IBIC 2022 International Beam Instrumentation Conference

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Pulse-by-pulse Photon Beam Position Measurements

at the SPring-8 Undulator Beamline

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Outlines

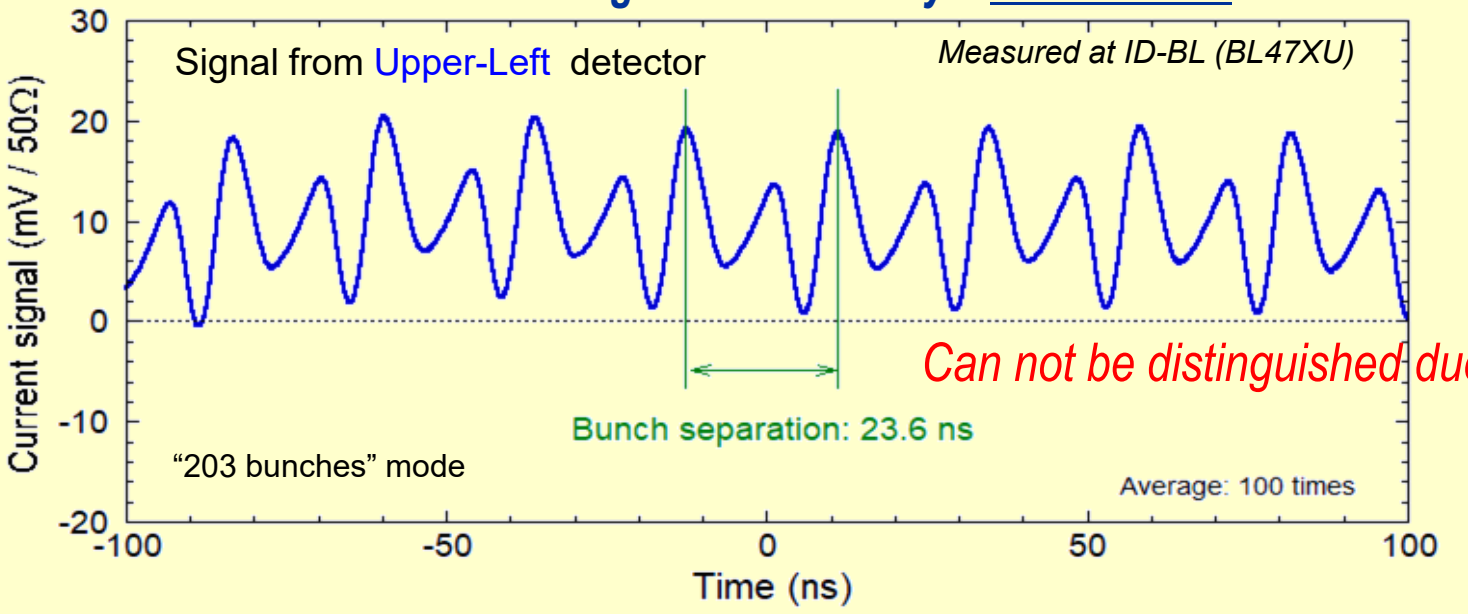
(XBPM: X-ray Beam Position Monitor)

- **Background**
  - Limit of conventional XBPMs
  - Prototype of a pulse-by-pulse (pulse-mode) XBPM
- **Modification for further heat resistance**
  - Modified structure of detecting elements
  - Comparison of waveforms between before and after
- **Evaluation tests at an undulator beamline**
  - Position sensitivity / Resolution /
  - Observation during beam injection
- **Summary**

Limitation of conventional (traditional) XBPMs

Conventional X-ray Beam Position Monitors (photoelectron emission type) have been used for a long time all over the world.
However, they are not possible to observe pulse-by-pulse beam fluctuation.

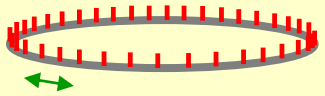
Waveform of current signal measured by a conventional XBPM



Can not be distinguished due to pileup!

Filling pattern: "203 bunches" mode (uniform filling)

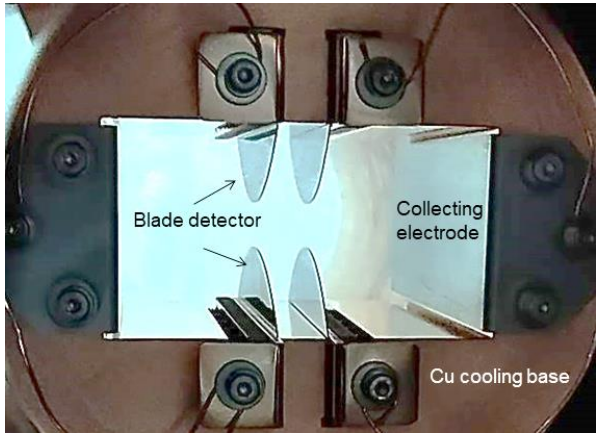
Bunch separation: 12 buckets (23.6 ns)

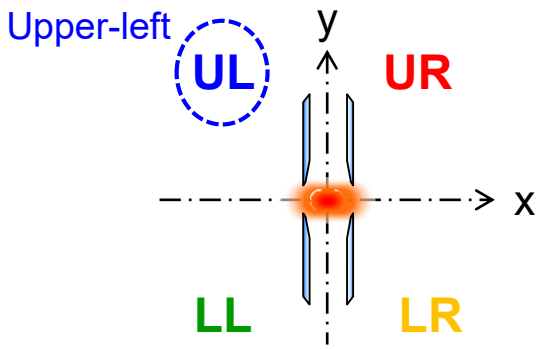


Bunch current: ~0.5 mA / bunch

For time-resolved experiments (user experiments), pulse-by-pulse measurement of photon beam is highly desired.

Conventional XBPM





Position is calculated from four detection elements.

$$X\,(mm) = \boldsymbol{Ax} \times \frac{(UR + LR) - (UL + LL)}{UL + UR + LL + LR}$$

$$Y\,(mm) = \boldsymbol{Ay} \times \frac{(UL + UR) - (LL + LR)}{UL + UR + LL + LR}$$

Design policy for a pulse-by-pulse *(pulse-mode, PM-)* XBPM

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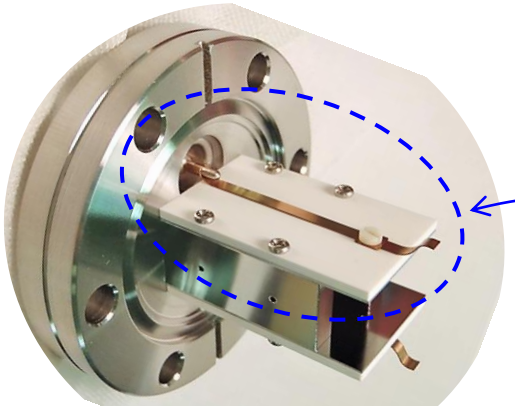
Two keywords to improve high frequency properties, while maintaining the heat resistance:

1. **Impedance matching** to 50 Ω : Microstripline and vacuum feedthroughs were newly designed.
2. **Small floating capacitance** (short time constant) : Size of the detecting elements were minimized.

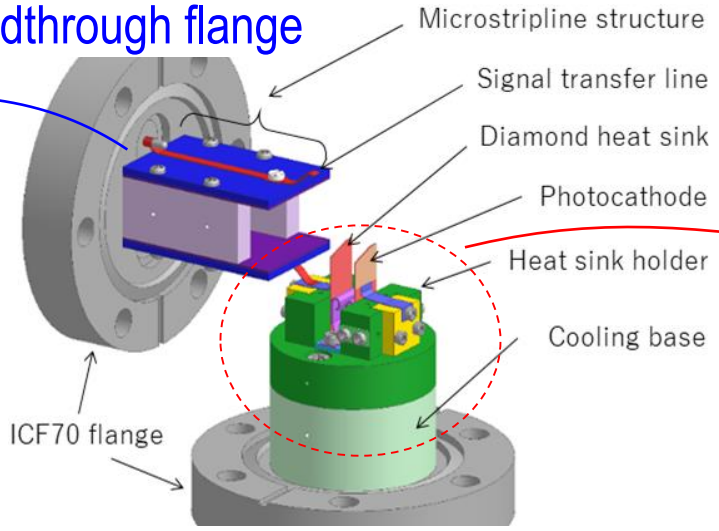
*We devised a detection element using **microstripline structure** and **diamond heatsink**.*



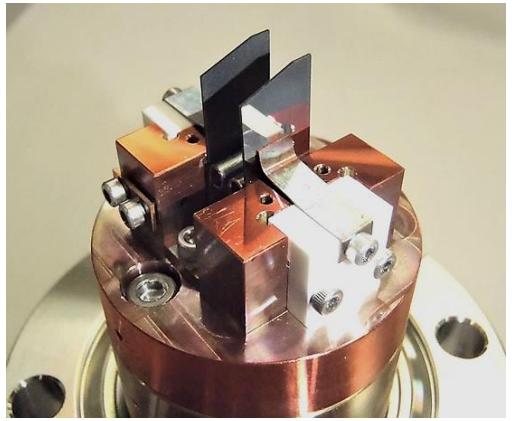
Microstripline

Vertically symmetrical structure

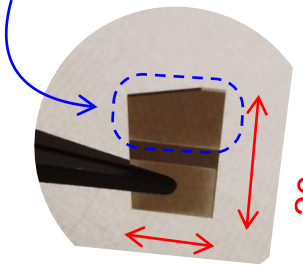
Vacuum feedthrough flange



Cooling base flange



Photocathode:
Ti sputter deposition
t = 1 μm

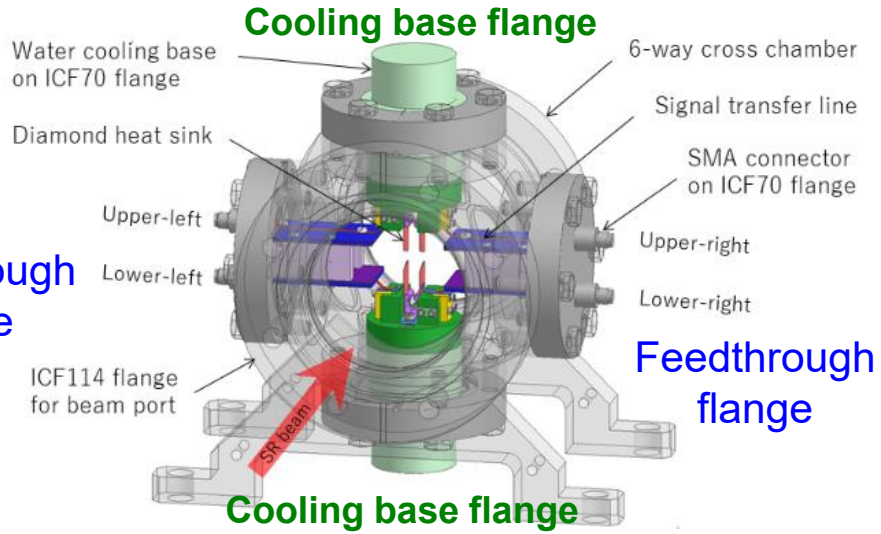


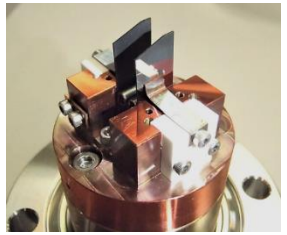
Diamond heatsink
t = 0.3 mm

Prototype of detection elements

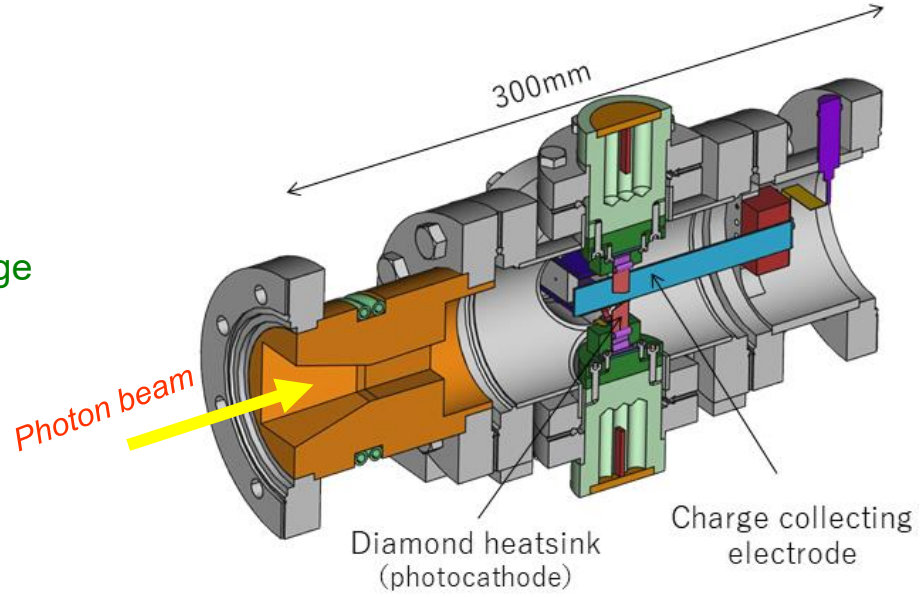
Structure of PM-XBPM *with the **prototype** detection elements*

Feedthrough flange

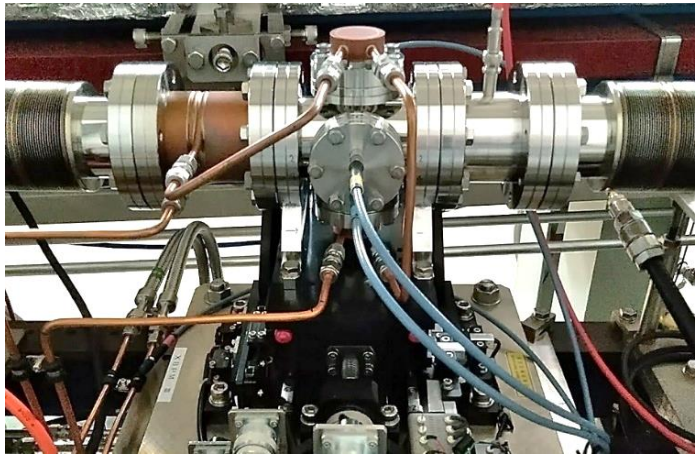




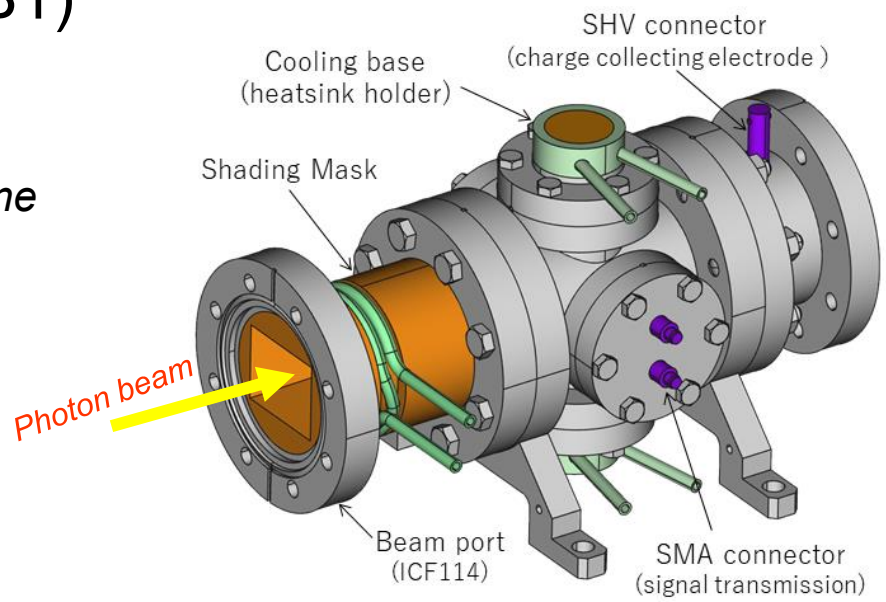
Cooling base flange



The prototype has been operating at the BM-BL (BL02B1) for over three years without any troubes.



BM-BL: Bending Magnet Beam Line



Modification for further heat resistance

Our goal is to perform at an ID-BL, which is irradiated by intense power.

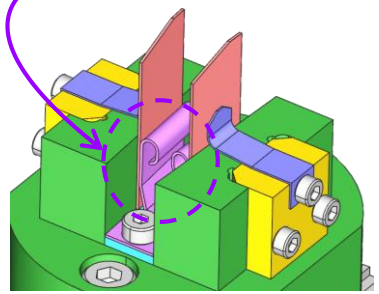
	Maximum power density	Actual irradiation power density
BM-BL	1.5 kW/mrad^2	~0.1 W/mm^2
ID-BL	~500 kW/mrad^2	< ~25 W/mm^2

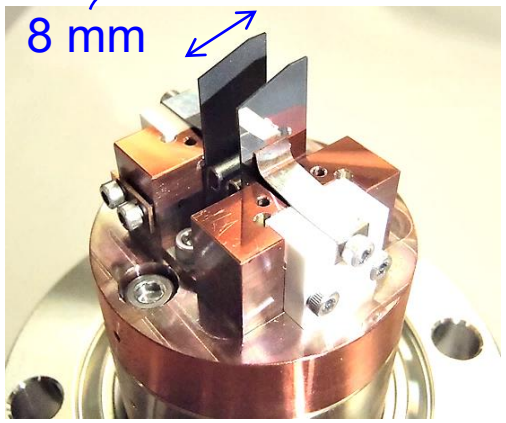
BM-BL: Bending Magnet Beam Line

ID-BL: Insertion Device Beam Line

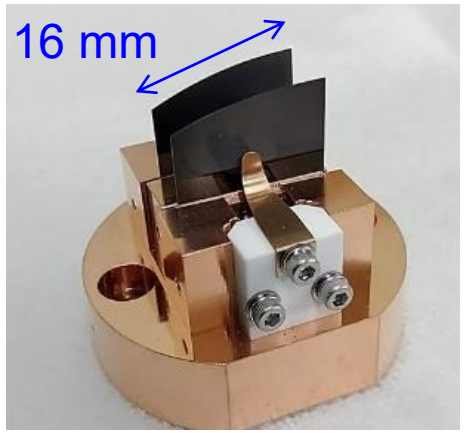
Therefore, the mounting method of the detection elements was modified.

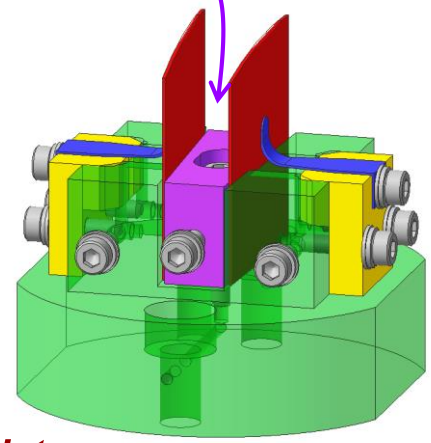
1. *Double the size along the beam axis to increase contact area with the cooling holder.*
2. *Clamp on the both sides of diamond heatsinks using a wedge-shaped Cu-plug.*





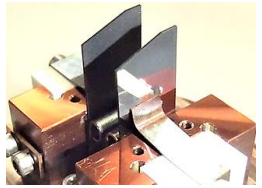
Prototype





Modified type

Waveform comparison between *Prototype* and *Modified type*

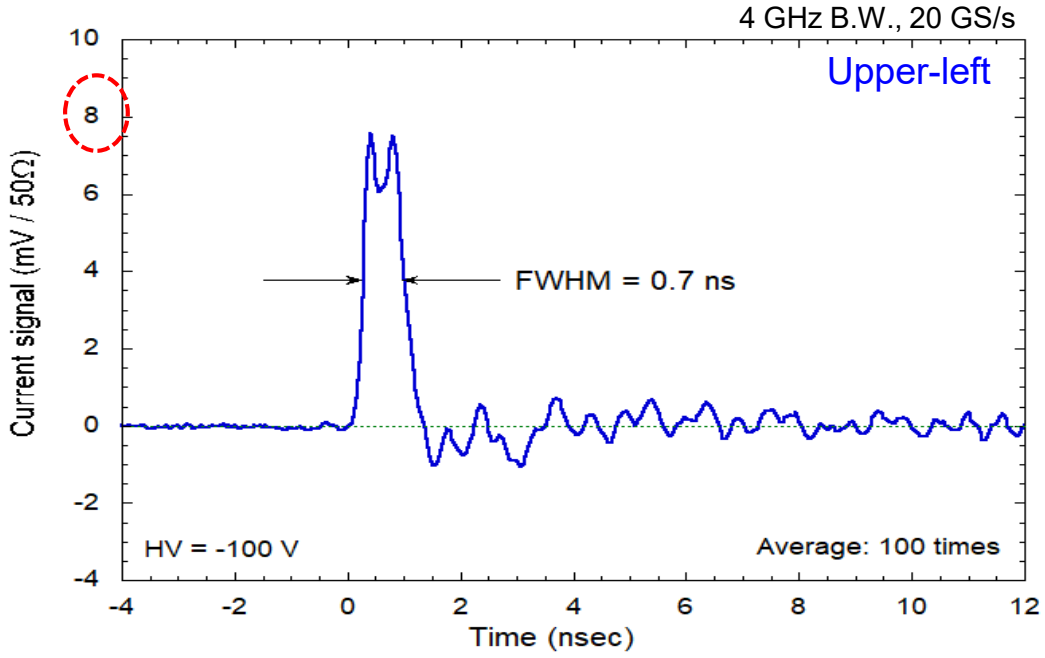


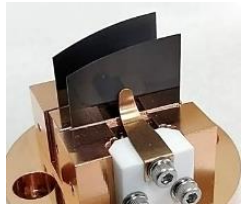
PRAB 24, 032803

Prototype

*Tested at **BM-BL** (BL02B1)*

3.0 mA / bunch

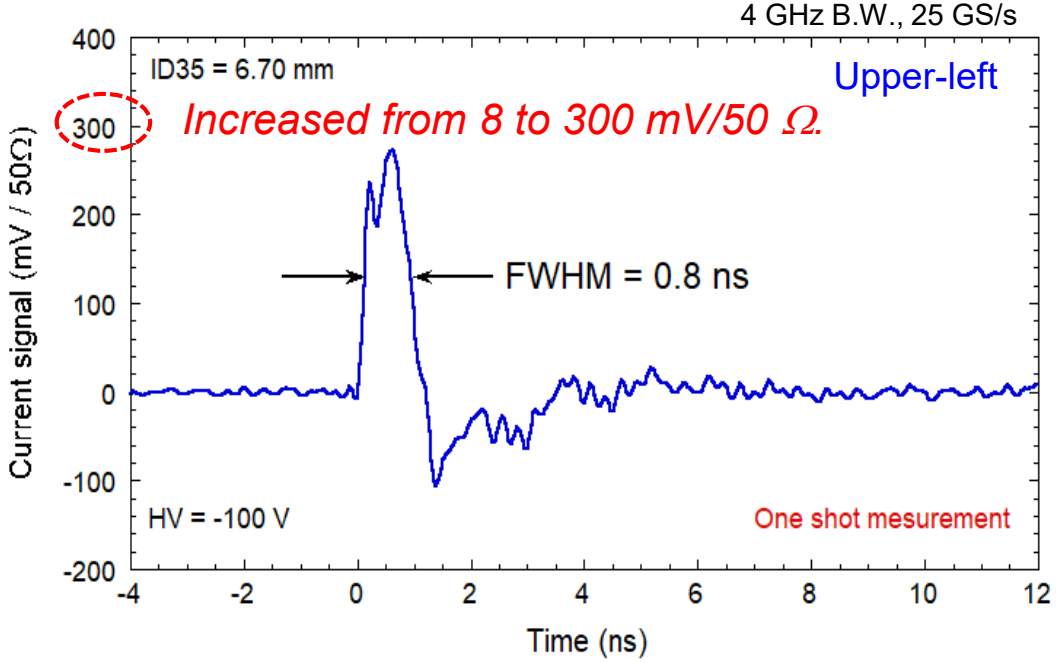




Modified type

*Tested at **ID-BL** (BL35XU)*

1.6 mA / bunch



There is no change in waveform, suggesting that basic performances are maintained.

An increase in current signal is directly beneficial for resolution.

Evaluation tests of PM-XBPM

equipped with the modified detection elements

at ID-BL

- Position sensitivity
- Resolution
- Observation during beam injection

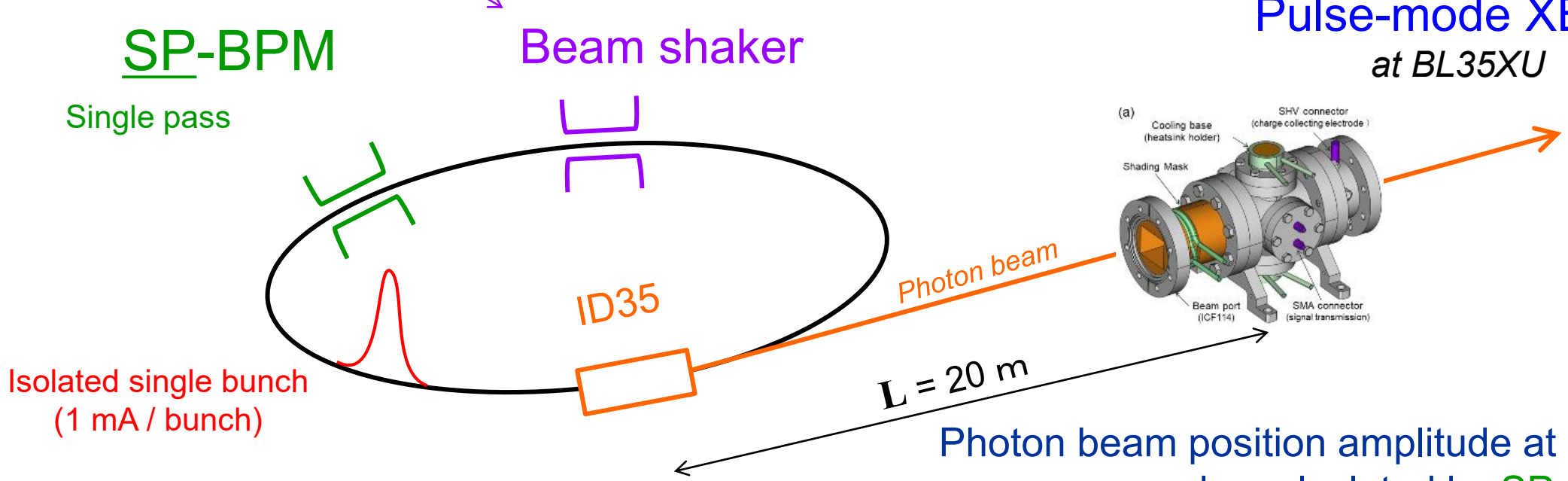
Position sensitivity : *Experimental setup and methods*

To know the sensitivity of a PM-XBPM, it is necessary to know a real motion of photon beam. But we presently do not have the means.

We compared PM-XBPM data with the perturbation amplitudes estimated from SP-BPM data.

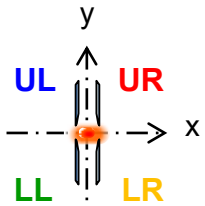
Stationary perturbation was excited by RFKO (Radio Frequency Knockout) .

Perturbation frequency
Horz : 28.9 kHz (ν_x = 41.1382)
Vert: 60.0kHz (ν_y = 19.3257)



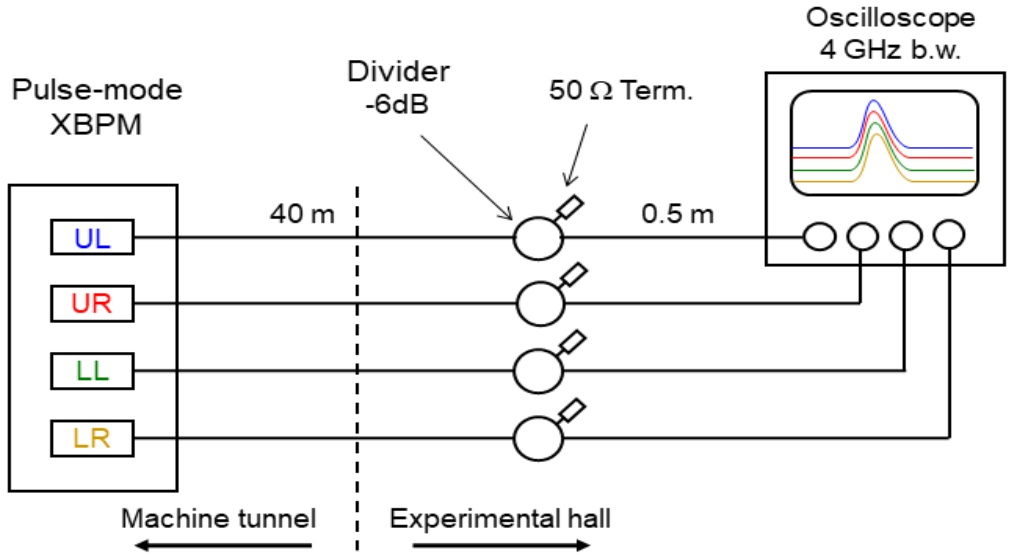
Photon beam position amplitude at PM-XBPM can be calculated by SP-BPM data.

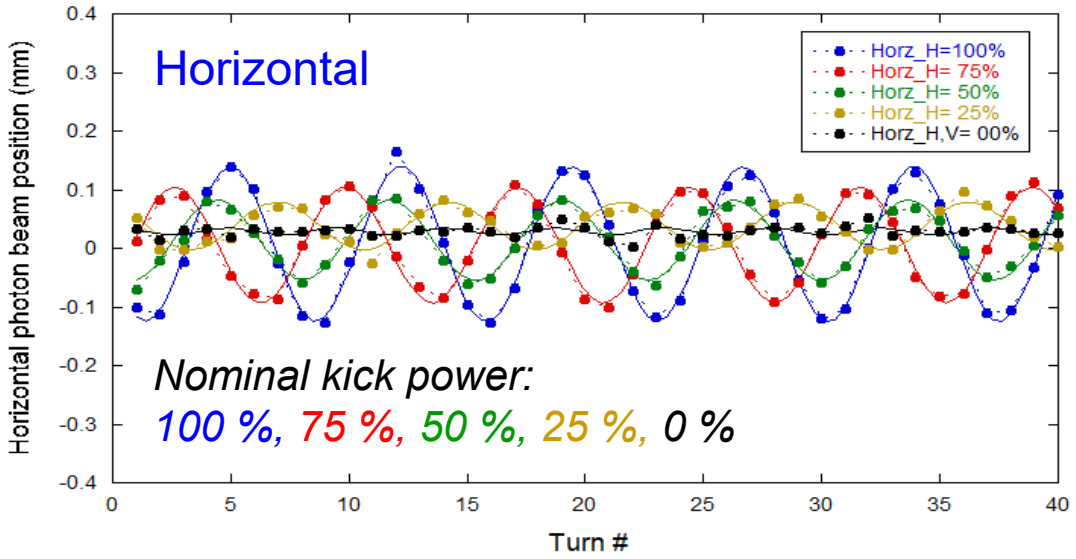
Position sensitivity: *Measurement by PM-XBPM*

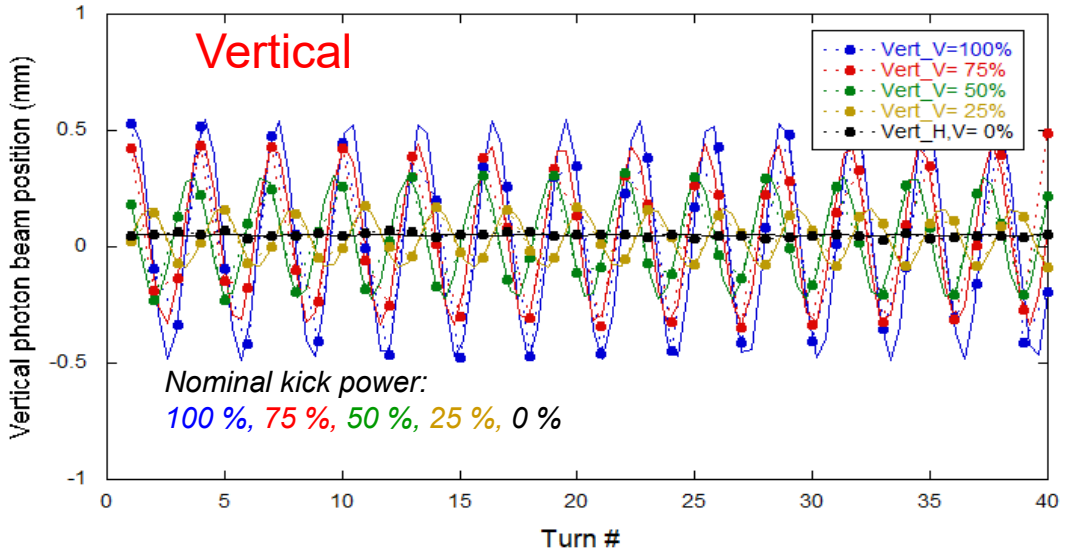


$$X(mm) = Ax \times \frac{(UR + LR) - (UL + LL)}{UL + UR + LL + LR}$$

$$Y(mm) = Ay \times \frac{(UL + UR) - (LL + LR)}{UL + UR + LL + LR}$$





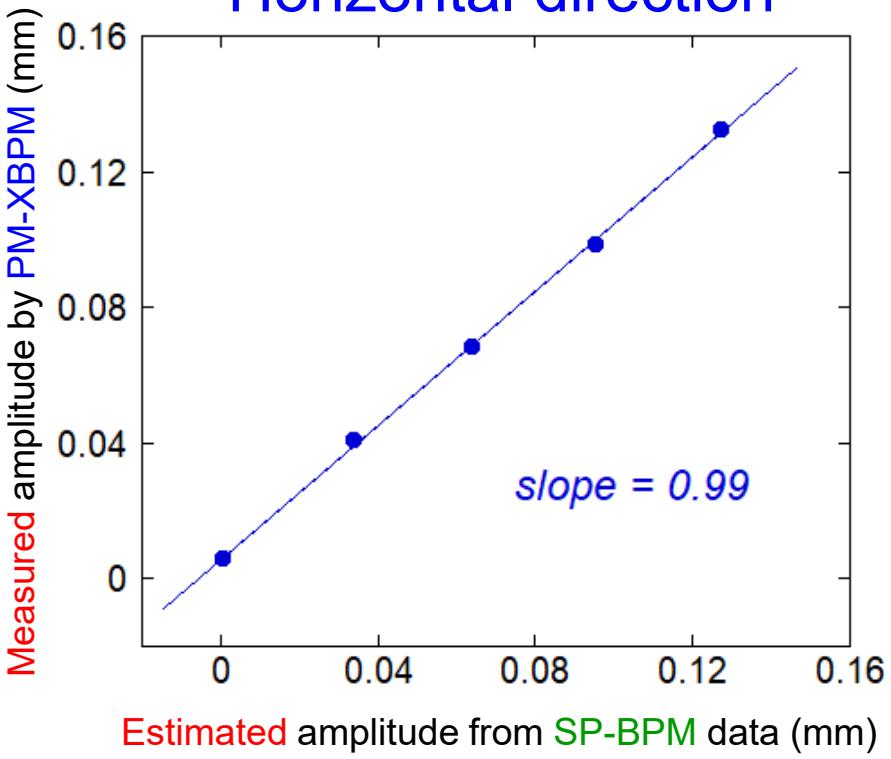


"Nominal kick power 100%" was defined when the amplitude of 0.1 mm observed by the SP-BPM.

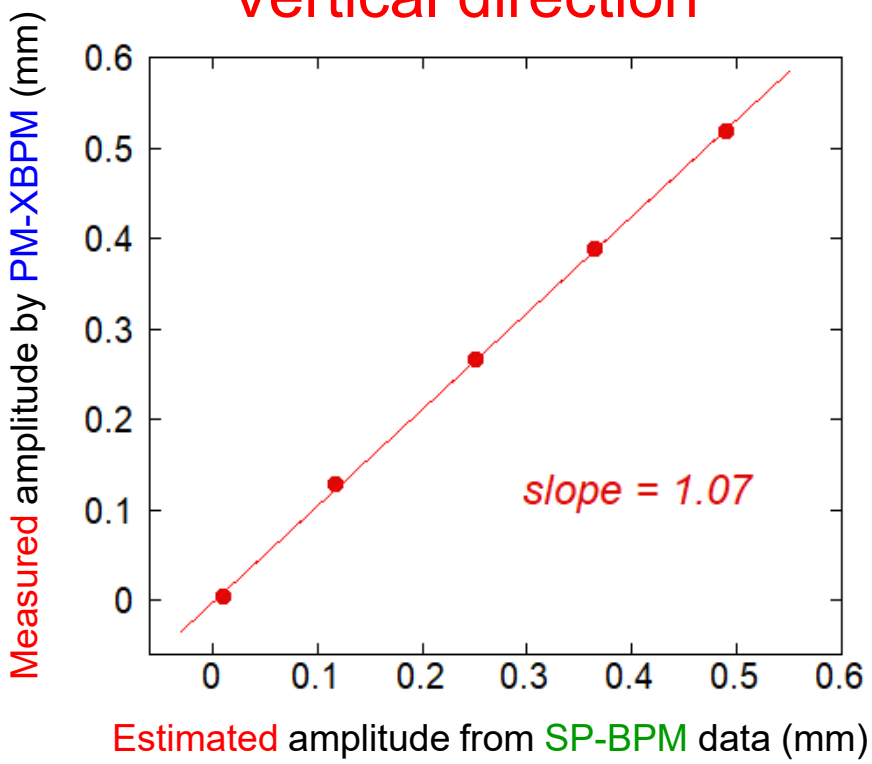
Position sensitivity: *Results*

Horizontal axis is the estimated amplitude from SP-BPM data.
Vertical axis is the measured amplitude by PM-XBPM.

Horizontal direction



Vertical direction



Sufficient linearity enough for practical uses was confirmed in both horizontal and vertical directions.

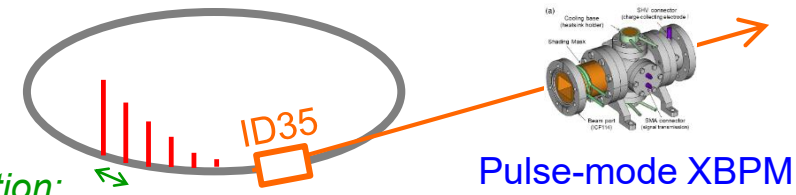
Resolution: *Experimental setup*

Filling pattern :“machine study special“ mode

Bunch current: 0.5 mA, 1 mA, 2 mA, 3 mA, 4 mA, 5 mA /bunch

Stable beam (No pertabation)

Revolution time:
4.8 μs (208 kHz)



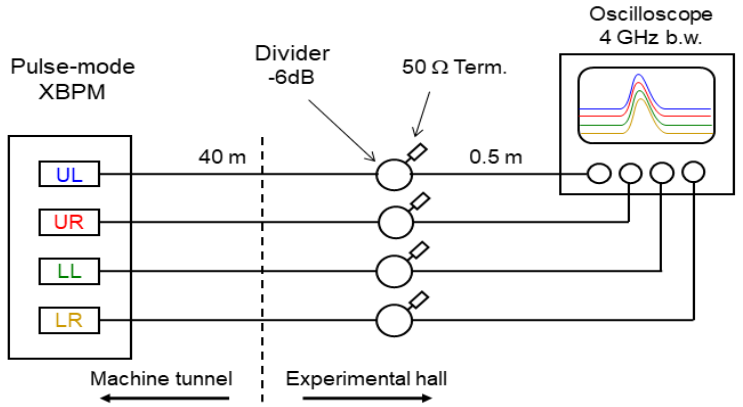
Bunch separation:
24 buckets (47.2 ns)

ID gap = 9.6 mm

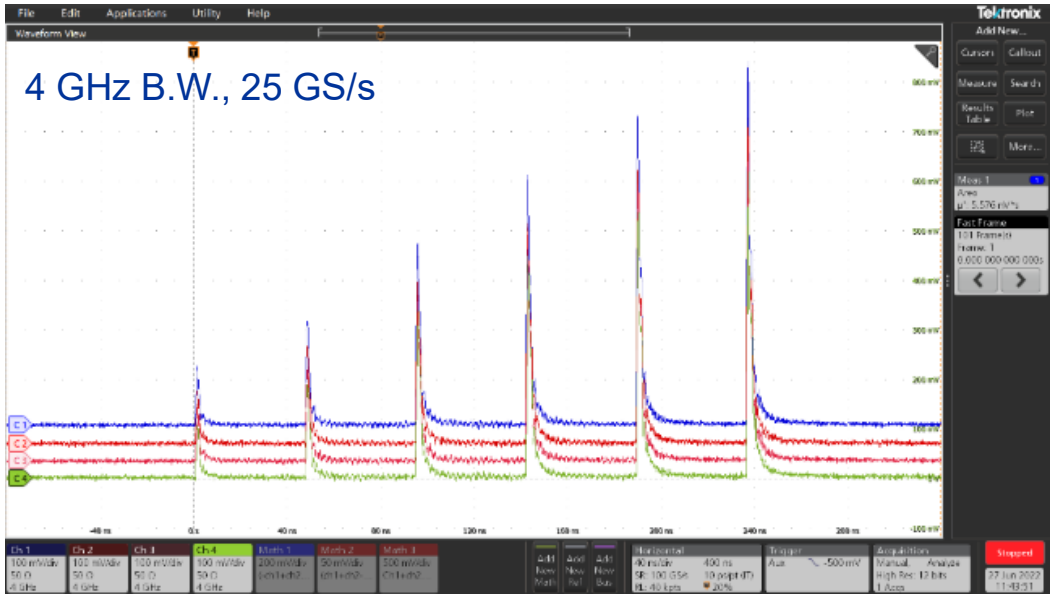
Pulse-mode XBPM
at BL35XU

HV = +300 V

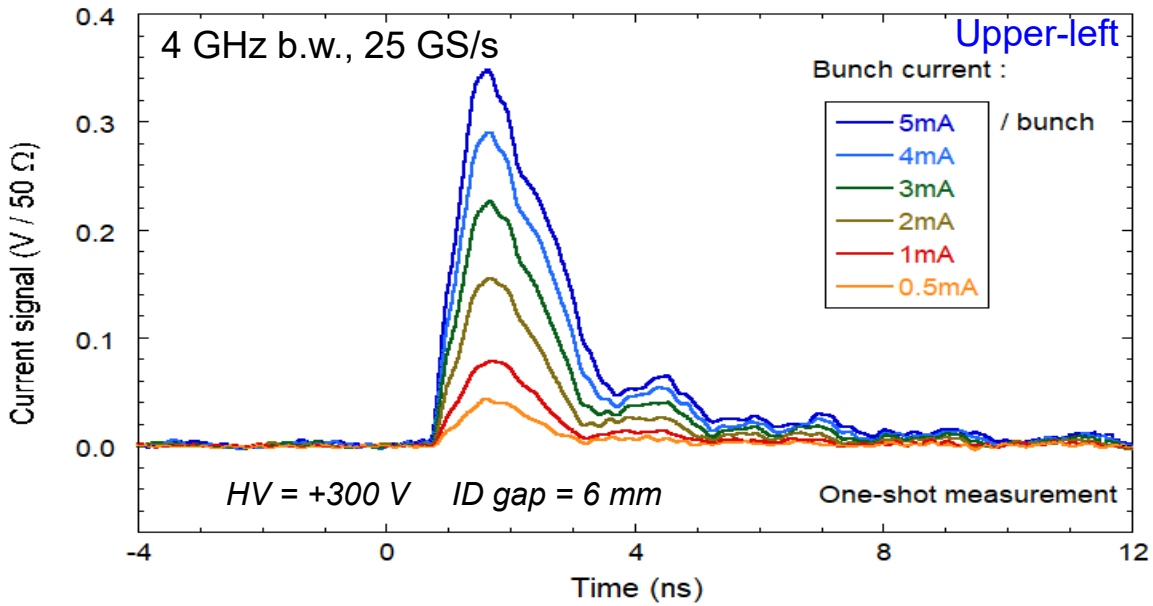
Setup: the same as the position sensitivity evaluation



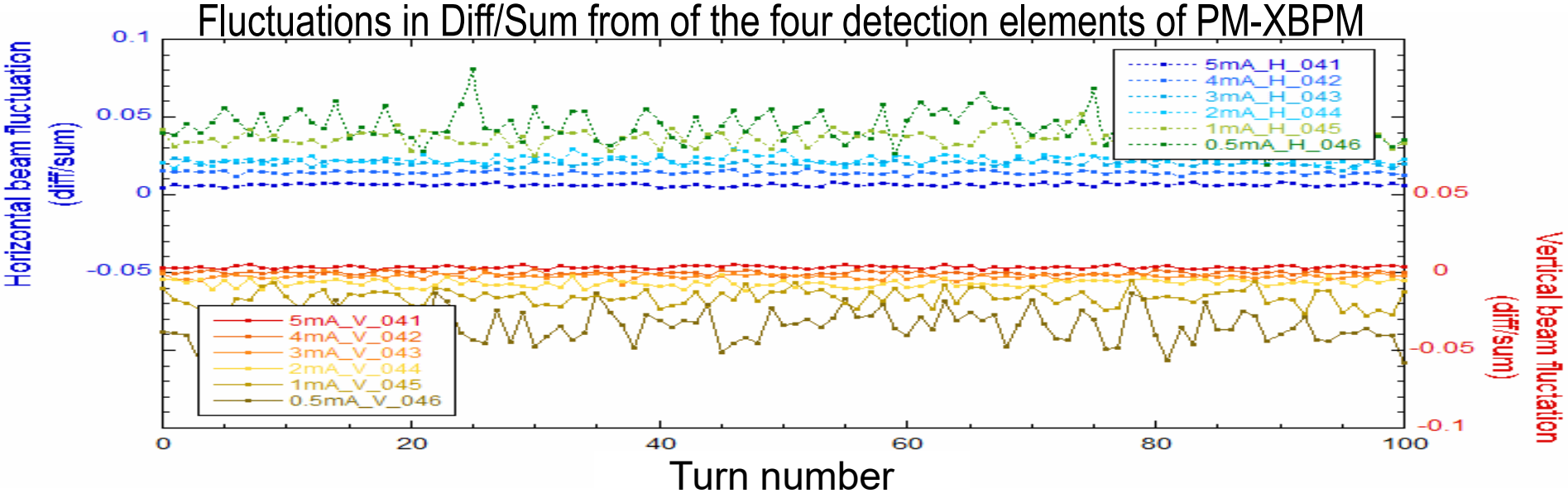
Screen shot of oscilloscope (Tektronix MSO64B)



Overlay of waveforms of each current from UL

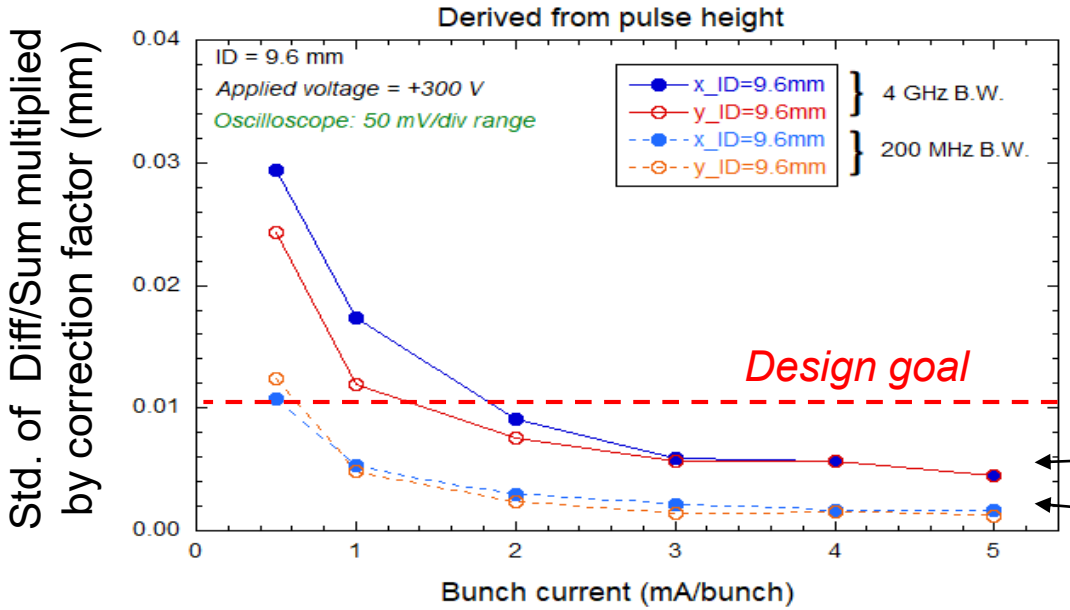


Resolution : Results



$$\frac{Diff}{Sum}(X) = \frac{(UR + LR) - (UL + LL)}{UL + UR + LL + LR}$$

$$\frac{Diff}{Sum}(y) = \frac{(UL + UR) - (LL + LR)}{UL + UR + LL + LR}$$



When the bunch current (>2 mA/bunch) is high , a resolution of 10μm (design goal) was achieved.

Even at low bunch currents, the resolution of 10 μm can be achieved by optimizing the range of the oscilloscope.

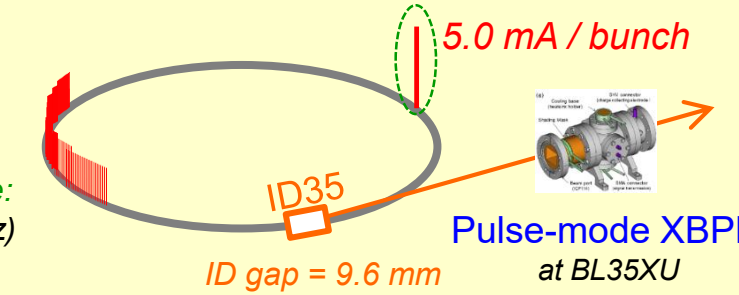
H: 4.5 μm std, V: 4.5 μm std in 4 GHz b.w.

H: 1.7 μm std, V: 1.2 μm std in 200 MHz b.w.

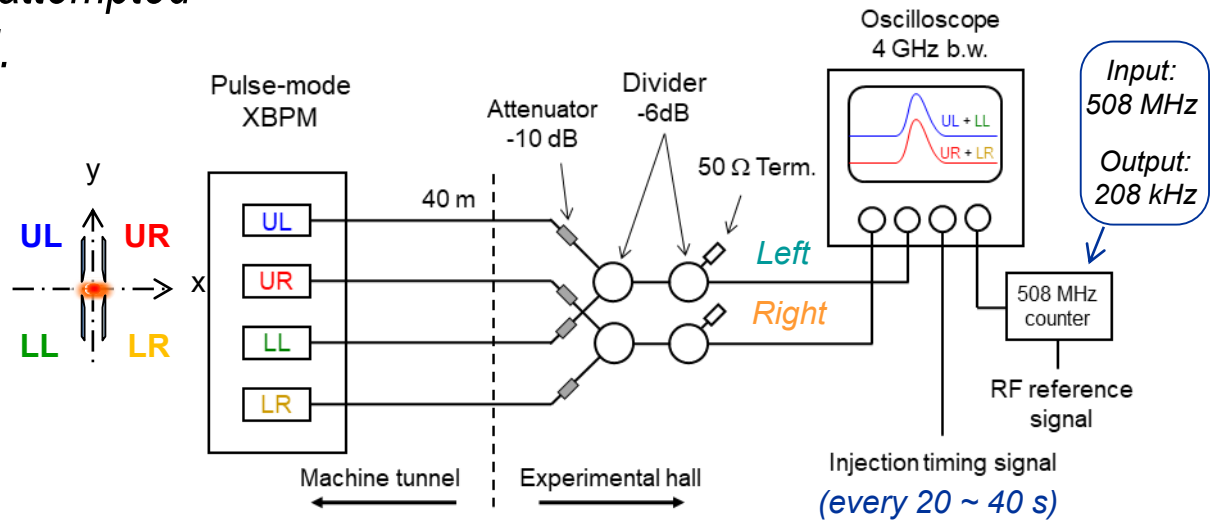
Observation of an oscillation during injection (part 1)

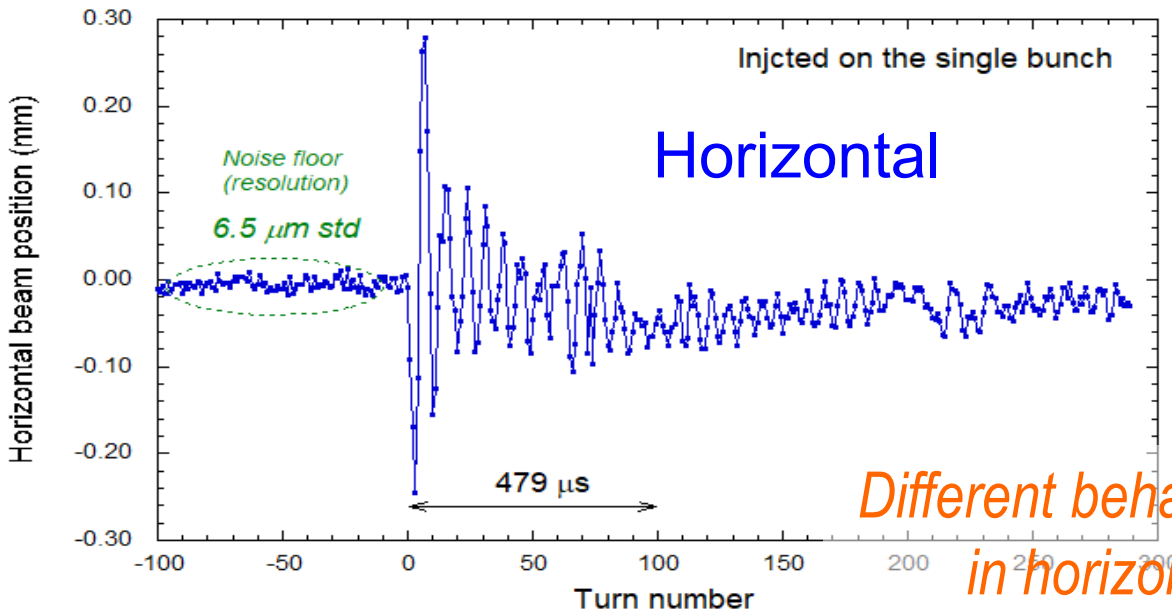
A top-up injection is regularly performed during user time. We attempted to observe pulse-by-pulse behavior when the beam is injected.

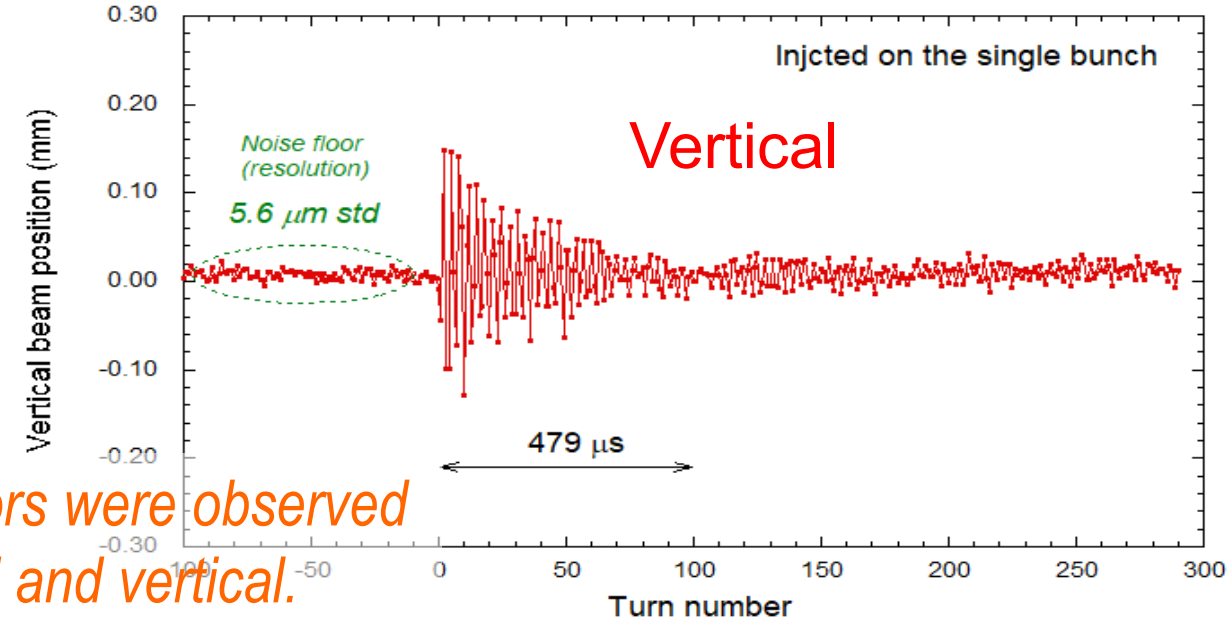
"11/29-bunches + 1 bunch" mode with **top-up injection**



Setup for a horizontal measurement





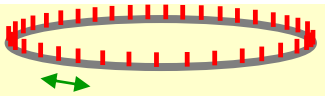


Different behaviors were observed in horizontal and vertical.

Observation of an oscillation during injection (part 2)

Vertical axis
Diff/Sum
(transverse position)

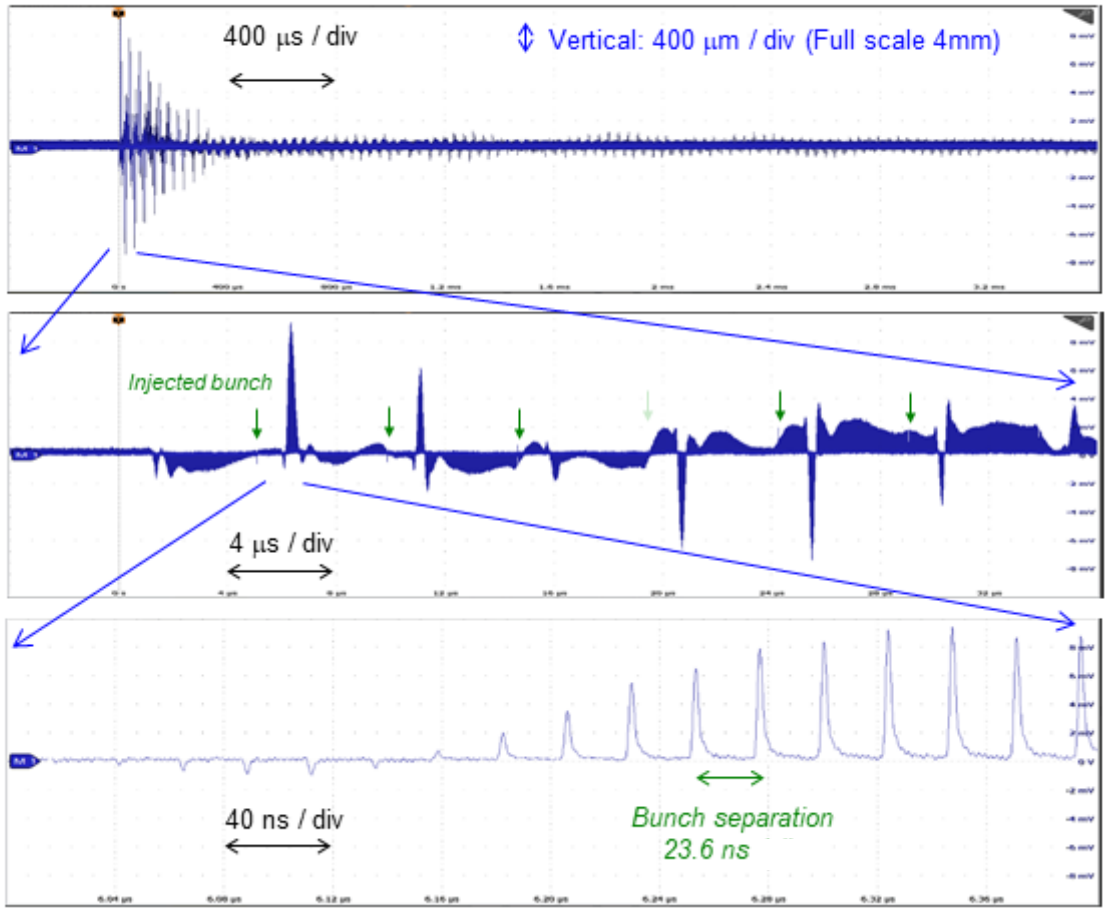
Filling pattern: "203 bunches" mode (uniform filling)
Bunch separation: 23.6 ns *~0.5 mA / bunch*



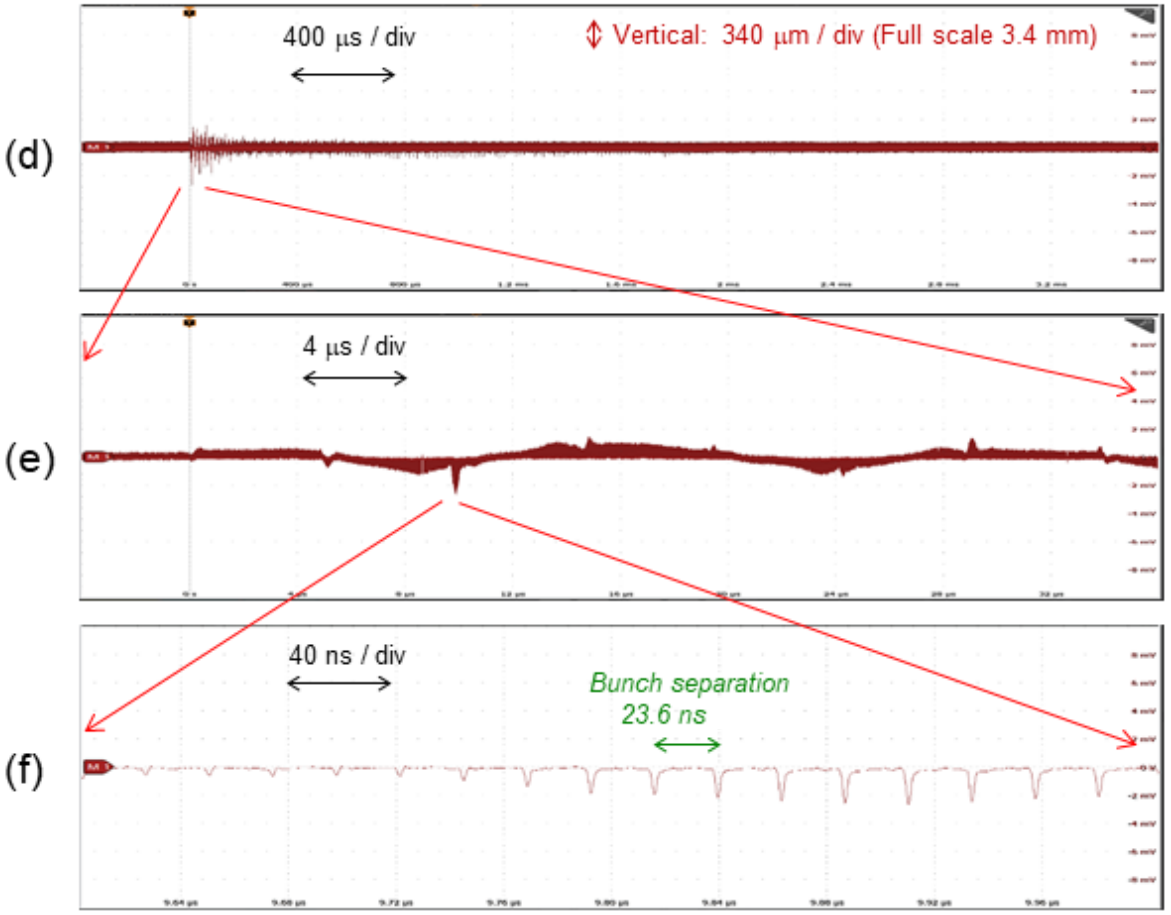
Setup: the same as part 1

All 203 bunches were tracked!

Horizontal



Vertical



For the first time, we have succeeded in pulse-by-pulse measurement of photon beam at ID-BL.

Summary

1. To operate PM-XBPM in ID-BL, the mounting method of the detection elements was modified for further heat resistance.

- There is no major depletion in the waveform, suggesting that the basic performance is maintained.

2. Evaluation tests are performed in ID-BL (BL35XU) .

- Durable under sever heat load condition (*Worked well for a whole year!*)
- Position sensitivity: Good linearity enough for practical use
- Resolutions: <10 μm RMS (*Design goal achieved!*)
- Observation during injection: First demonstration of a PM-XBPM at ID-BL

<Next steps >

- Optimization of operating conditions (bandwidth, applied voltage and so on)
- Construction of a signal processing (fast ADC) system for user operation