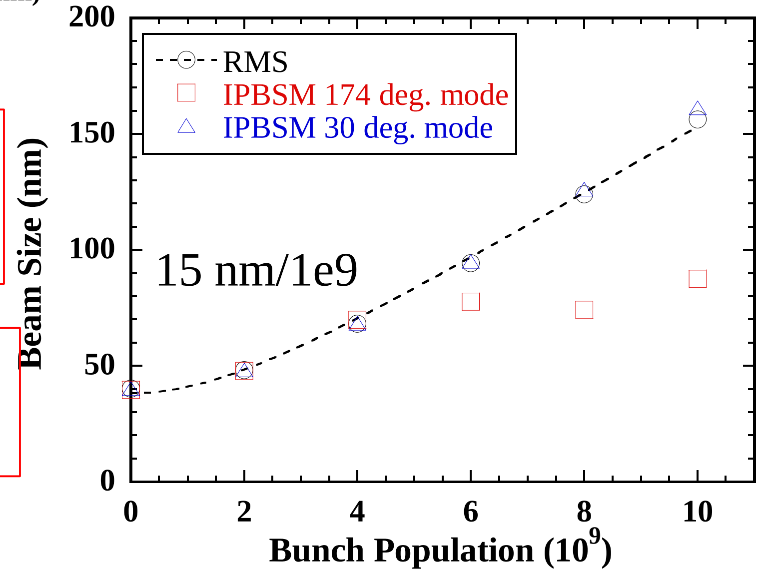
Static effect (simulation)

Set random misalignment of Cavity BPMs, bellows and flanges.
Results from one particular set of random numbers.

Beam profile at IP



RMS beam size and "measured" beam size

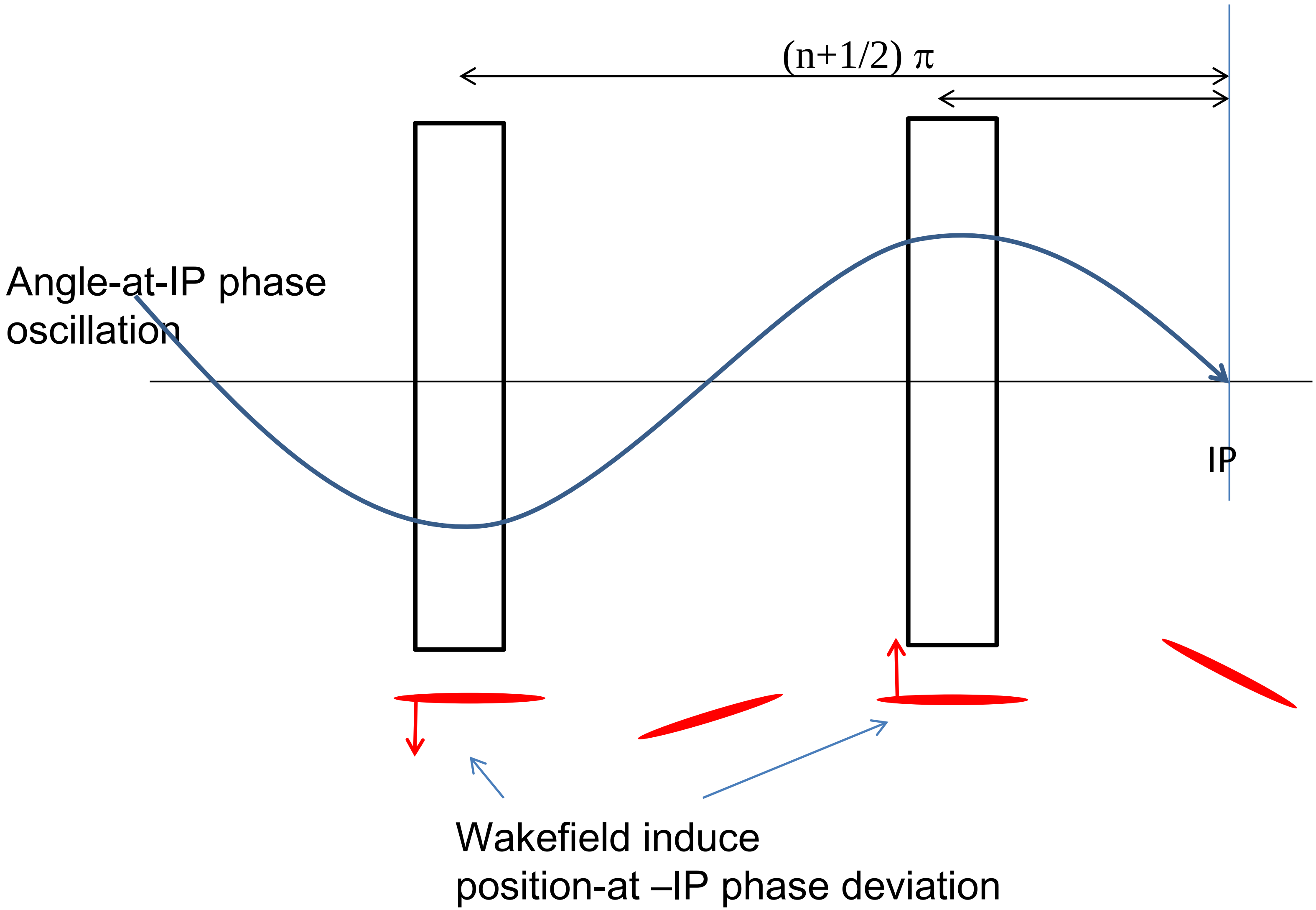


Need M>0.25 for reliable measurement
→ Use 30 deg mode of IPBSM

Dynamic effect (wake + orbit jitter)

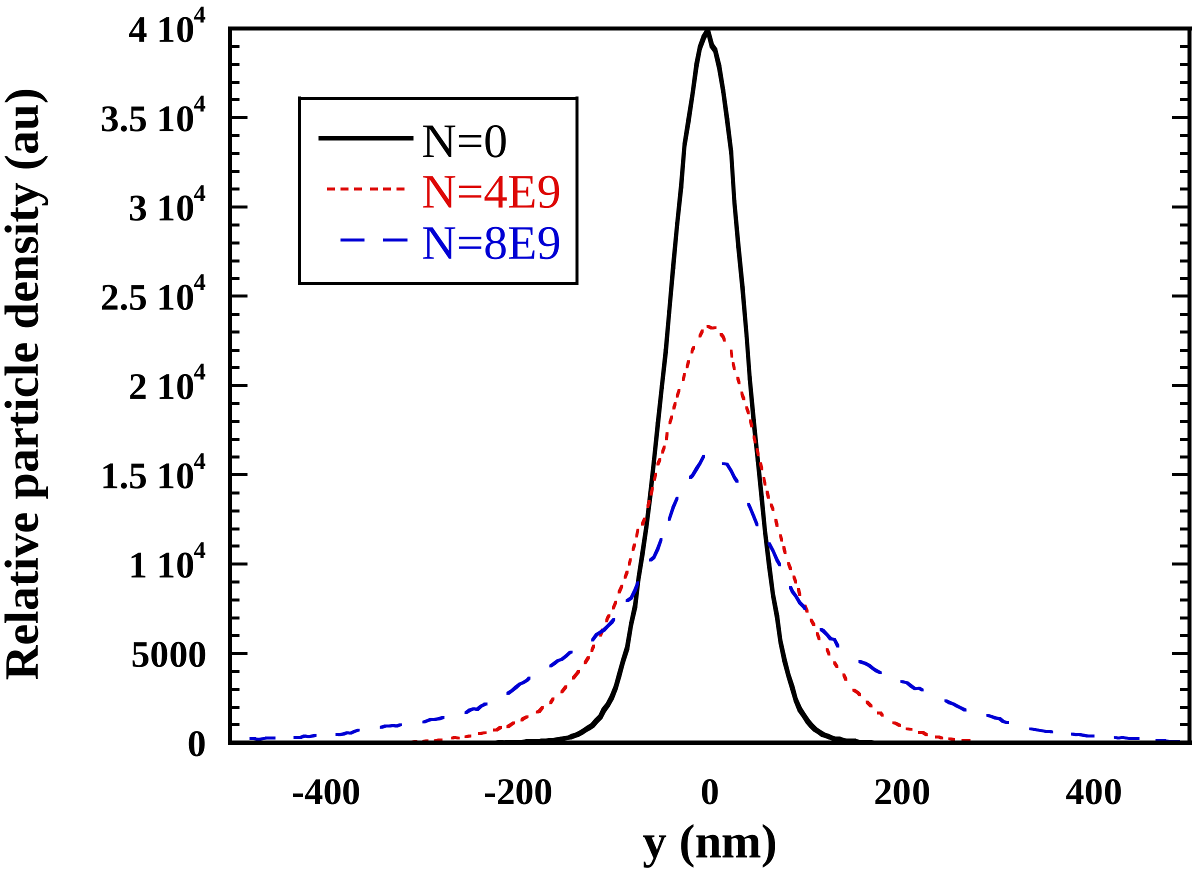
- We observed orbit jitter in EXT-FF line about 0.2-0.3σ of nominal beam size.
- 0.3σ “position at IP” phase jitter will increase measured beam size only 4%
- But, with wakefield, effect of “angle at IP” phase jitter can be significant.

Dynamic effect (wake + orbit jitter)

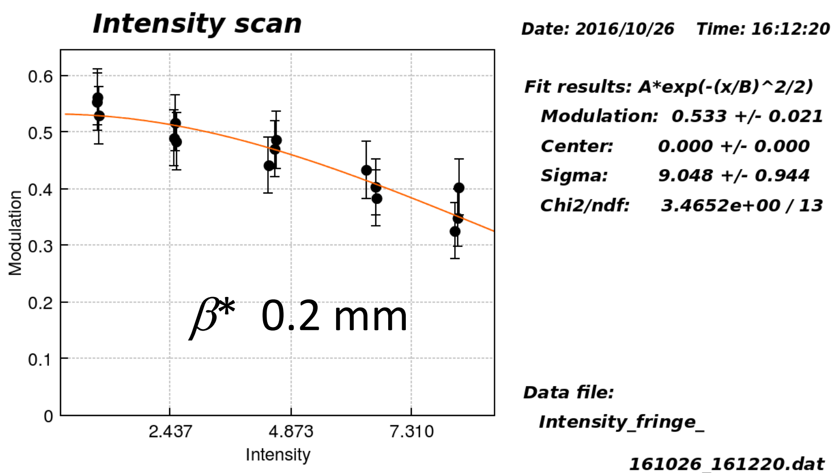


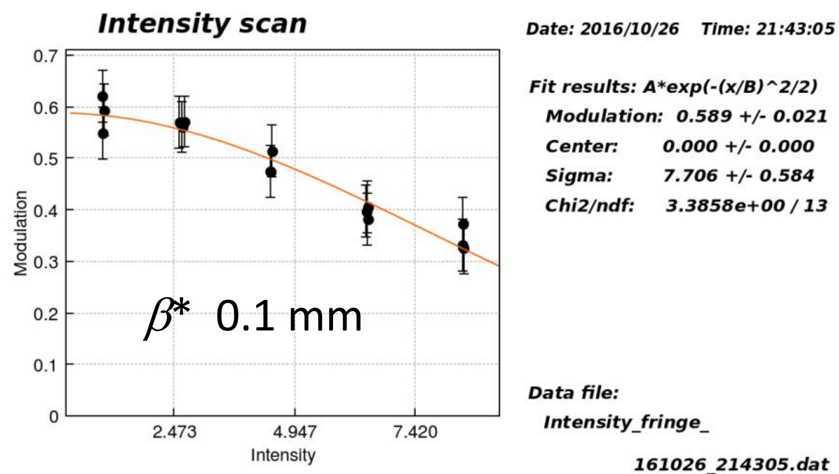
Projected beam profile at IP - simulation

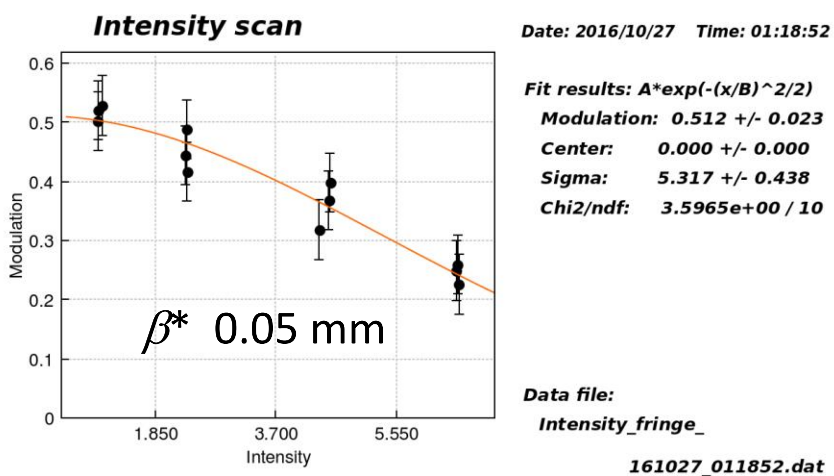
Orbit jitter 0.3σ, sum of 100 pulses



Intensity dependence data with 3 different optics (2016. Oct. 26)







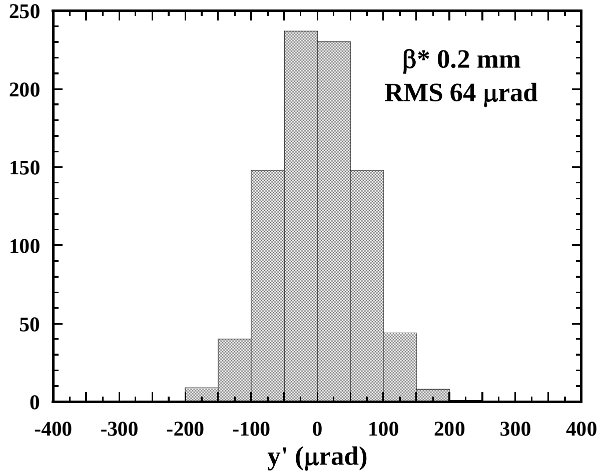
“design” beta_y*

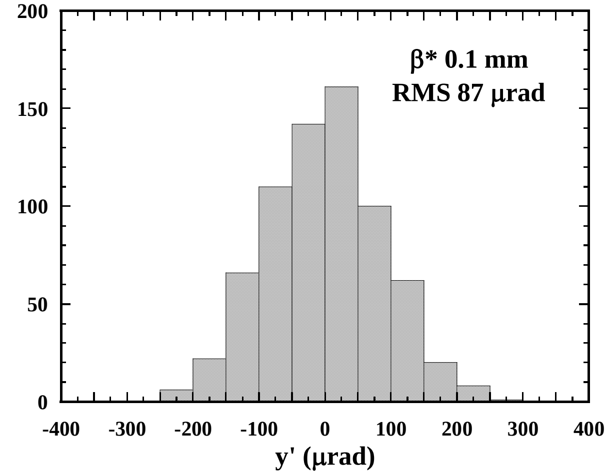
0.2 mm

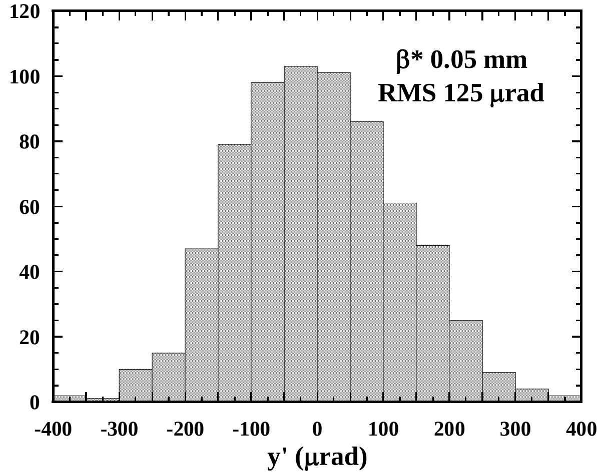
0.1 mm

0.05 mm

Angle (y’) at IP distribution



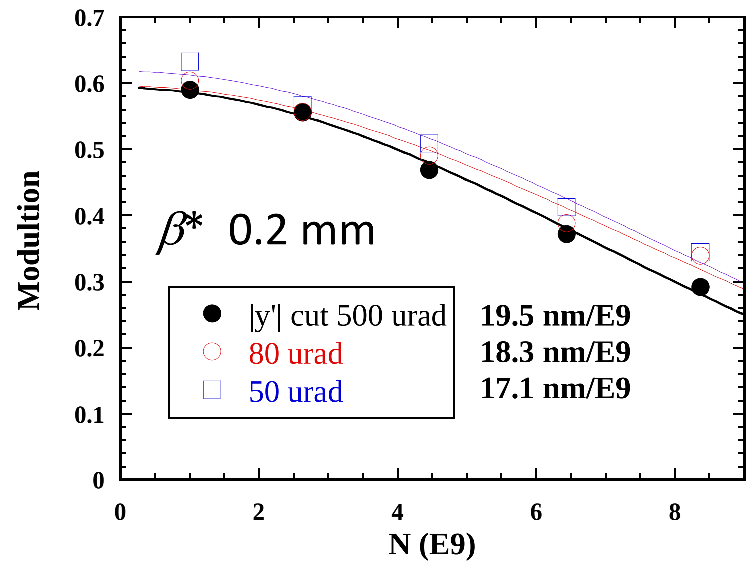


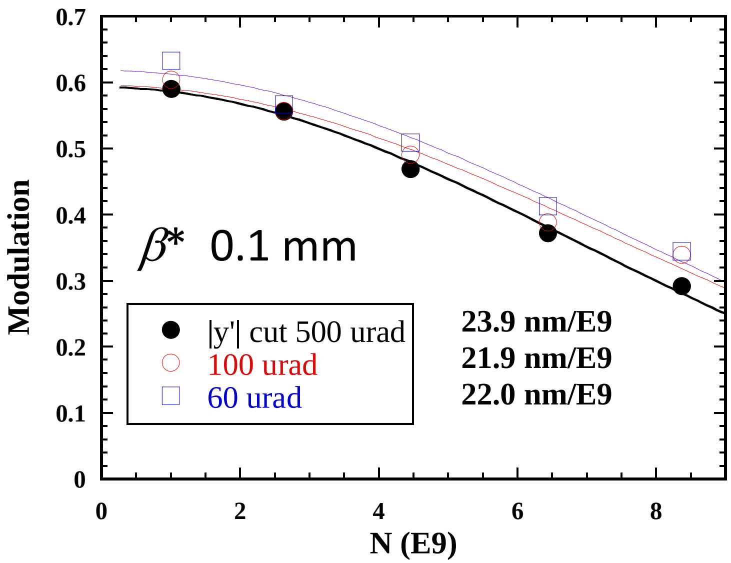


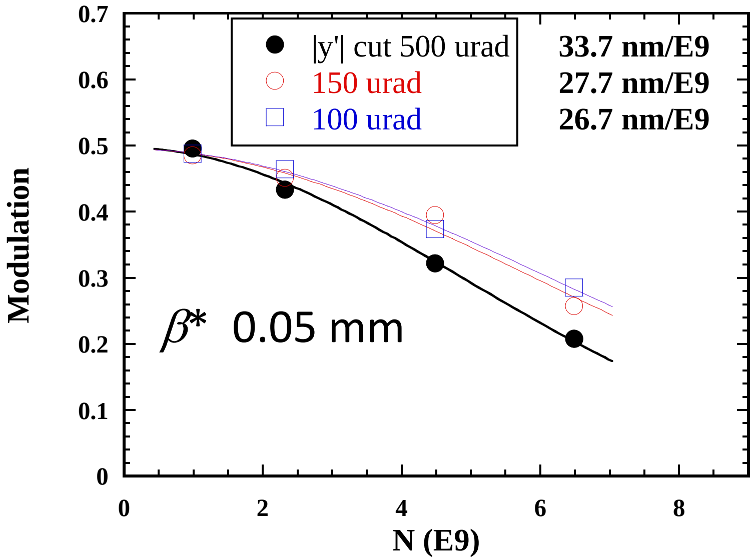
Fitted y’ from BPM data
(3 highest intensity data for each beta*)

Data selection by angle at IP
→ next slide

Modulation v. Intensity with y' cut

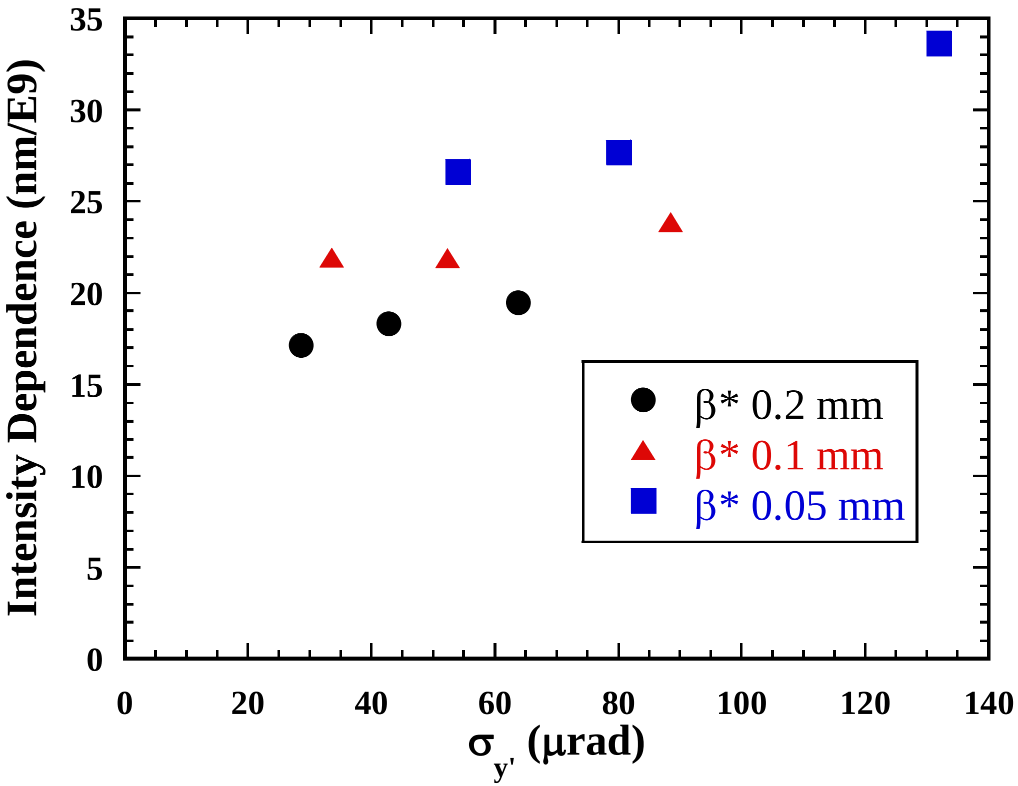






Intensity dependence reduced for narrow y' width

Intensity dependence vs. RMS of y' at IP



Clear correlation between intensity dependence and angle jitter.
Intensity dependence is not proportional to angle jitter.
Lower beta* → larger dependence for the same RMS jitter.
Static wakefield effect or other effect?

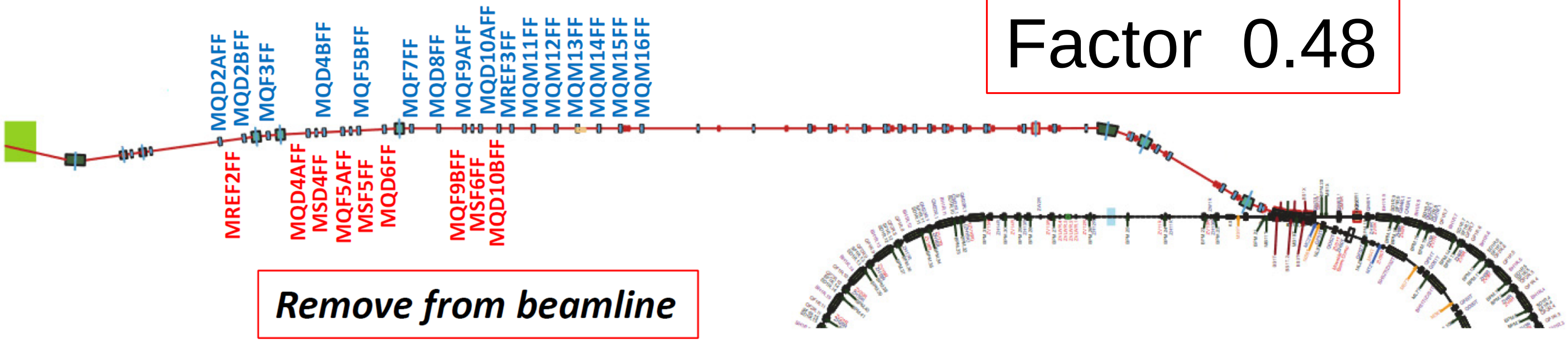
Reduction of wakefield in November 2016

- Remove some Cavity BPMs in high-beta region
  - Expect wakefield effect reduction by ~1/2
- Shield flange gaps
- Change chambers at bending magnet
- Remove some other components

Removal of some Cavity BPMs in Final Focus Line (High-beta region)

$$\sum \beta :\ 64000\,\mathrm{m} \rightarrow 31000\,\mathrm{m}$$

Factor 0.48



Remove from beamline

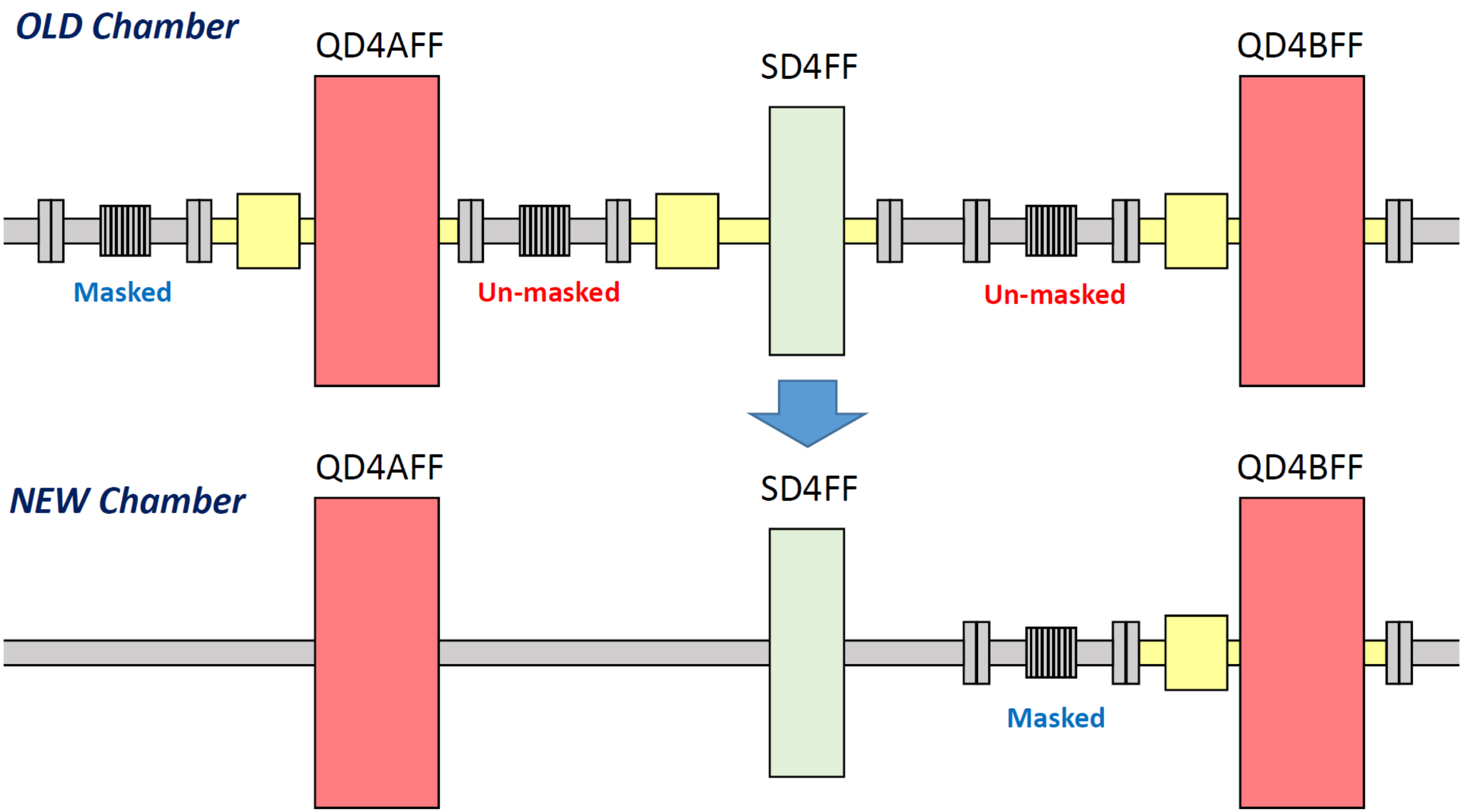
Number of elements overall ATF2 beamline

	Sensor cavity BPM	Un-masked Bellows	Flange gap
OLD Chamber	23	11	87
NEW Chamber	15	5	69
Difference	8	6	18

Most of the removed components are in large betaY.

Okugi, ATF Operation meeting 20160924 (modified)

Chamber Modifications in November 2016



Number of elements in QD4 section

	Sensor cavity BPM	Un-masked Bellows	Flange gap
OLD Chamber	3	2	8
NEW Chamber	1	0	3

Okugi, ATF Operation meeting 20160924

"2-Dimensional Scan"
(orbit and wake source)

Set different "angle at IP" phase orbit
(by changing steering magnet ZVFB1FF, orbit change monitored at MQD10AFF)
-- Change effect of all wakefield sources downstream

Search position of MREF3FF (wakefield source on mover) to minimize beam size at IP

Result gives ratio of
effect of total wakefield sources and
effect of MREF3FF

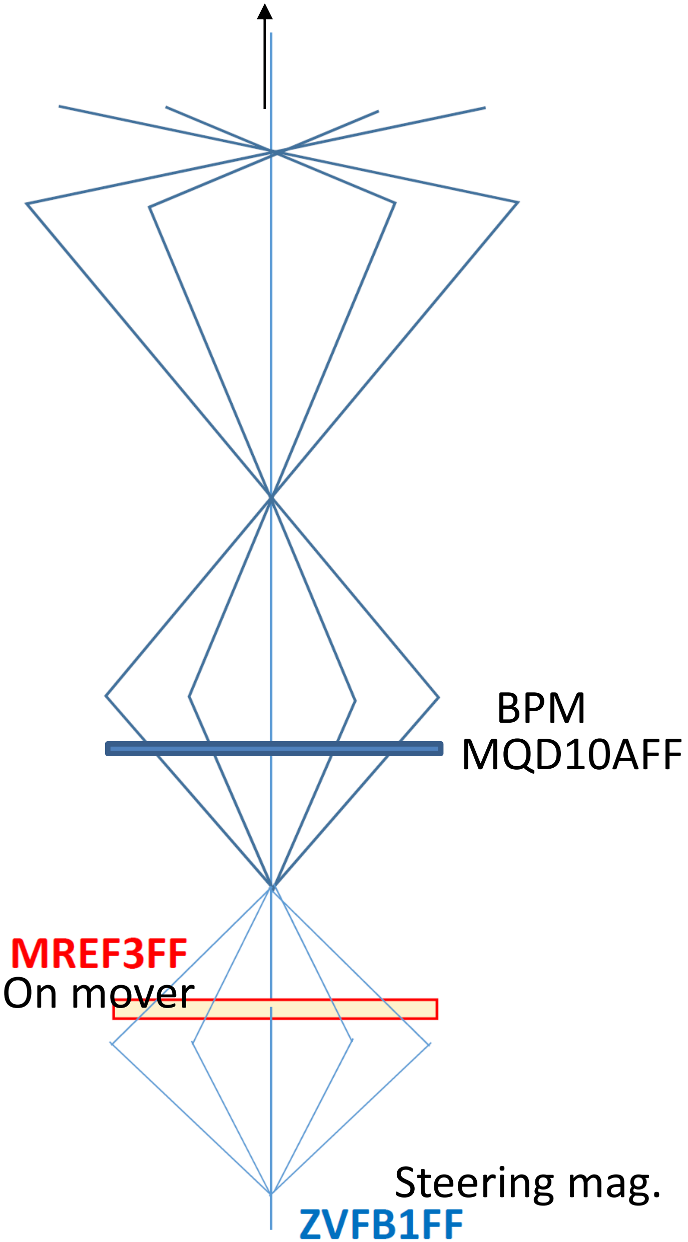
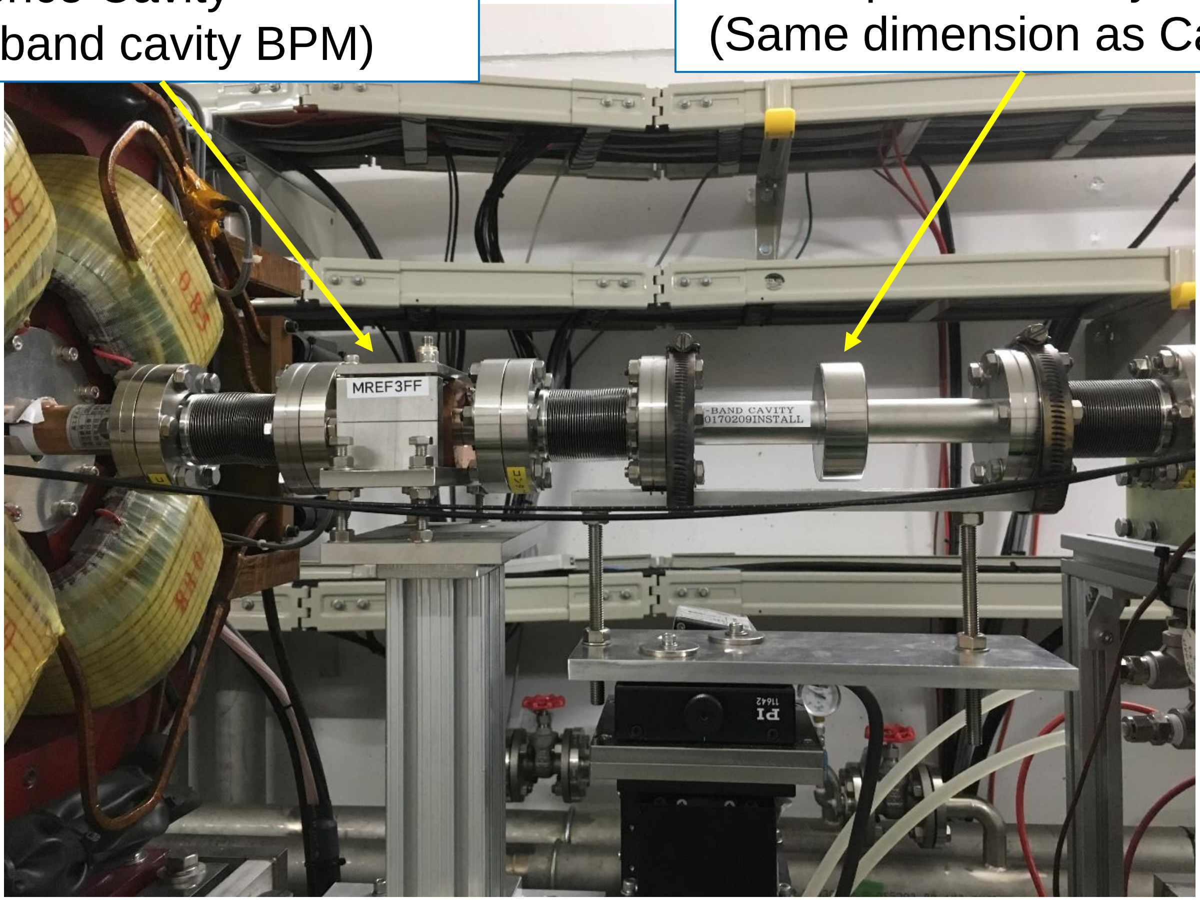


Figure by Okugi (modified)

Two different wakefield sources on mover in high beta region

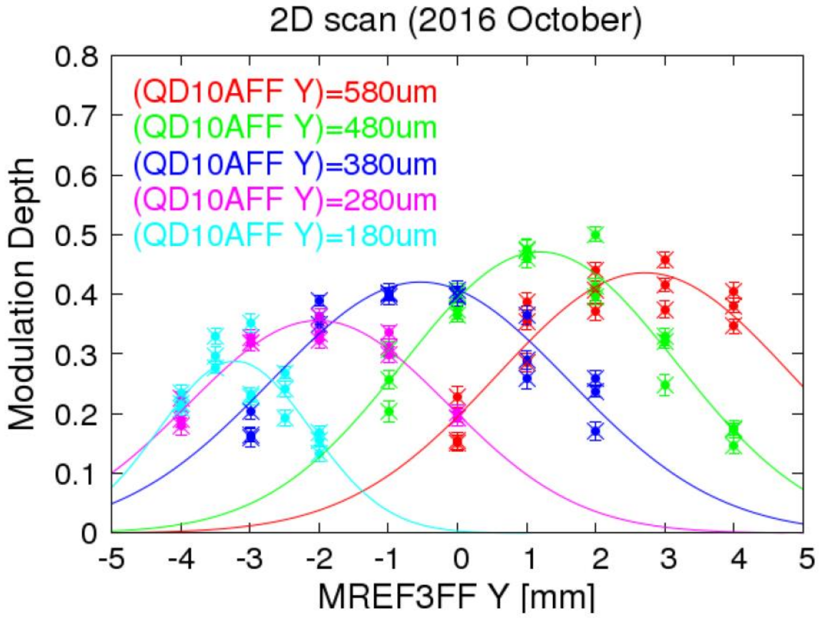
Reference Cavity
(for C-band cavity BPM)

C-band pill-box cavity
(Same dimension as Cavity BPM)

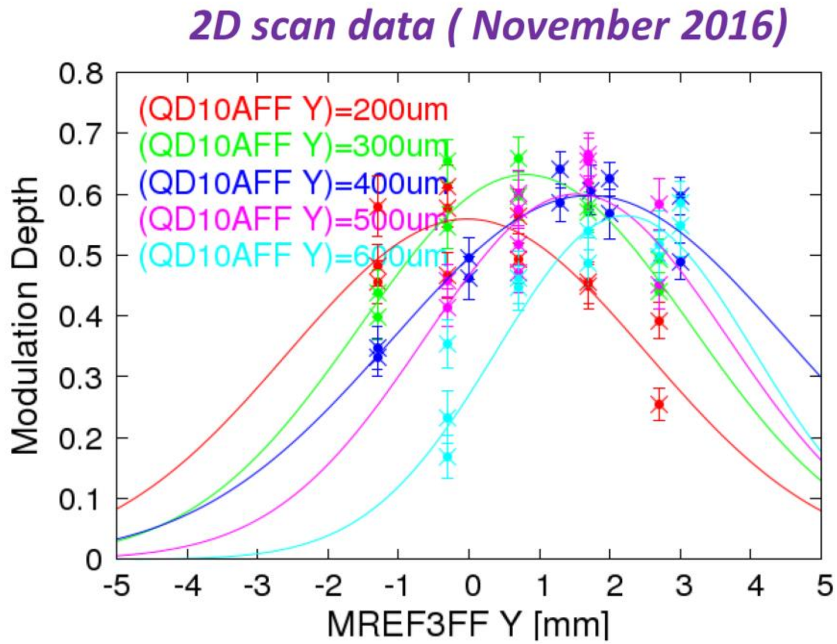


2-D scans in Oct. and Nov. 2016

Oct.



Nov.

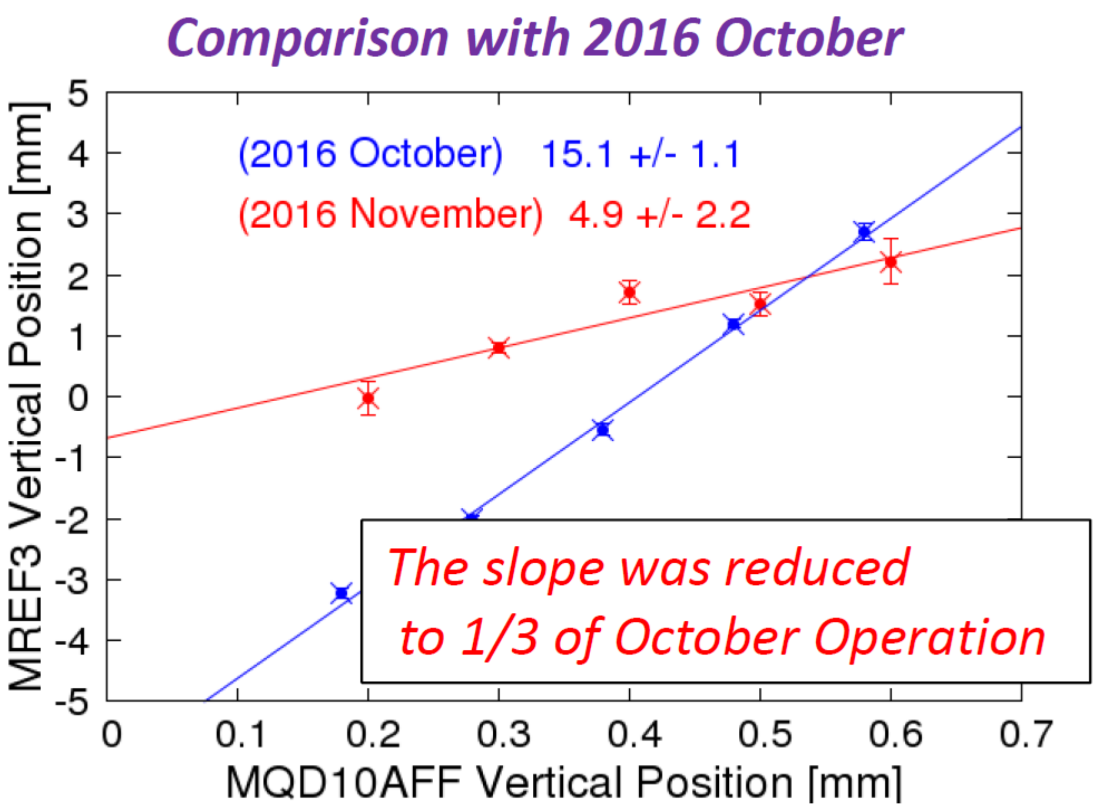


Okugi, ATF Operation meeting 20161028 and 20161125

2-D scan in Oct. and Nov. 2016

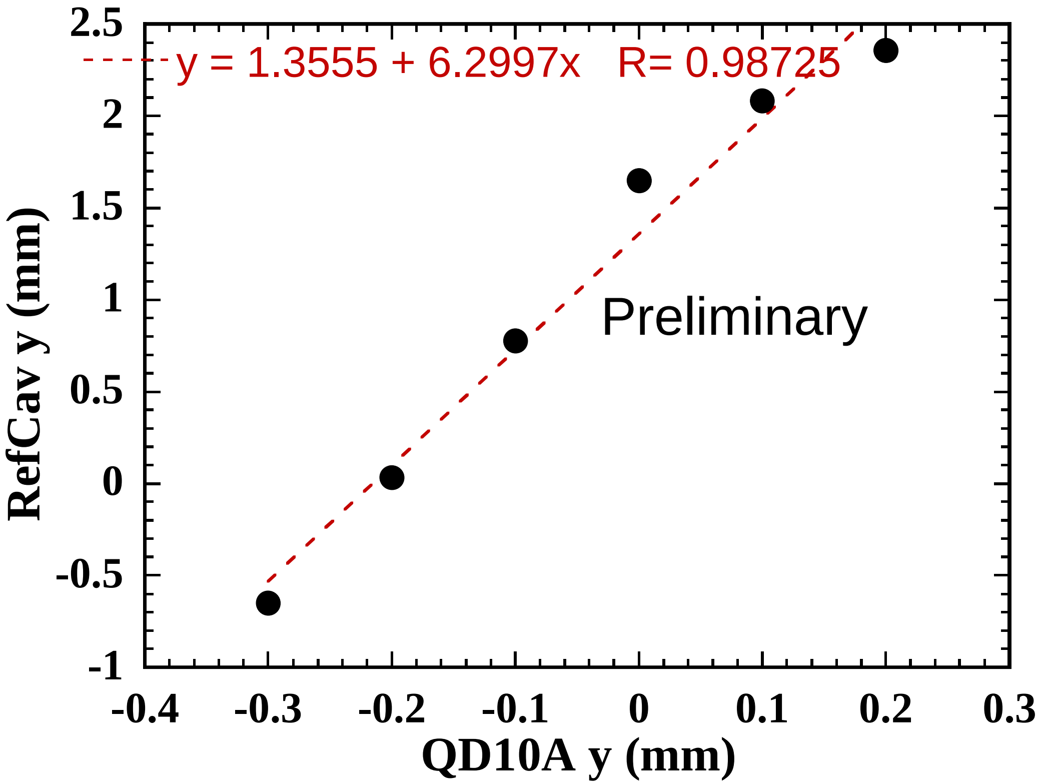
Slope: wake strength ratio of RefCav and all in beam line

Experiment



Okugi, ATF Operation meeting 20161125

2-D scan in May. 2018



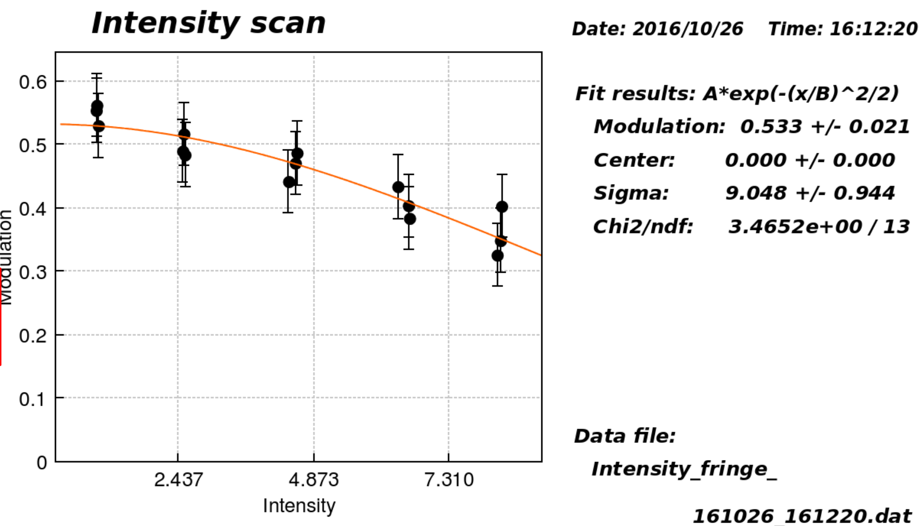
	Slope
2016 Oct	15.1 +-1.1
2016 Nov	4.9 +-2.2
2018 May	6.3

Consistent within error

Intensity dependence reduced (2016)

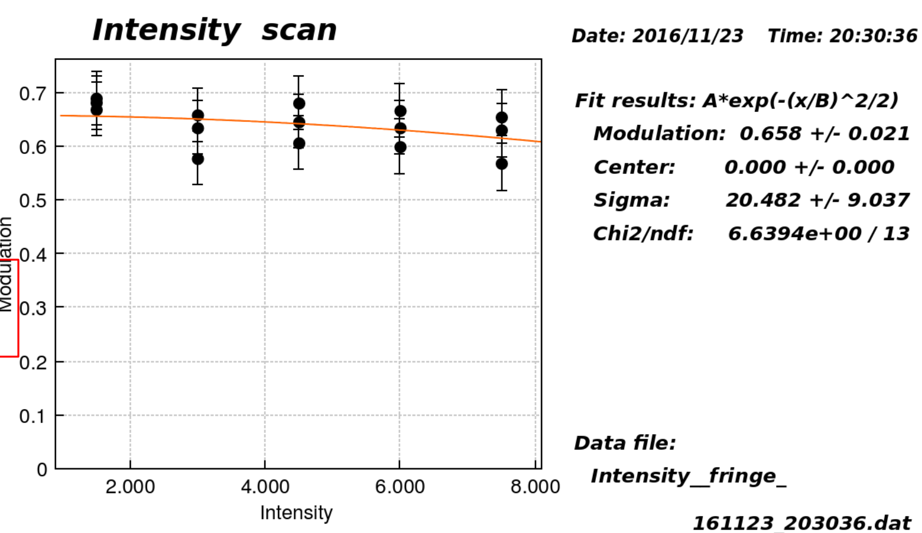
October

18 nm/1e9



November

8.0 nm/1e9



Wakefield cancellation by structures on movers

1 mover

- 2 reference cavities
- 1 reference cavity

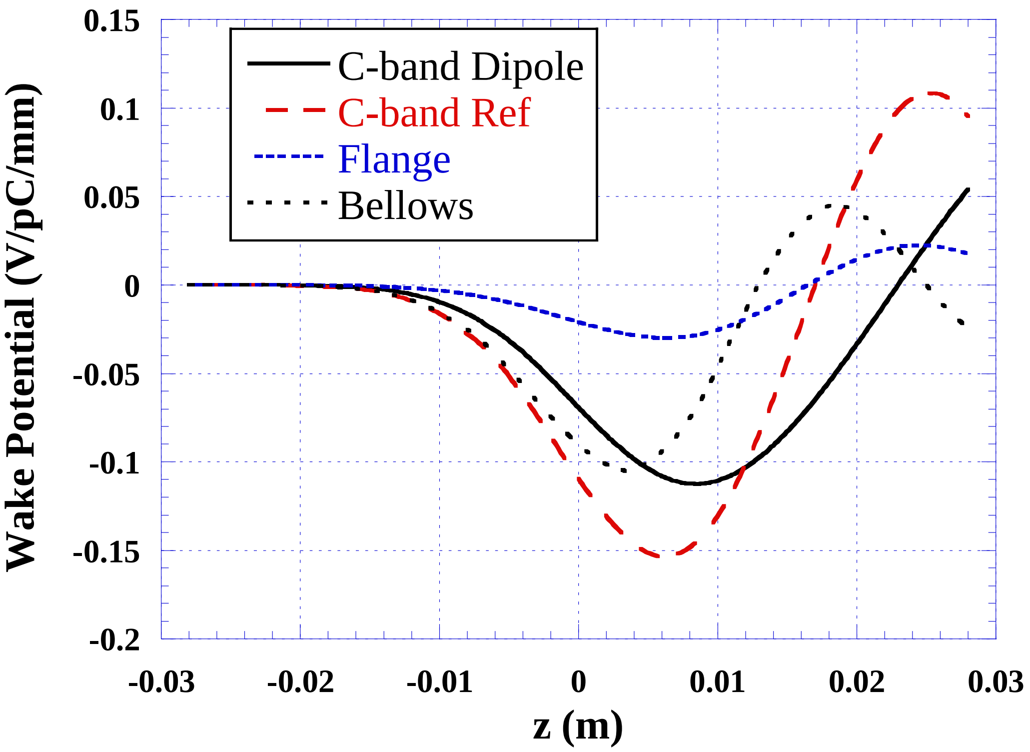
2 mover

- Reference cavity and model CBPM (C-band dipole cavity)
- Reference cavity and straight pipe (masked bellows)

mOTR chambers (OTR0, 1, 2, 3)

Wake-potential of components

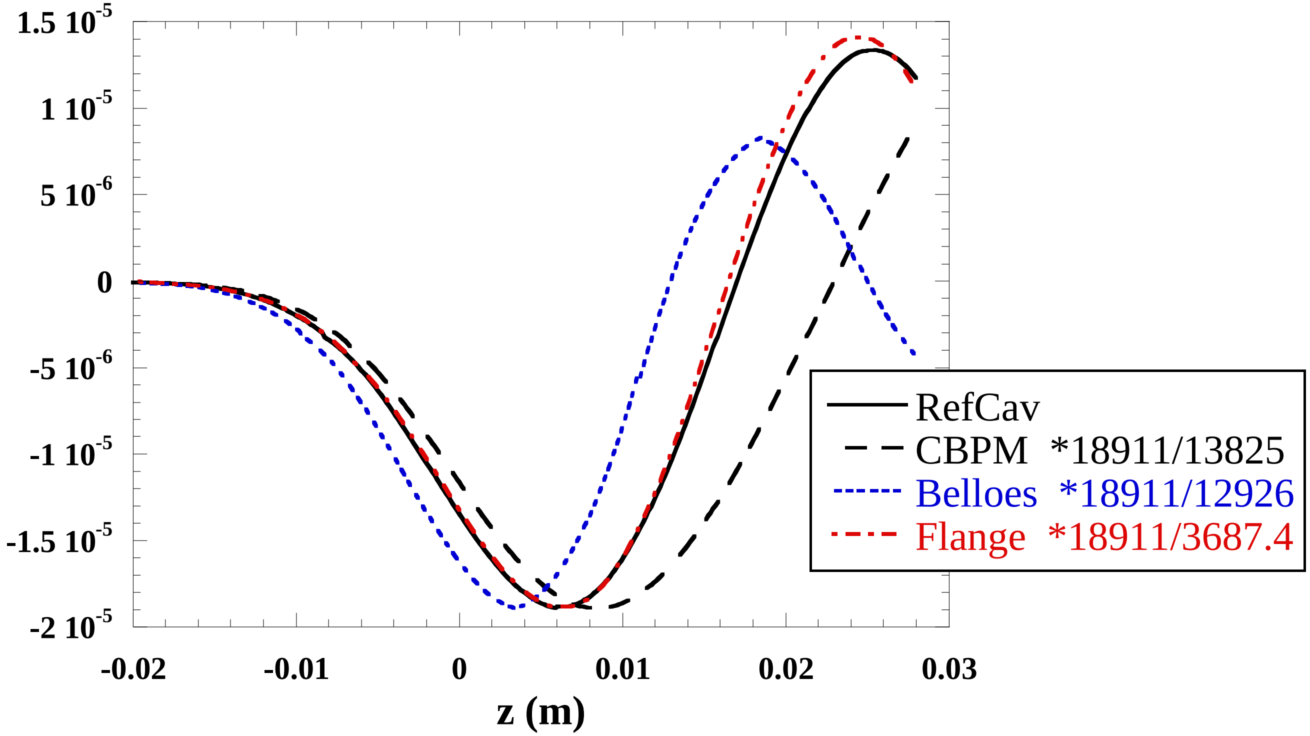
Calculated by Alexey Lyapin



Wake-potential of components

Calculated by Alexey Lyapin

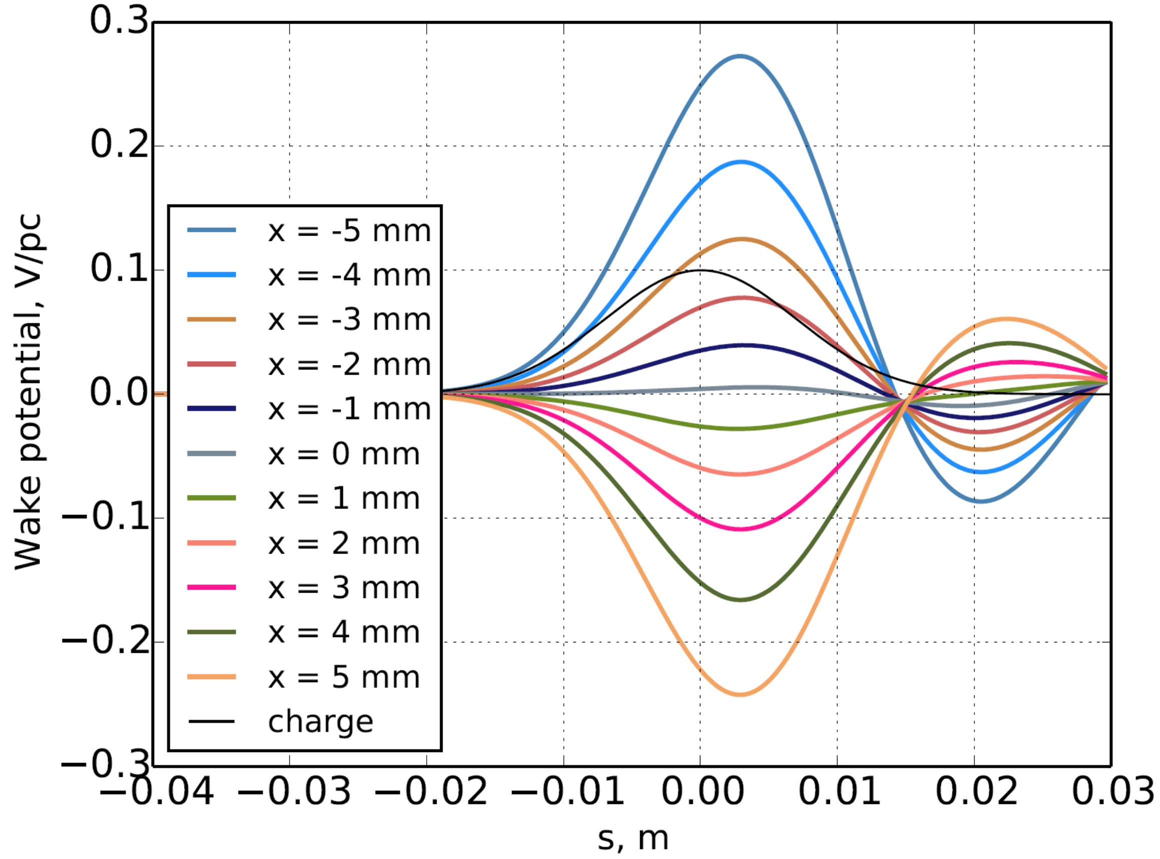
Shapes of wakepotential (normalized to have same peak)



Inductive ← Bellows (Flange, RefCav) CBPM → Capacitive

Wake of OTR monitor chamber

Calculated by Alexey Lyapin



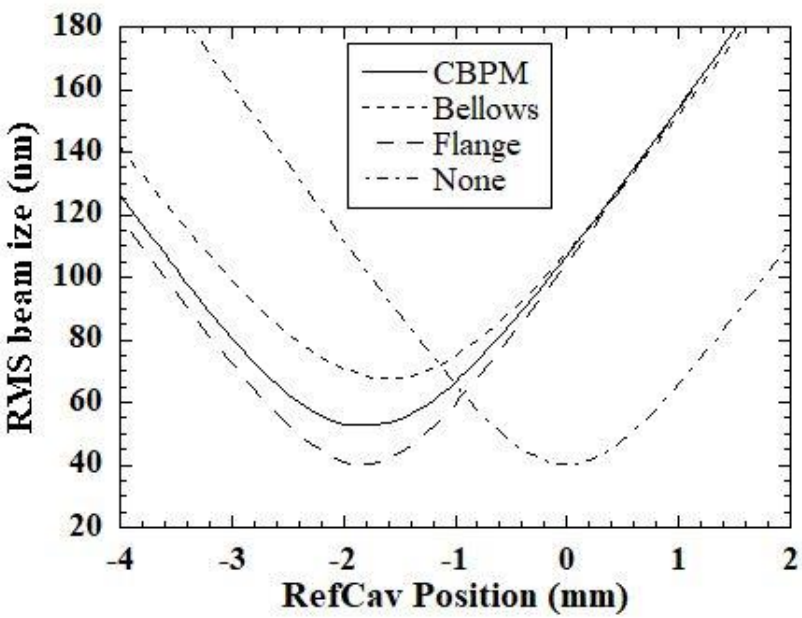
Similar to bellows?

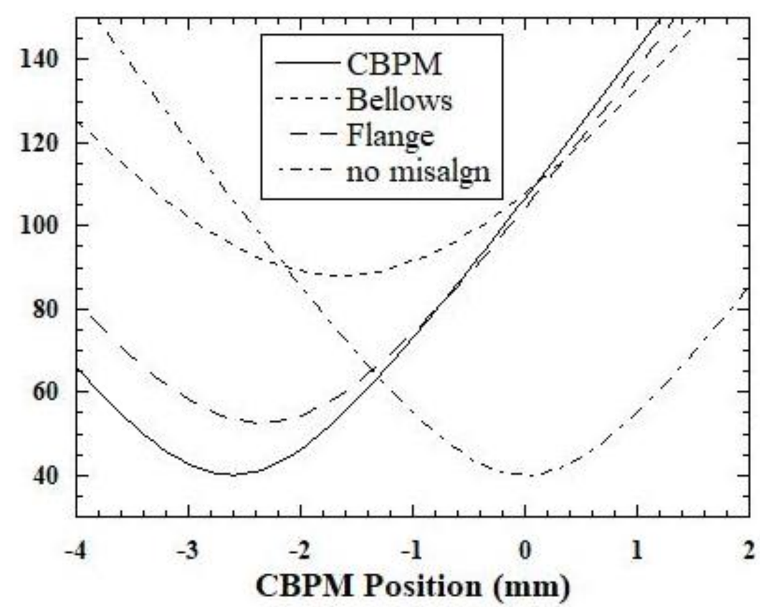
Cancellation of wakefield (simulation)

4 cases:

- Set misalignment of one of CBPM, Bellows or Flange, for IP beam size ~ 110nm.
- No misalignment.

Beam size vs position of RefCav (left fig.) or CBPM (right fig.) on mover.



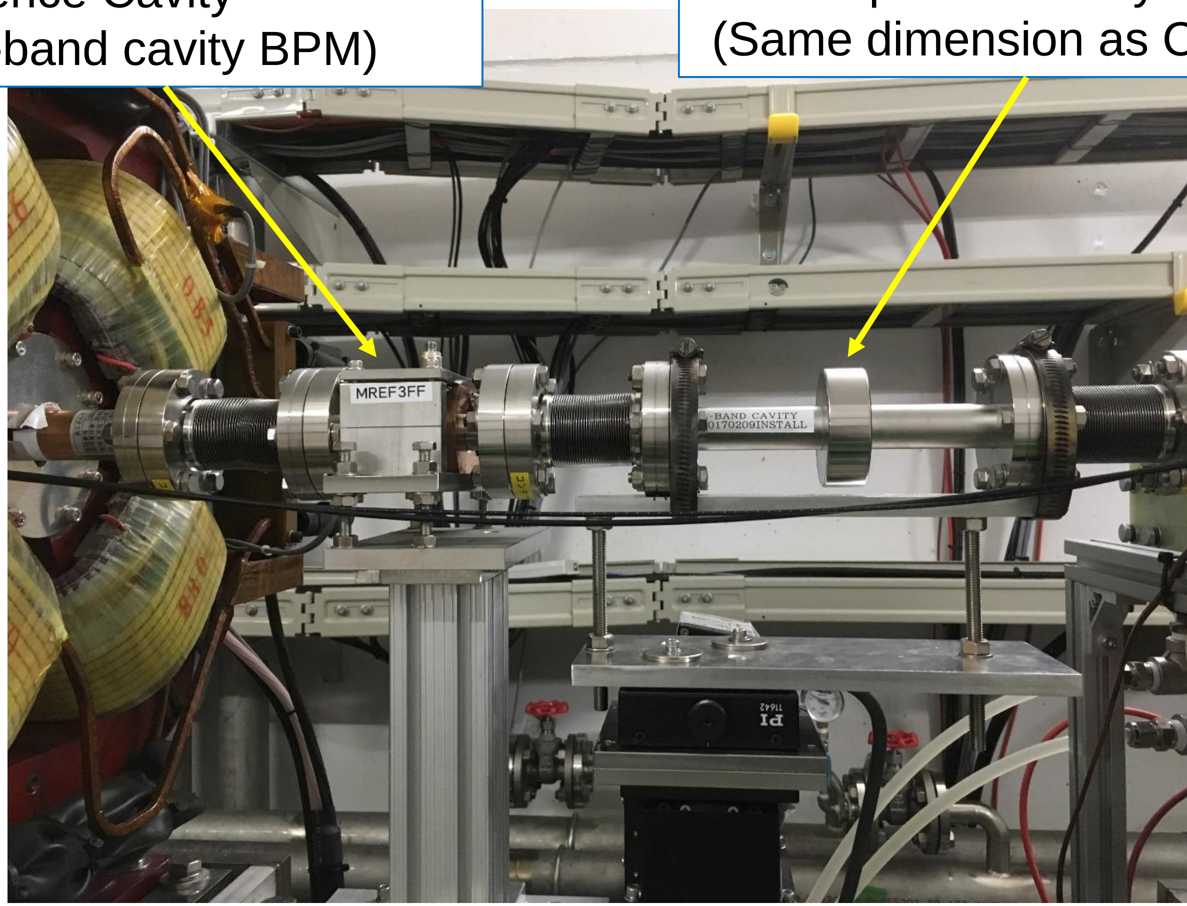


Wake of bellows is not well cancelled.

Two different wakefield sources on mover in high beta region

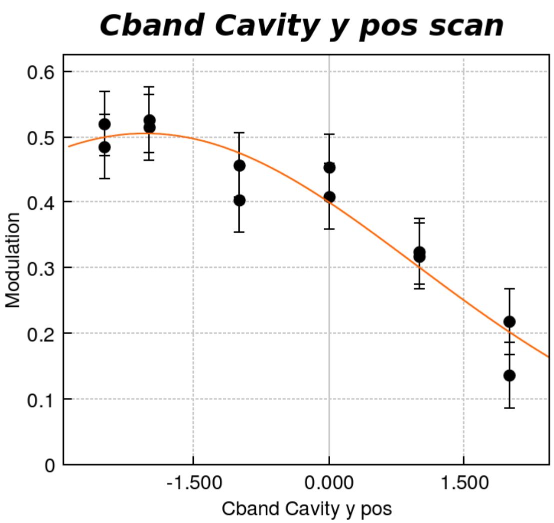
Reference Cavity
(for C-band cavity BPM)

C-band pill-box cavity
(Same dimension as Cavity BPM)

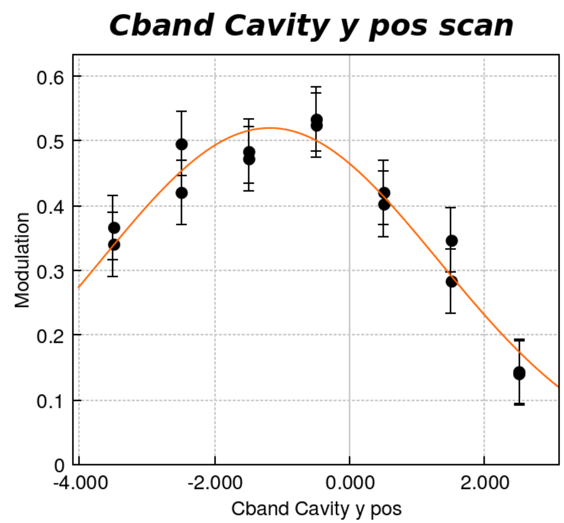


“2-Dimensional scan”: scan C-band cavity with different position of Reference cavity

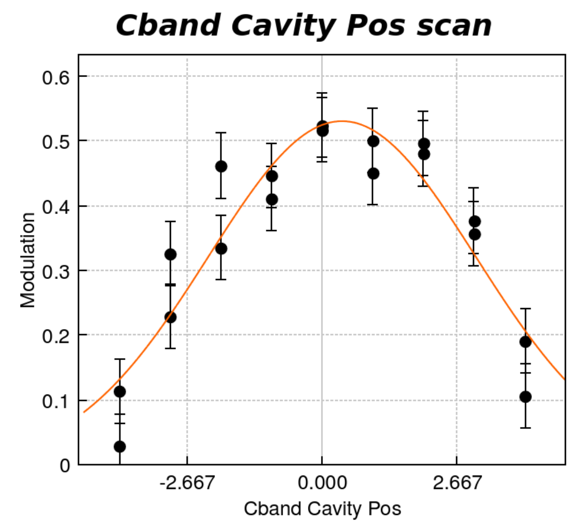
RefCav +2 mm



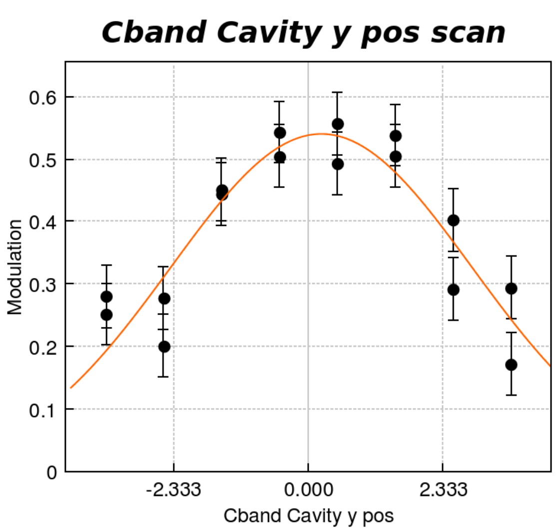
RefCav +1 mm



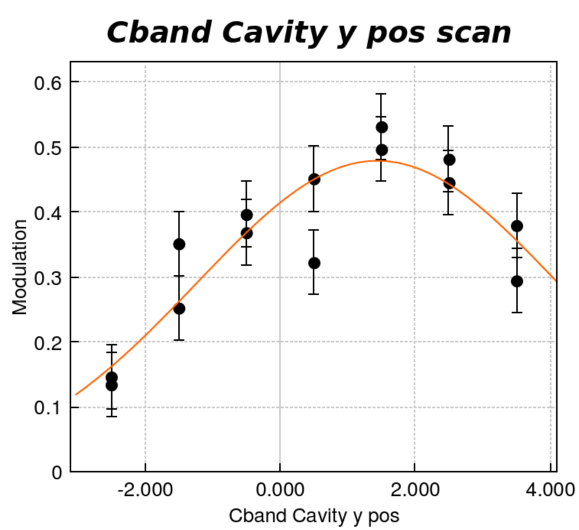
RefCav 0 mm



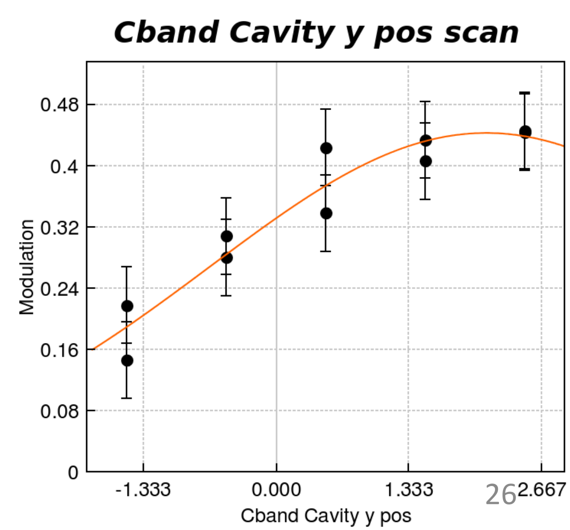
RefCav 0 mm



RefCav -1 mm

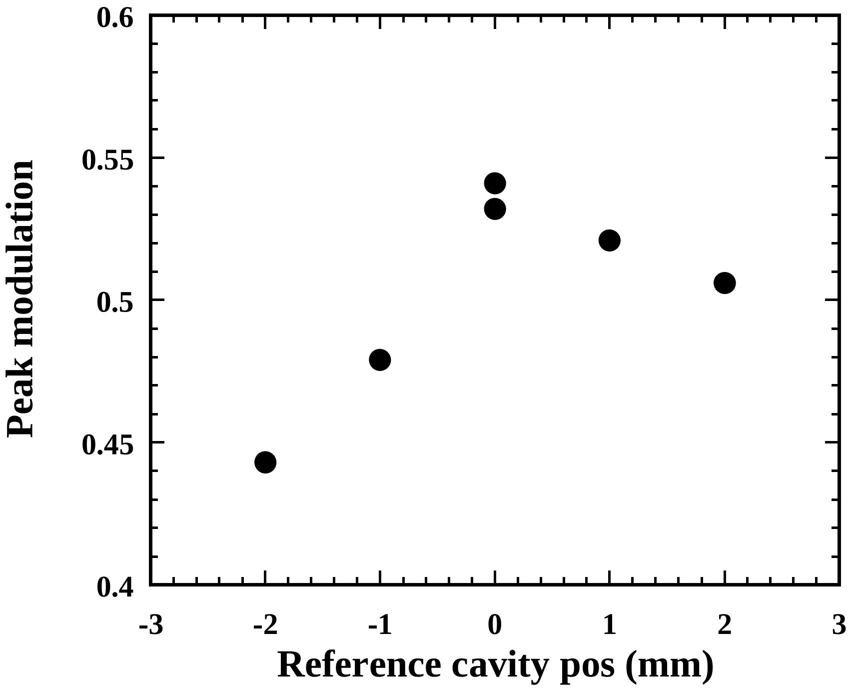


RefCav -2 mm



Result of 2-D scan

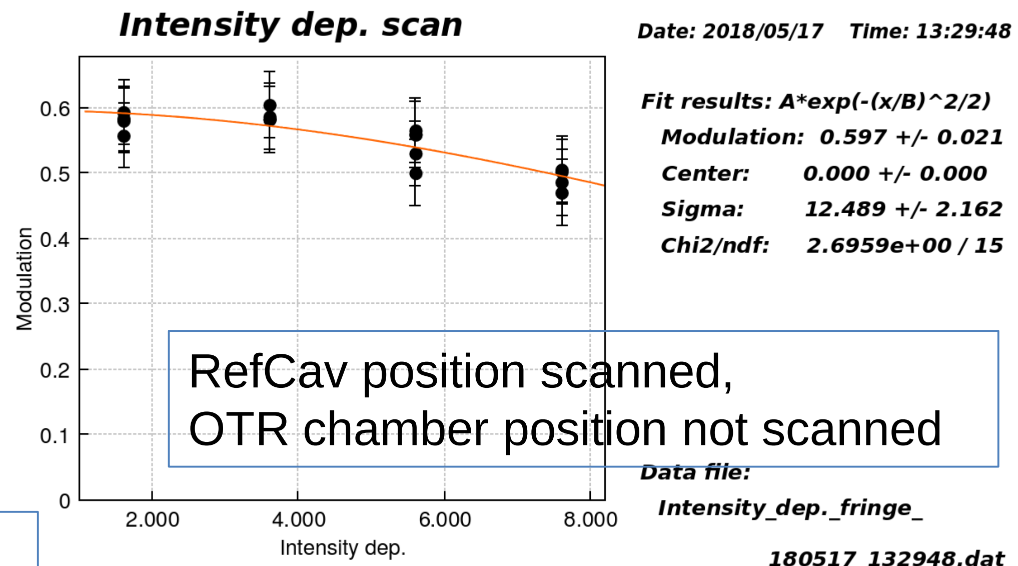
Peak Modulation vs. position of Reference cavity



Wakefields of The two sources are not completely canceled.
There is one optimum setting.
Suggesting
Two sources on mover can cancel wkaefields of others better than one.

May 2018 1st week

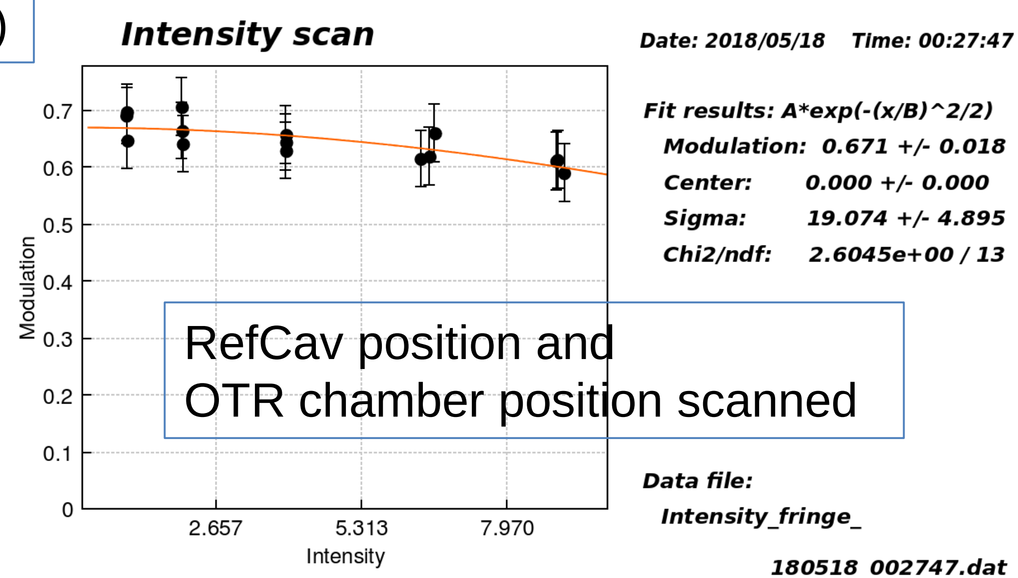
13.1 nm/1e9



RefCav position scanned,
OTR chamber position not scanned

YAG screen monitor
Removed (May 17,2018)

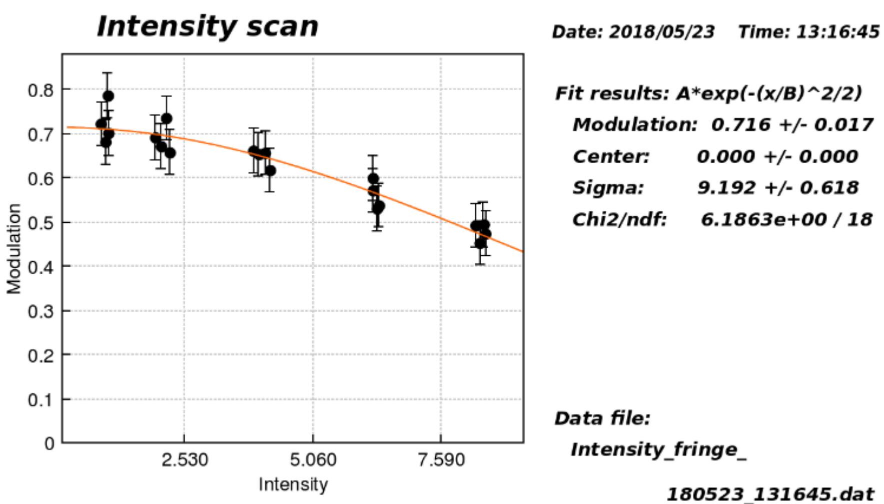
8.6 nm/1e9

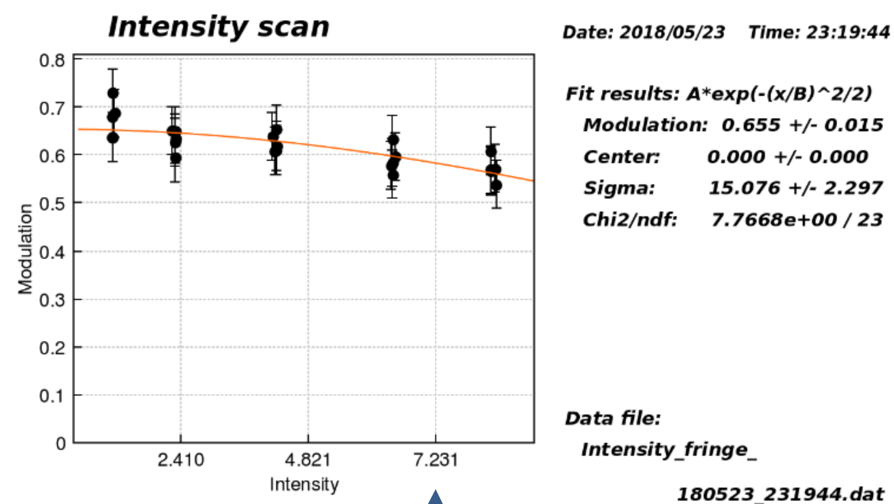


RefCav position and
OTR chamber position scanned

May 2018 2nd week

Adjusting positions of OTR chamber(s) (in addition to RefCav, Straight pipe on movers) could reduce intensity dependence.



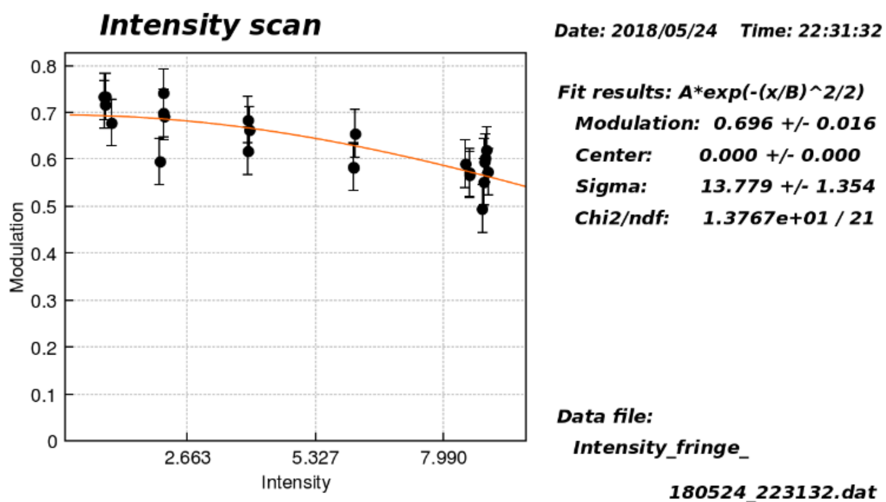


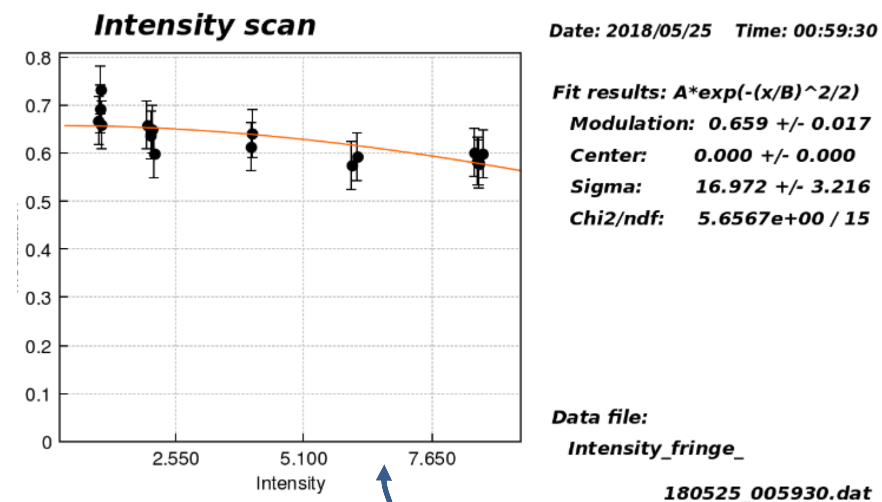
More tuning (RefCav, Pipe OTR positions)

May 23 day and swing shift
17.8 nm/1e9 → 10.9 nm/1e9
Nominal(?) beta_y*, angle jitter 85 urad

May 2018 2nd week

Adjusting positions of OTR chamber(s) (in addition to RefCav, Straight pipe on movers) could reduce intensity dependence.





mOTR chamber position tuning

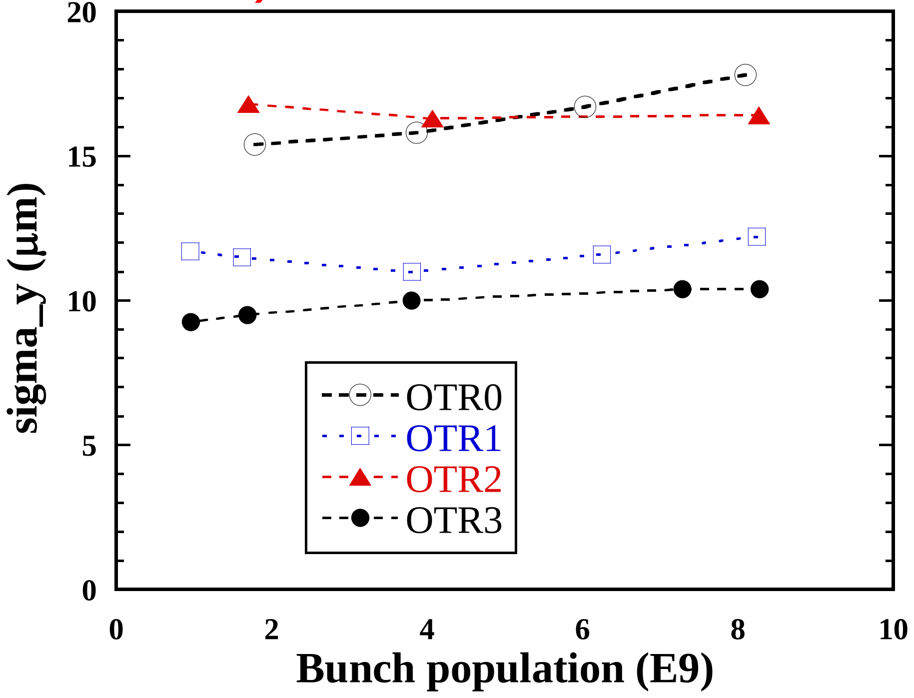
May 24 swing shift

11.9 nm/1e9 → 9.6 nm/1e9

Large beta_y*, angle jitter 25 urad

Intensity dependence in upstream May 2018 2nd week

- Beam sizes measured using multi OTR monitors, changing bunch intensity.
- Very weak intensity dependence observed.
- Intensity dependence sources are downstream (in Final Focus Line).



Summary

- Wakefield + angle jitter (angle at IP phase orbit jitter) is significant source of beam size intensity dependence
  - But cannot explain all dependence.
- Reduction of wakefield in 2016. Removal of cavity BPMs, etc.
  - Intensity dependence reduction factor about 1/2
- Removal of YAG monitor in May 2018
  - Intensity dependence reduction factor about 2/3 (?)
- Cancellation by wakefield sources on mover
  - Incomplete cancellation of wakefield by single wake source.
  - Two sources (RefCav + Dipole cavities) -> better than one
  - OTR chamber position change is also effective.
  - More experiments with different types of wake sources?

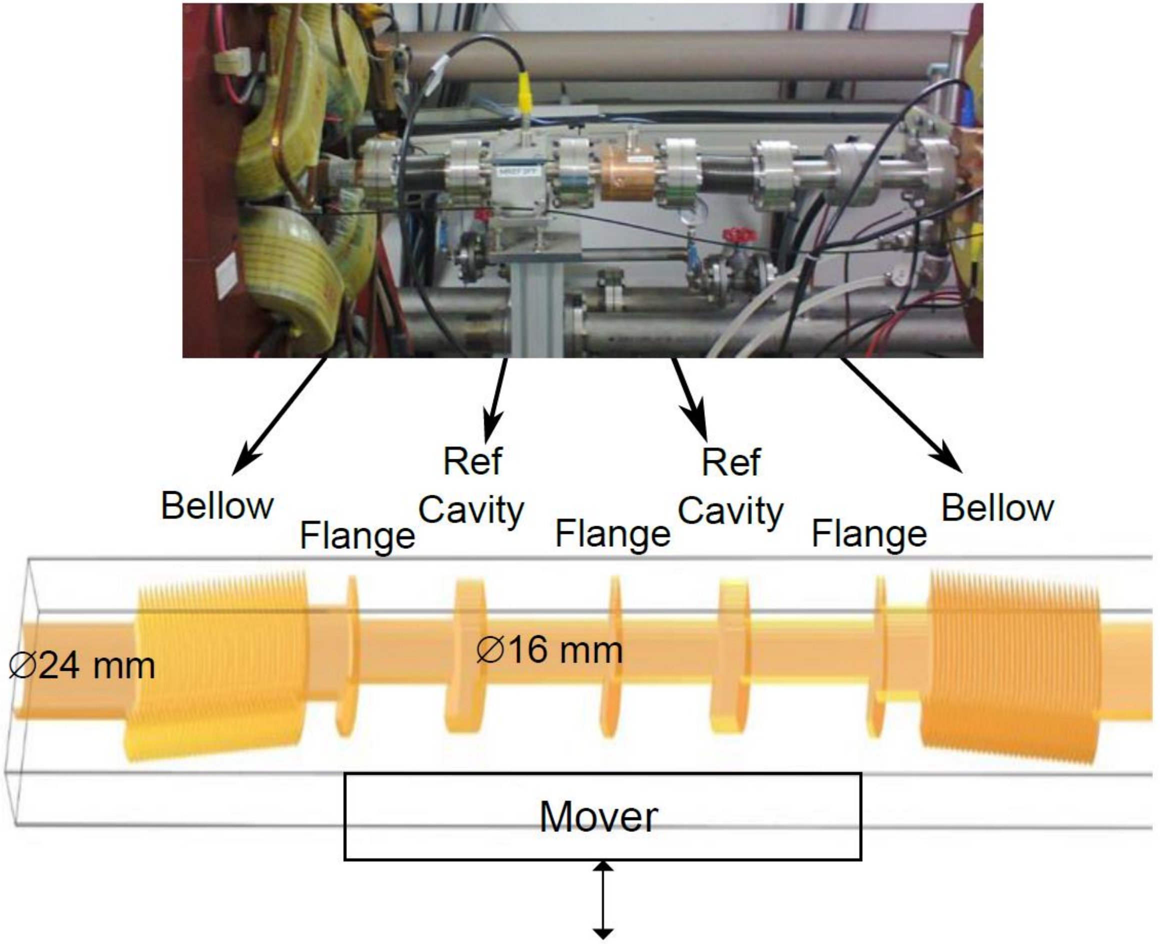
Supplement

- Wake source on mover
  Calculations and experiments

- Wakefield at ILC and ATF2

Orbit change vs. position of wake source on mover

J. Snuverink et.al., Phys. Rev. Accel. Beams 19, 091002



Orbit response to position change of Cavity BPM reference cavity (old setup: 2 cavities on mover)

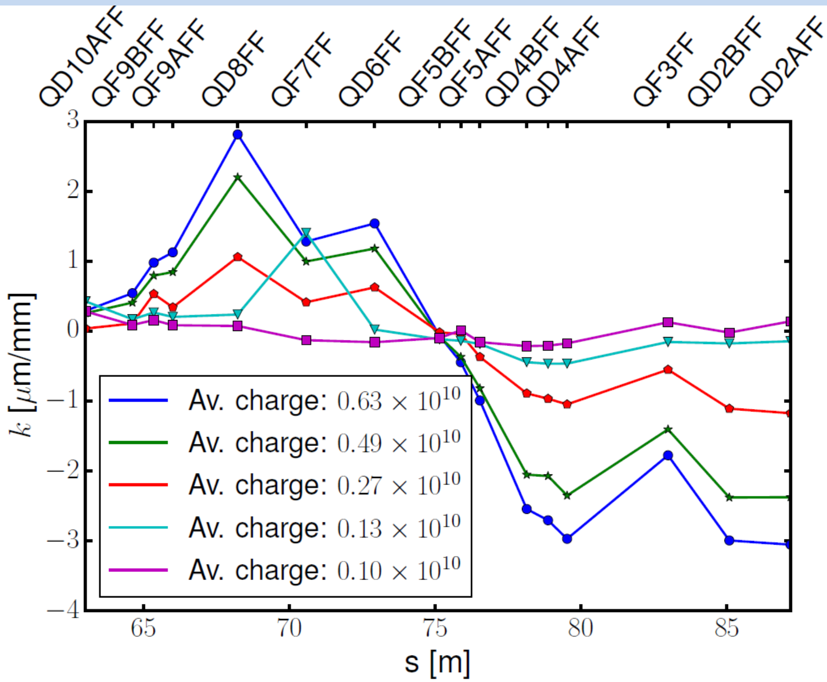


FIG. 11. The vertical orbit response for each CBPM with respect to the movable section position for different bunch intensities after pulse averaging and jitter subtraction.

Measured response agreed with simulation within factor 1.2

J. Snuverink et.al., Phys. Rev. Accel. Beams 19, 091002

IP beam size vs mover position experiment and calc.

ATF2 weekly meeting 20130708 K.Kubo

Effect of wake source at the mover, offset 1 mm, bunch charge 1 nC.
IP beam size increase (nm/mm/nC)

	C-band ref.	No mask Bellows	Masked Bellows
Experiment	55	47~50	7
Calc	32.2	22.6	?

Measured response agreed with simulation within factor 1.5 ~ 2

Very rough and preliminary calculation.
More accurate calculations???

Comparison of Wakefield effect ILC and ATF2

Assumptions

- Wakefield sources (discontinuities in beam pipe)
  - At every quadrupole magnet
  - Similar structure in ILC and ATF

- Same random misalignment.

- Same orbit jitter relative to beam size

Estimate beam size growth relative to beam size at IP

Effect of wakefield with Random misalignment

$$\frac{\sqrt{\sigma^2-\sigma_0^2}}{\sigma_0} \propto \frac{qW}{E\sqrt{\varepsilon}}\sqrt{\sum \beta}$$

q : bunch charge
W : strength of wakefield
E : beam energy
ε : emittance
β : beta-function at wake source

	ILC	ATF2	Ratio of effect
E (GeV)	125	1.3	0.01
W (bunch length effect)	0.4	1	0.5
Emittance (pm)	1.6	12	2.7
$\sum \beta$ (m)	3.9E5	6.1E4	2.5
Total			0.033

Effect of wakefield with Orbit distortion (orbit jitter)

$$\frac{\sqrt{\sigma^2 - \sigma_0^2}}{\sigma_0} \propto \frac{qW}{E} \sum \beta$$

	ILC	ATF2	Ratio of effect
E (GeV)	125	1.3	0.01
W (bunch length effect)	0.4	1	0.4
$\sum \beta$ (m)	3.9E5	6.1E4	6.4
Total			0.026

Wakefield effects in ILC and ATF2

Effect in ILC Final Focus line is factor

0.026~0.033

of effect in ATF2 Final Focus line

for the same charge/bunch

ATF2 minimum beam size observed with

~0.1E10 e/bunch

→ Corresponds to 3.0~3.8E10 e/bunch > 2E10

Effect in ILC: smaller than ATF2 low intensity operation

We did not realize the significance of wakefield effects and ATF2 beam line was not carefully designed.

→ May expect further reduction in ILC.

Backup

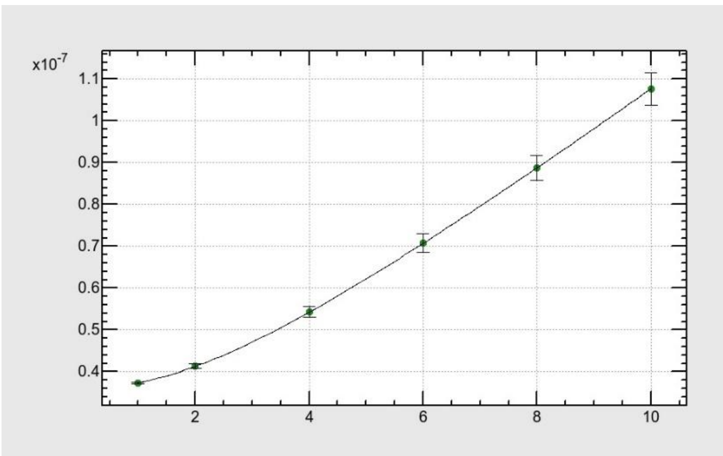
Simulation: orbit jitter + wakefiled
rms beam size (projection of many pulses)
and IPBSM measurement

Old config.

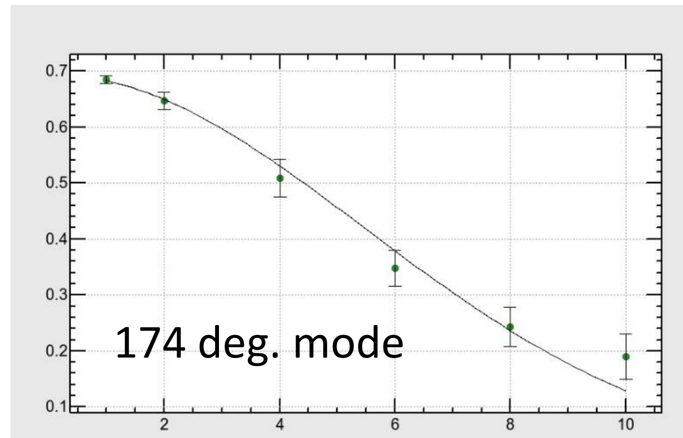
K.Kubo, 20160909 ATF operation meeting

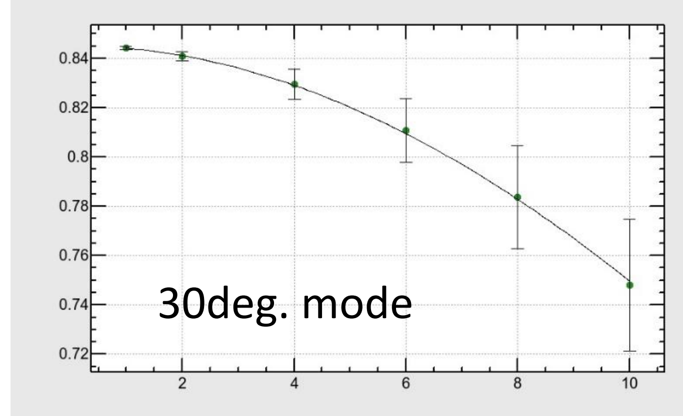
Initial emittance 12 pm, beta* 0.1 mm, angle jitter 0.2-sigma

Projected beam size (m) vs. intensity (E9)



Modulation vs. intensity (E9)





Fitted dependence:
- 10.1 nm/E9 (projection)
- 7.8 nm/E9 (174 deg. mode)
- 8.0 nm/E9 (30 deg. mode)

Effect of Wakefield + Orbit jitter

Asuuming:

i-th wakefield source is at $(n+1/2)\pi$ phase to IP, beta-function β_i

"Angle at IP" jitter amplitude: a-sigma of nominal divergence

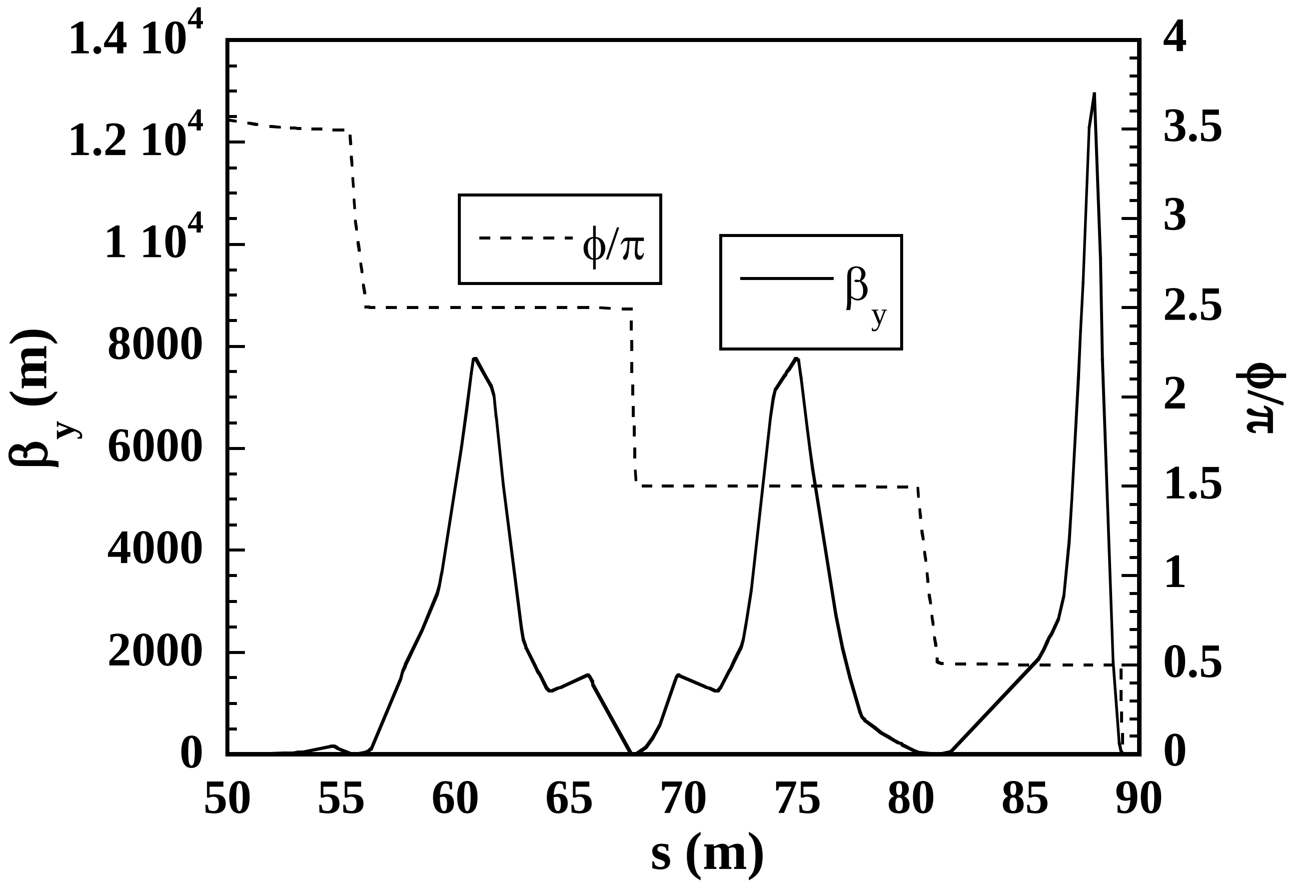
$$\text{effect to beam size} \propto a\sqrt{\beta_{IP}\varepsilon}\sum_i \beta_i W_i$$

$$\text{Each wakefield source contributes as} \propto \beta_i W_i$$

If β_{IP} is changed, proportional to "angle at IP" jitter

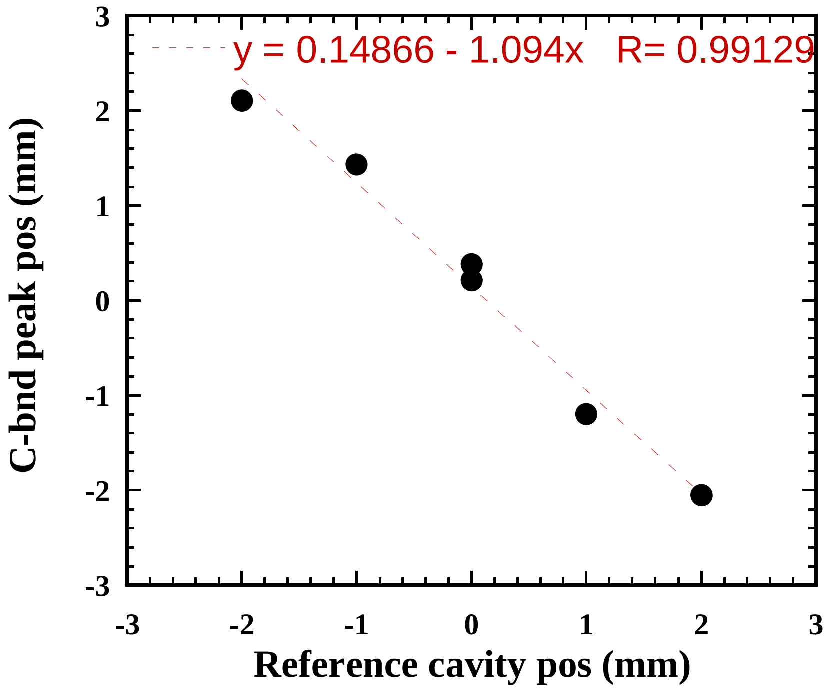
$$\Theta \propto \underbrace{a\sqrt{\varepsilon / \beta_{IP}}}_{\text{Angle jitter}}\sum_i \underbrace{\beta_{IP}\beta_i W_i}_{\text{constant}}$$

Large beta region to IP
Phase ~ (n+1/2)π



Result of 2-D scan

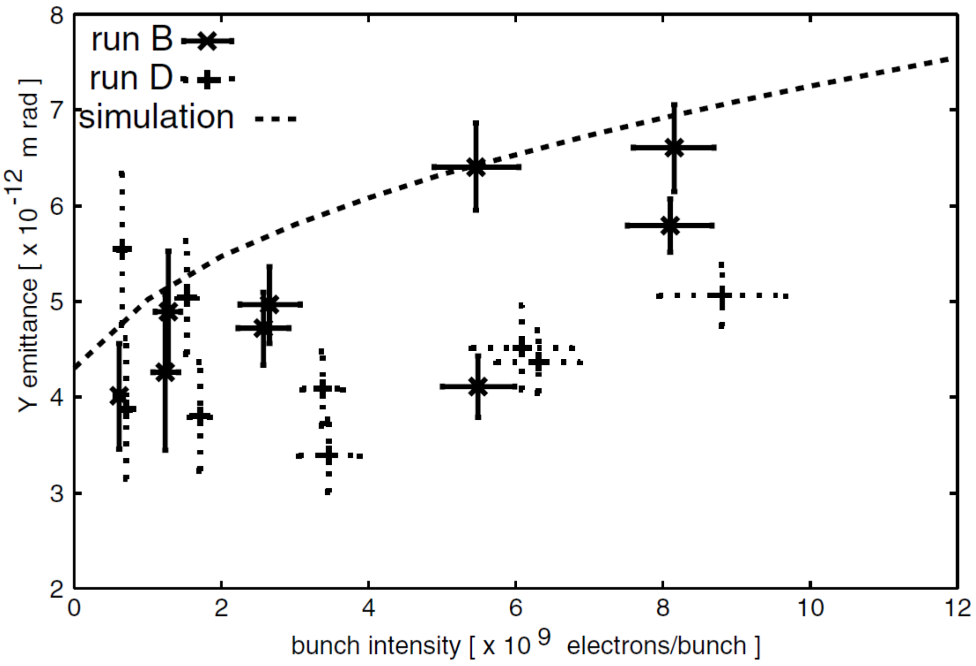
Position of C-band cavity giving Modulation peak
vs. position of Reference cavity



Effect of Reference cavity move is
10~20% larger than effect of C-band cavity move

Intensity dependence in upstream (In Damping Ring)

- Emittance measurement and simulation of intra-beam scattering effect (Phys. Rev. Lett. 92, 054802 (2004))



Small effect compared with ATF2 design emittance, 12 pm.