IPAC22

Online Measurement of Bunch Lengths and Fill-pattern in the PLS-II Storage Ring Using a Fast Photodiode

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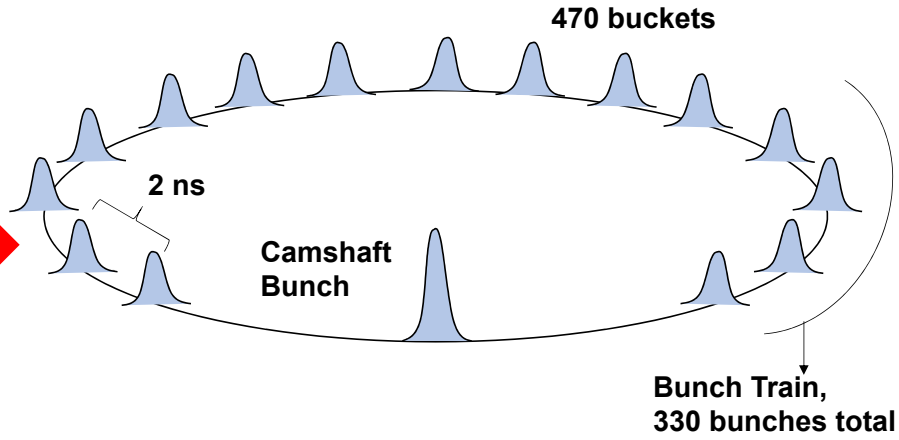
Pohang Accelerator Laboratory



PLS-II Parameter	Value	Unit
Beam Energy	3	GeV
Beam Current	400	mA
Circumference	281.82	m
RF Frequency	499.97	MHz
RMS Bunch Length	6.4	mm

- PLS-II operates a hybrid filling pattern to serve time-resolving experiments.
- Online bunch length and filling pattern monitoring is requested by users.

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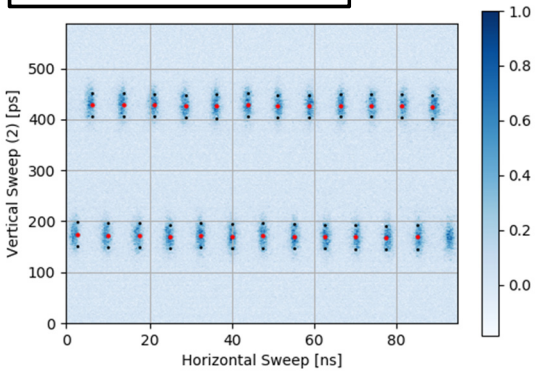
Longitudinal Beam Diagnostics

Bunch Length



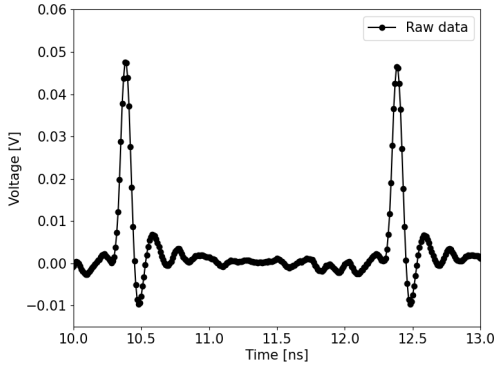
Streak Camera

- High temporal resolution (< RMS 1 ps)
- Slow acquisition rate
- Incompatible for turn-by-turn measurements

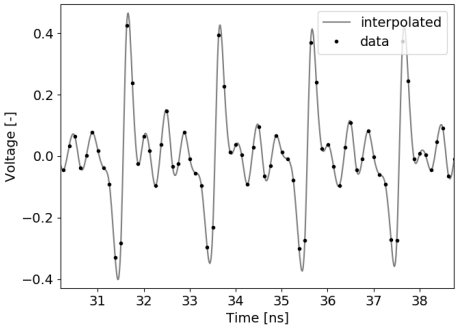
Bunch Length + Fill-Pattern

Fast Photodiode

- Intermediate resolution (~2 ps)
- Bunch length and fill-pattern real time measurement



Fill-Pattern



BPM pick-up

- Fill-pattern monitoring
- Limited bandwidth
- Moderate accuracy
- Non-linear behavior causes intolerable error

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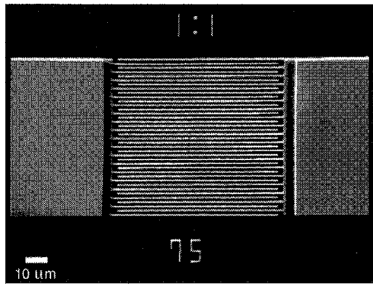
MSM Photodiode

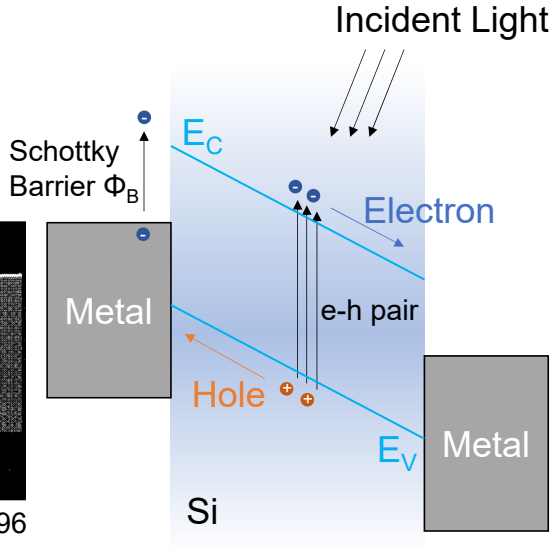
- Metal-Semiconductor-Metal Photodiode
  - Metal-semiconductor Junction
  - → Schottky diode's potential barrier is ruled by the metal and silicon work functions.

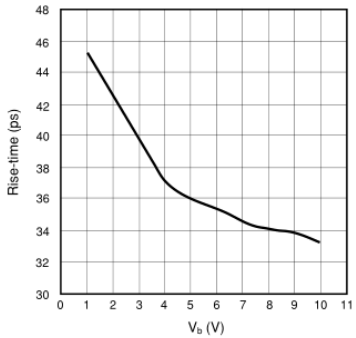
MSM photodiode has fast response.

- Hamamatsu G4176-03 (GaAs MSM photodiode)
  - Rise time ~ 35 ps @ 7 V bias
  - Active area : 200 μm^2
  - Dark current : 100 pA @ Ta = 25 °C

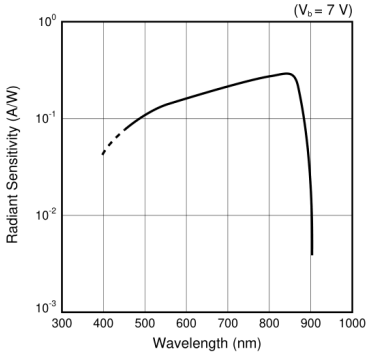


P. R. Berger, 1996





Rise time vs. Applied Voltage



Spectral Response

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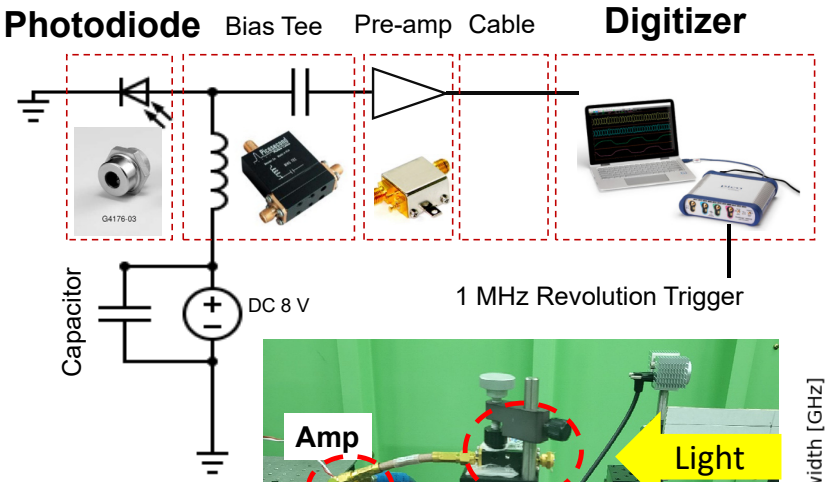
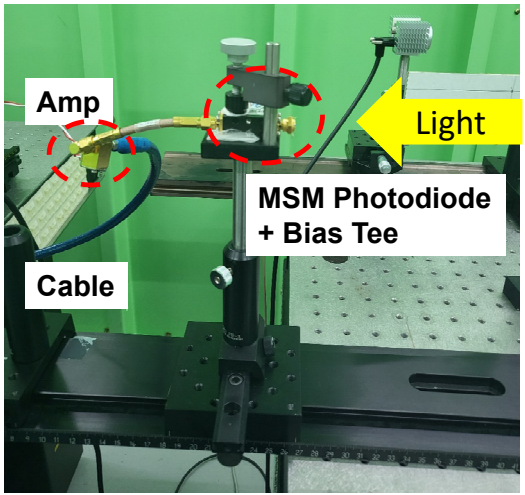
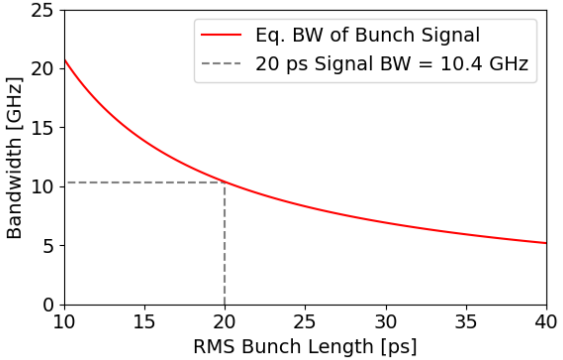
Experimental Setup





- Fill-pattern and bunch lengths are obtained by direct measurements of the synchrotron radiation (visible light).
- The system consists of wide-bandwidth electronics for short bunch length measurements.



Component	Bandwidth
Photodiode	**10 GHz**
Bias Tee	26 GHz
Amplifier	14 GHz
Cable	26.5 GHz
Digitizer	**16 GHz**

→ Signal processing method is mandatory for precise reconstruction.

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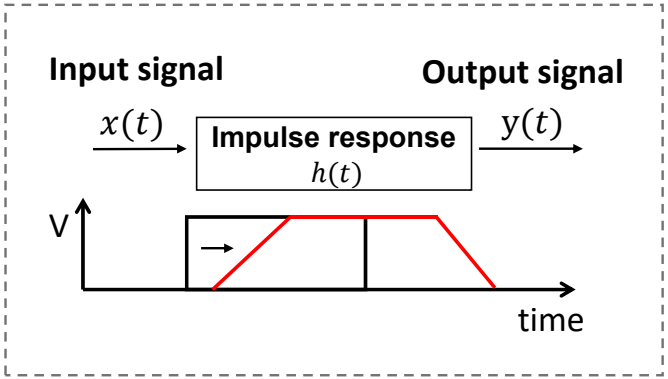
Analytic Gaussian Deconvolution



$$y(t) = x(t) * h(t) = \int x(\tau)h(t-\tau)d\tau$$

System response function
: $h_{sys} = h_{PD} * h_{bias\,T} * h_{amp} * \cdots$

$$\sigma_y^2 = \sigma_x^2 + \sigma_h^2$$

- The input signal is reconstructed by analytically deconvolving the output signal with a Gaussian kernel.
- The system's impulse response is used as a deconvolution kernel.

	Analytic Gaussian Deconvolution
Pros	• Practical • Fast
Cons	• Inaccuracy (Error with Gaussian assumption)

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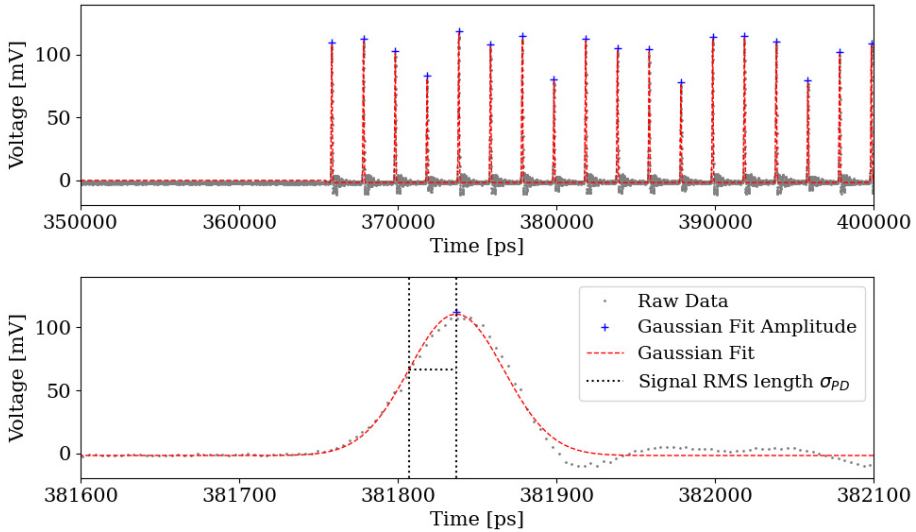
Analytic Gaussian Deconvolution

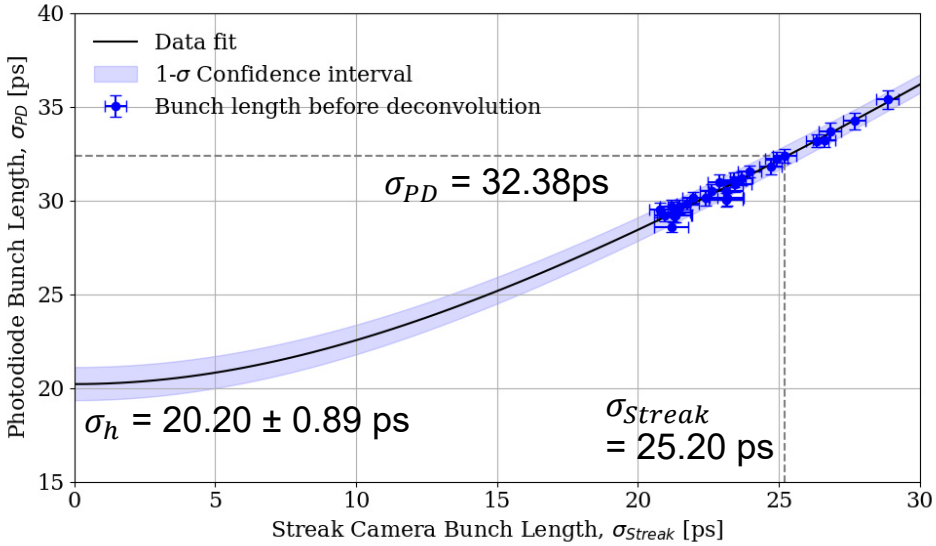
Fill Pattern Measurement



- Measurement limit of beam current = 6 μA
- Resolution (SNR = 1) = 3 μA

Bunch Length Calibration

- The photodiode is calibrated using a streak camera by varying bunch length to find σ_h.



$$\sigma_{decon.} = \sqrt{\sigma_{PD}^2 - \sigma_h^2} = \sqrt{(32.38\,ps)^2 - (20.20\,ps)^2}$$

$$= 25.31\,ps$$

$$\sigma_{Streak} = 25.20\,ps$$

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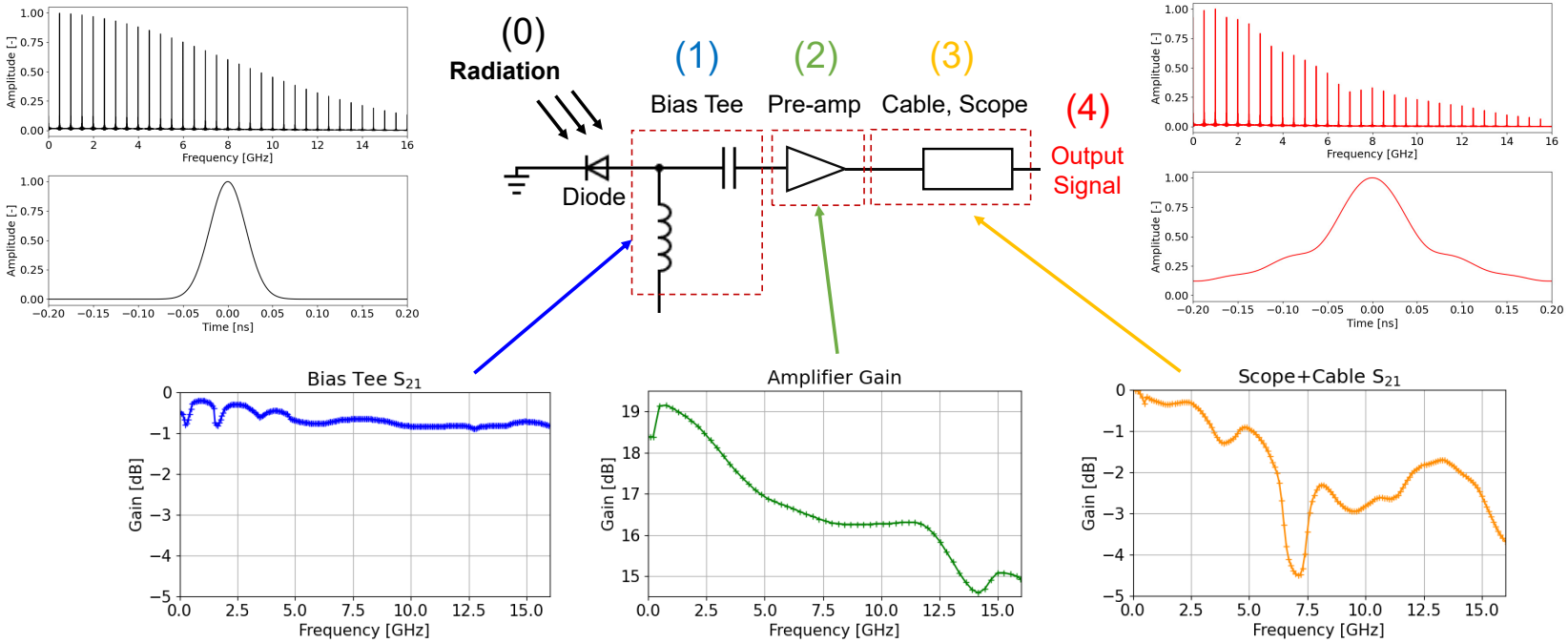
Numerical Compensation



→ **The measured signal is distorted strongly by the frequency response of analog components.**

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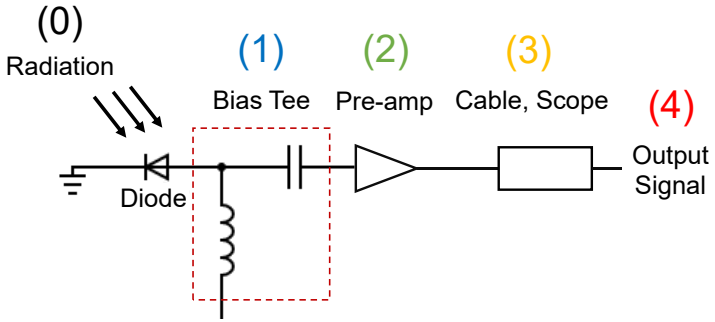
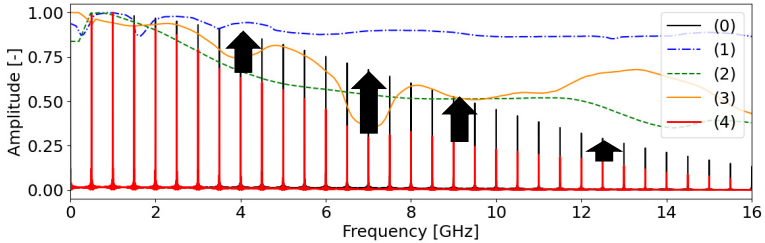
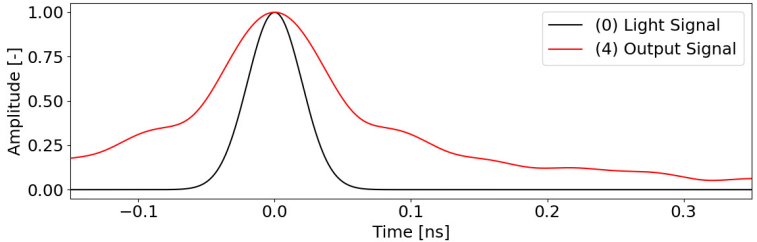
Numerical Compensation







- The beam shape is retrieved by applying the measured frequency response of each component to the numerical compensation method.
- Frequency response of each device has to be measured precisely at least digitizer bandwidth.

	Numerical Compensation
Pros	• Still fast • Accurate
Cons	• Frequency response can be changed according to circumstance. (ex. Temp, Connection …)

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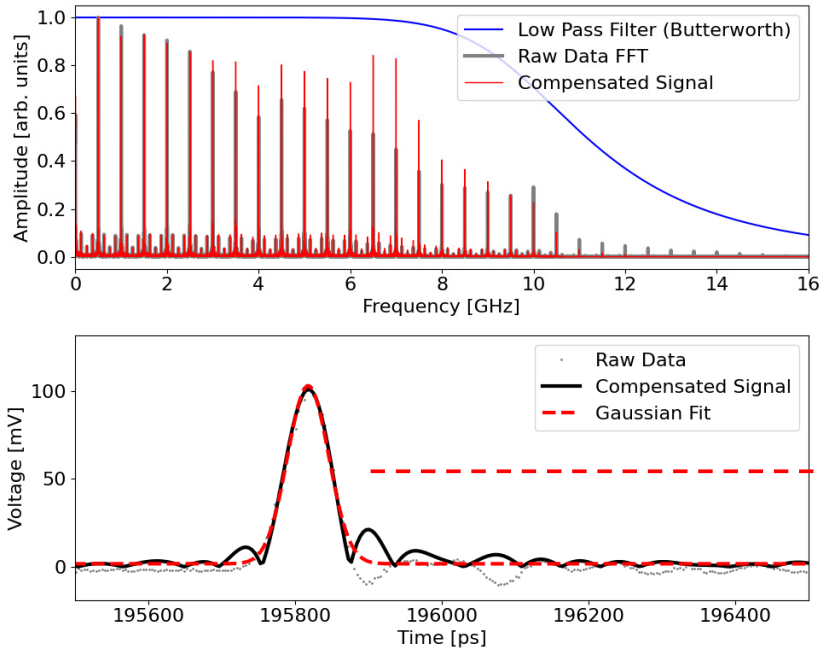
Numerical Compensation



- Low pass filter is used to eliminate high-frequency noise.
- Obtain the charge and length of each bunch by inverse FFT of the signal recovered in the spectral domain.
- The diode response is subtracted in the same way as Gaussian deconvolution.

Fit Model

$$Ae^{\left(\frac{-(t-\mu)^2}{2{\sigma_t}^2}\right)} + G$$

G : Ground level

μ: Central Position

A :Bunch Charge (Fill-pattern)

σ_t : Bunch Length → $\sigma_{numer.} = \sqrt{{\sigma_t}^2 - {\sigma_{calib}}^2} + c$

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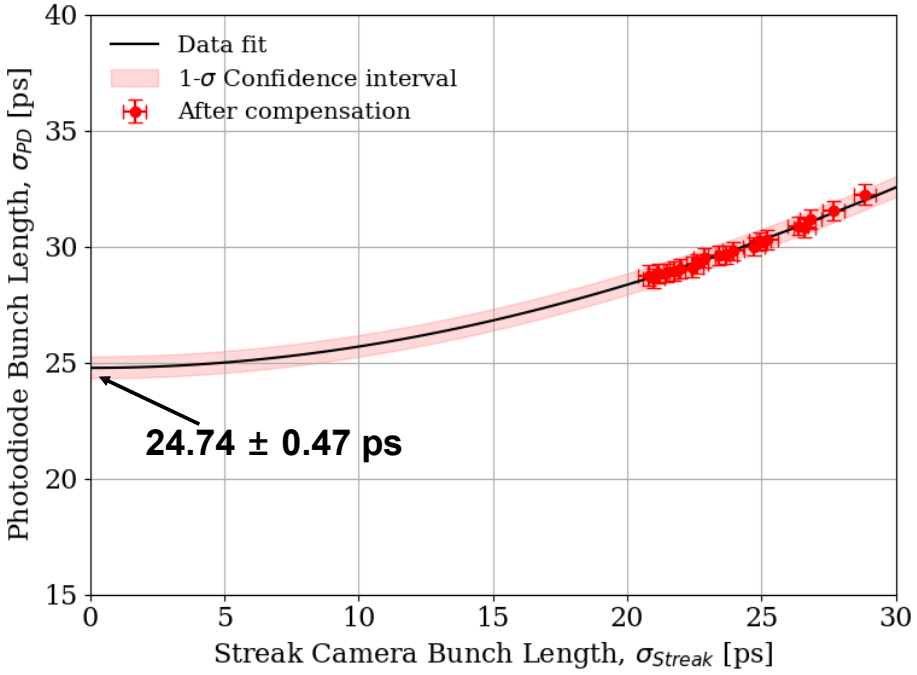
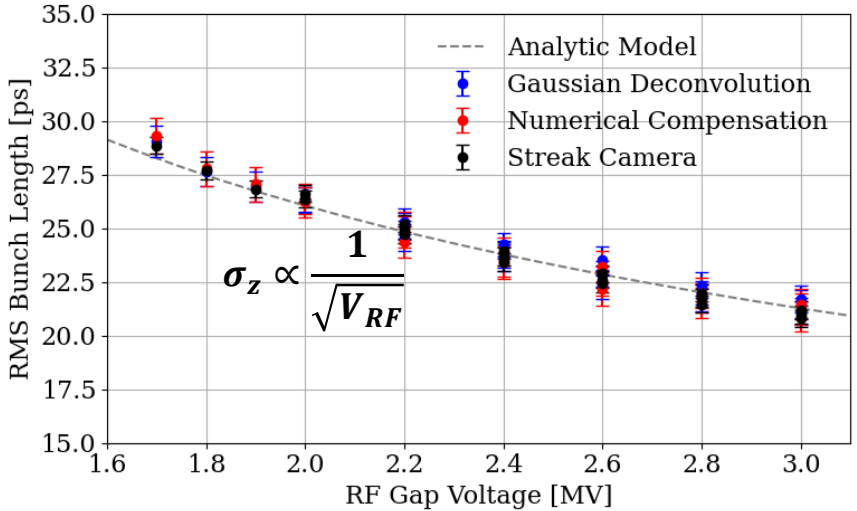
Bunch Lengthening Experiment

Calibration Result



Bunch Lengthening Experimental Result



- The bunch length changes by varying field gradients in RF cavities and its behavior agrees quantitively well with the theory.

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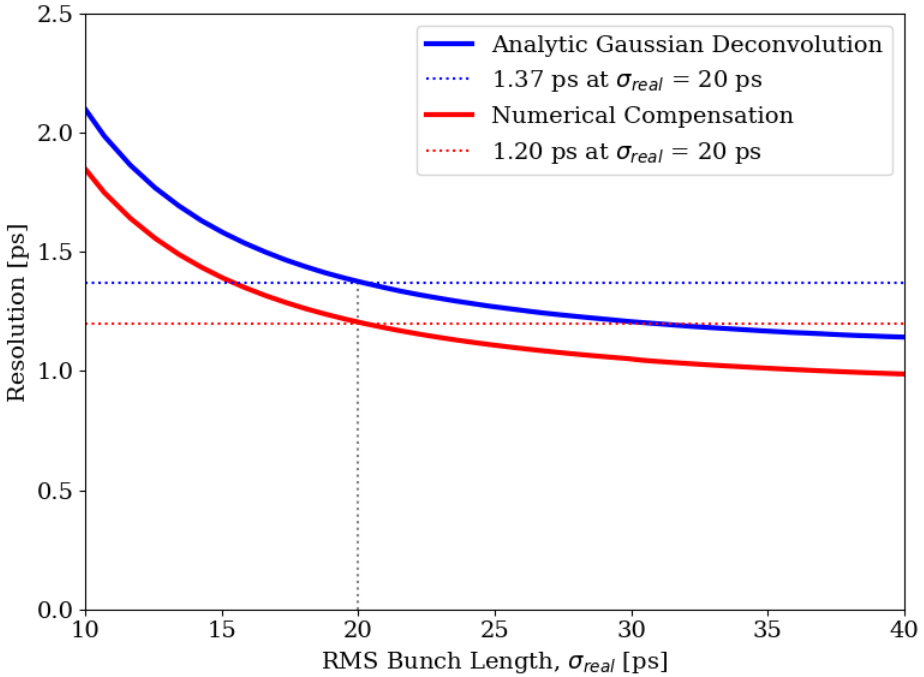
Statically Estimated Resolution



- **Systematic error** of the system depends on the absolute bunch length due to a finite bandwidth.
- It is mainly determined by fitting errors and trigger jitter.
- The numerical compensation method reduces the systematic error since it enables a precise retrieval of the beam signal.

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Summary

- We have experimentally demonstrated a compact monitor that enables **filling pattern** (~ 3 μA resolution) and **bunch length** (~ 1 ps resolution) monitoring with visible light at the PLS-II storage ring.
- Analytical Gaussian deconvolution and numerical compensation were investigated to improve measurement accuracy.
  → Numerical compensation can achieve better resolution.
- Online Turn-by-turn/Bunch-by-bunch measurements are under contemplation as a future upgrade project.

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Thank you for your attention

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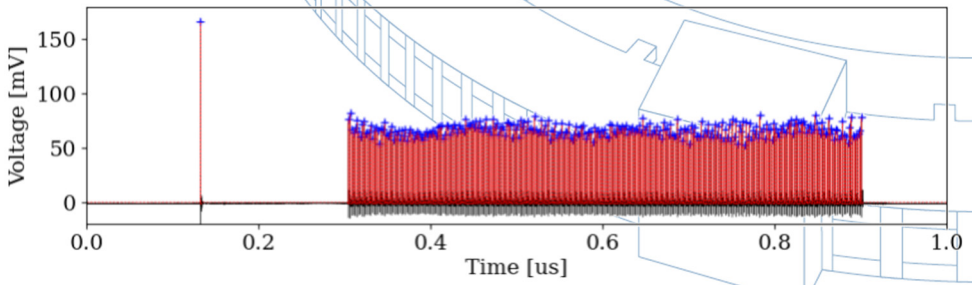
PLS-II



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