기초과학연구원 Institute for Basic Science

Capacitive pick-up type bunch shape monitors for low-energy ion beams at RAON

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Contents

Introduction

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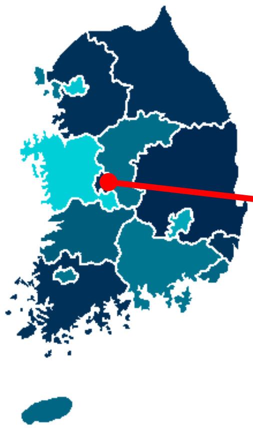
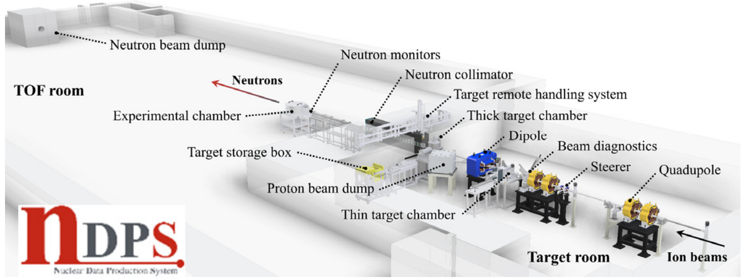
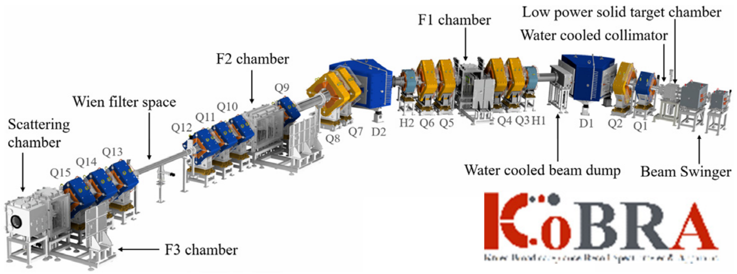
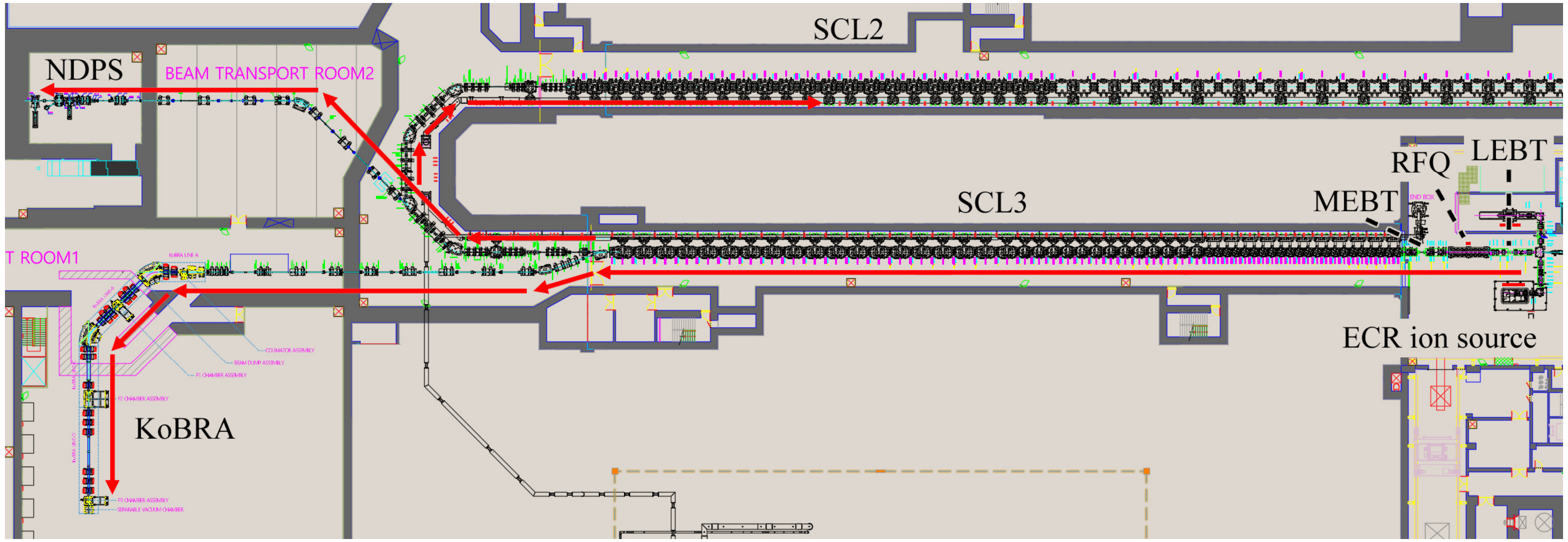
RAON Heavy ion accelerator









✓ Beam parameters at KoBRA and NDPS

Beam energy: 1 MeV/u to 83MeV/u

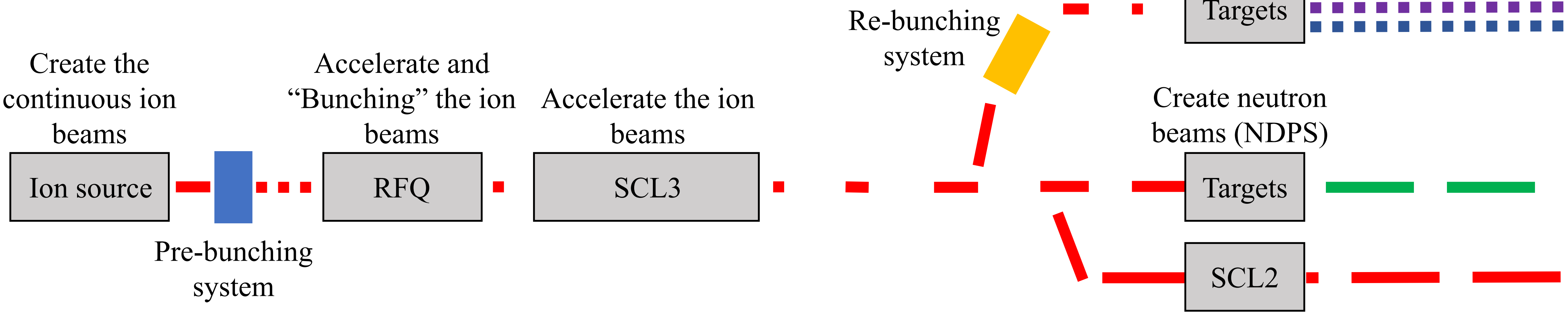
A/q: 1 to 7

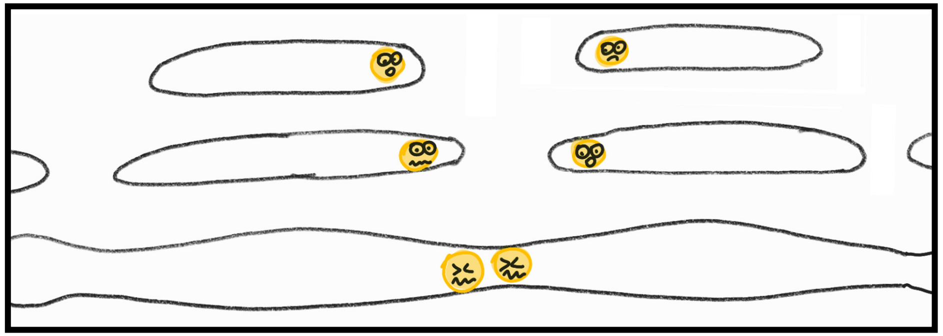
Relativistic β: 0.05 to 0.40

✓ Both facilities are capable of conducting **Time Of Flight (TOF)** experiments

Introduction

Factors which disrupting the TOF experiments



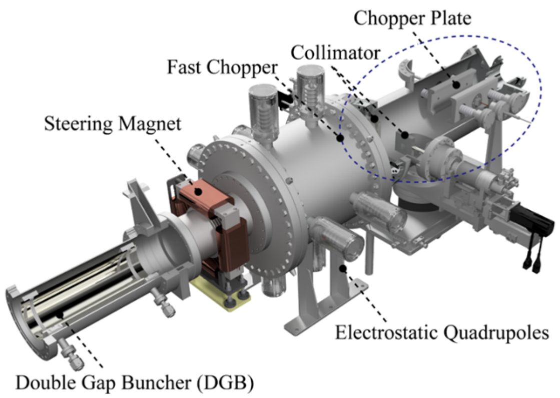


✓ Required repetition rates at target positions:

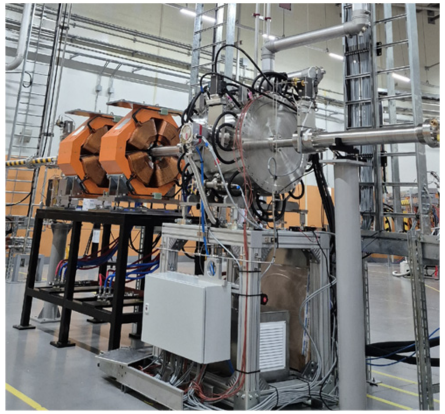
Several hundred kHz (NDPS) to several MHz (KoBRA)

✓ Required bunch length at target positions: 0.1 ns to 0.5 ns in σ

Pre-bunching system: Manage the repetition rate



Re-bunching system: Manage the bunch length



To verify the operation of the pre-bunching system

➡ Measuring **repetition rate** of the beam near the targets

To verify the operation of the re-bunching system

➡ Measuring **bunch shape** of the beam near the targets

To perform TOF experiments

➡ Measuring **arrival time** of the beam bunches near the targets

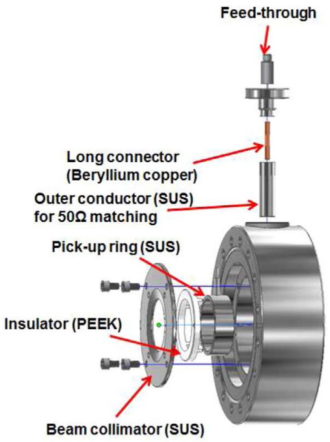
Capacitive Pick-Up type Bunch Shape Monitors (CPU-BSMs) were developed to perform all these measurements using a single type of **non-destructive** monitor

Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

Design optimization of the CPU-BSM

- ✓ The bunch length of primary ion beams at the production targets: **0.1 to 0.5 ns in σ**
- ✓ The **Fourier transformation** of a Gaussian distribution with σ = 0.1 ns: a Gaussian distribution with σ = 1.59 GHz
- ✓ Integration of this Fourier-transformed Gaussian distribution: **99% of its area** is contained within **±4.1 GHz**
- ✓ Therefore, we have decided to design the CPU-BSM to ensure it **operates efficiently at frequencies up to 4.1 GHz**
- ✓ The CPU-BSM was designed in a form similar to that of phase probes



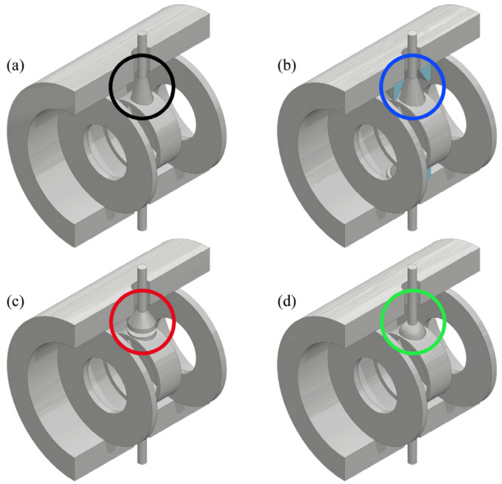
Ji-Gwang Hwang, et al., NIM A, 837 (2016): 34-39.,
High precision capacitive beam phase probe for KHIMA project

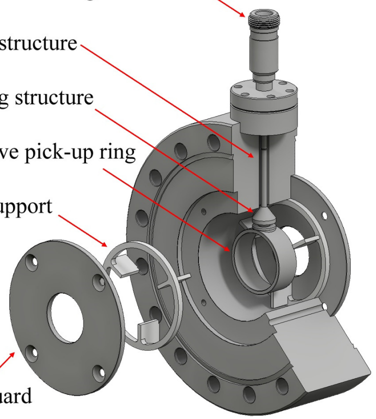
Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

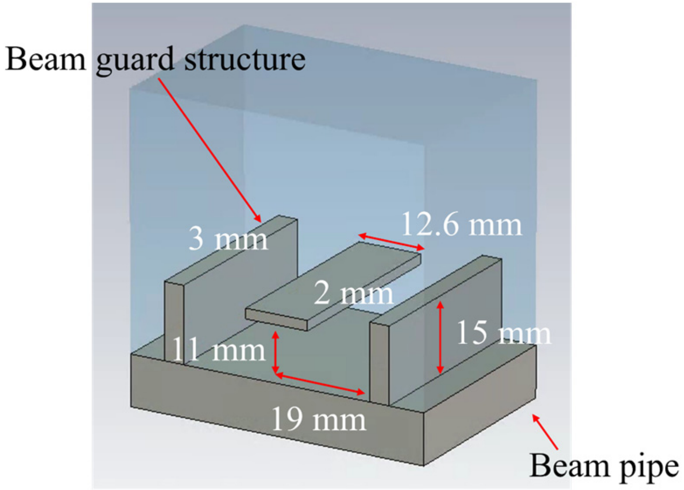
Design optimization of the CPU-BSM

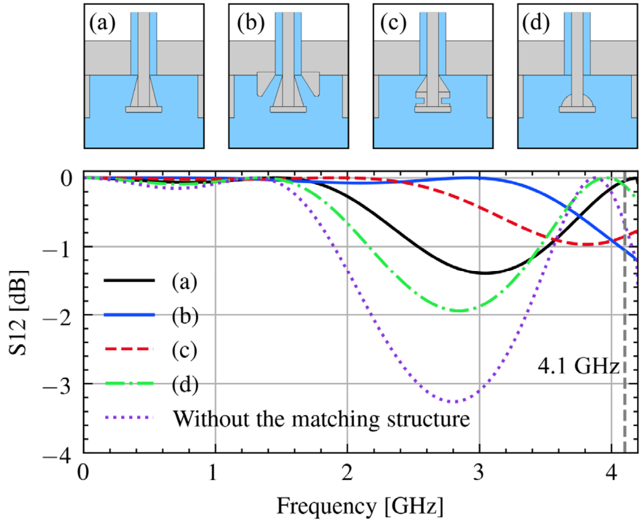
✓ The design optimization process was divided into three parts:

1) The coaxial structure
2) The ring part with beam guards
3) The matching structure.



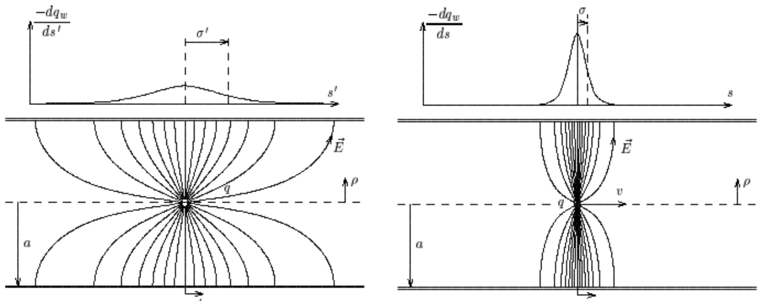


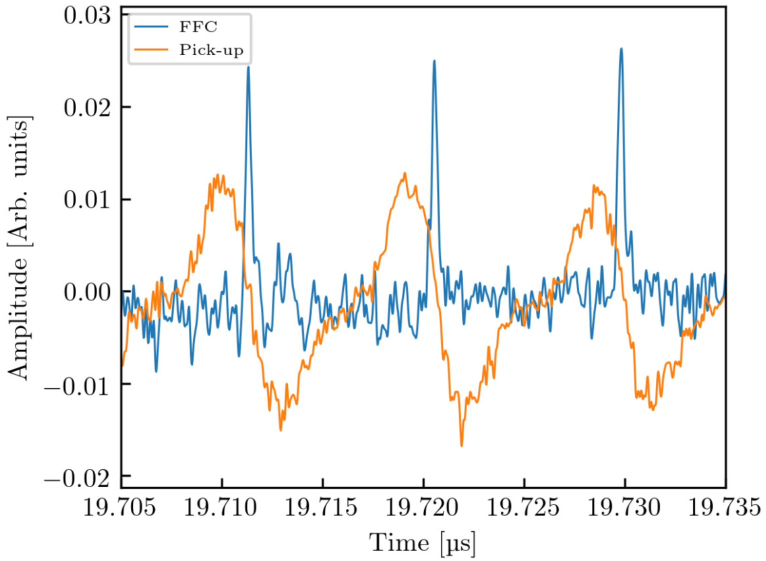




Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

Algorithm for reconstruction the shape of the beam bunches





R. Singh, et al., IBIC 2021,
COMPARISON OF FESCHENKO BSM AND FAST FARADAY CUP WITH LOW ENERGY ION BEAMS

- ✓ Consider a point-like beam bunch having a total charge of Q_b
- ✓ The signal generated in the CPU-BSM due to the induced electric field E_{ind} is represented as a current signal $I_{im}(t)$.
- ✓ We assume that the time integrated value of the current signal (i.e, total induced image charge, Q_{im}) is a function of time, $G(t)$.

$$I_{\mathrm{im}}(t) = \frac{dQ_{\mathrm{im}}(t)}{dt}, \quad Q_{\mathrm{im}}(t) = \int I_{\mathrm{im}}(t')dt' \equiv Q_{\mathrm{b}}G(t),$$

where

$$Q_{\mathrm{im}}(t) = \int_S \sigma_{\mathrm{ind}} da.$$

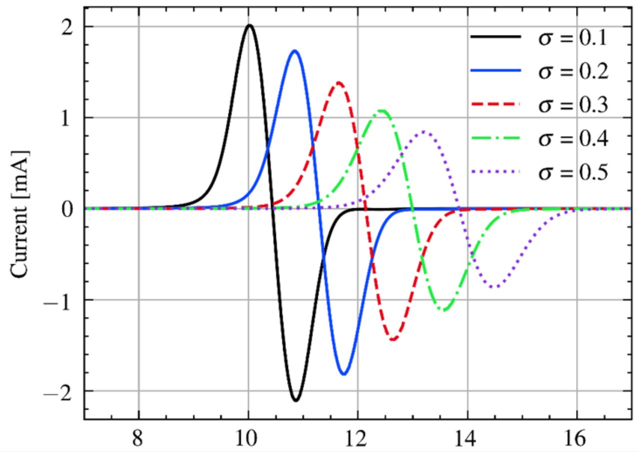
(The induced charge on the CPU-BSM surface is $\sigma_{ind} = \epsilon_0 E_{ind}$)

Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

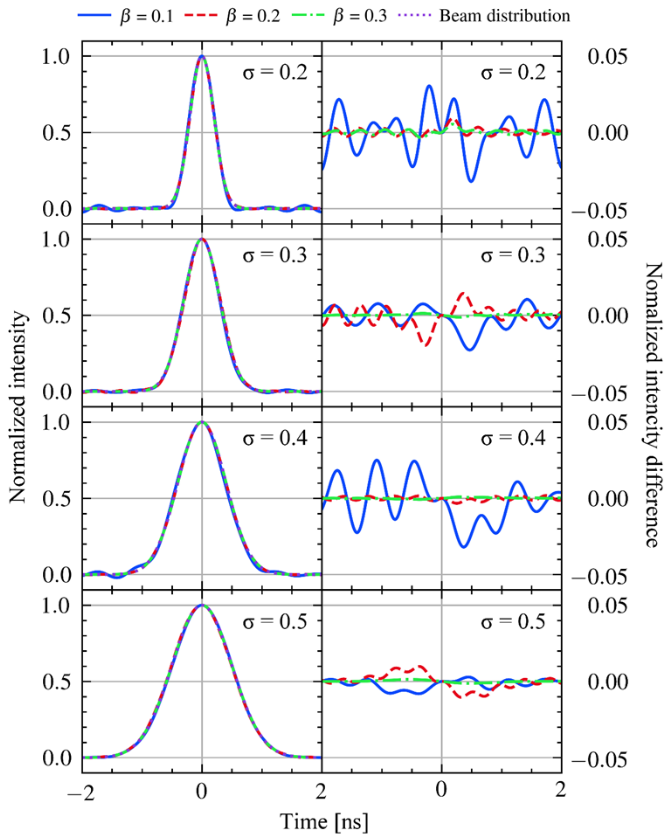
Algorithm for reconstruction the shape of the beam bunches

- ✓ Now suppose that a beam bunch with a longitudinal distribution $H(t)$ passes through the CPU-BSM
- ✓ The integrated signal from the CPU-BSM with the beam bunch $\approx H(t) * G(t)$

  ($H(t)$ is normalized as $\int H(t)dt = 1$ and $G(t)$ acts as a Green's function)
- ✓ Fourier transforms of the $H(t)$ and $G(t)$ functions: $\tilde{H}(f)$ and $\tilde{G}(f)$
- ✓ Fourier transform of $H(t) * g(t)$ is $\tilde{H}(f) \times \tilde{G}(f)$
- ✓ By the $\tilde{H}(f)$ function allows us to deduce the longitudinal shape of the beam bunch through Fourier and inverse Fourier transformations



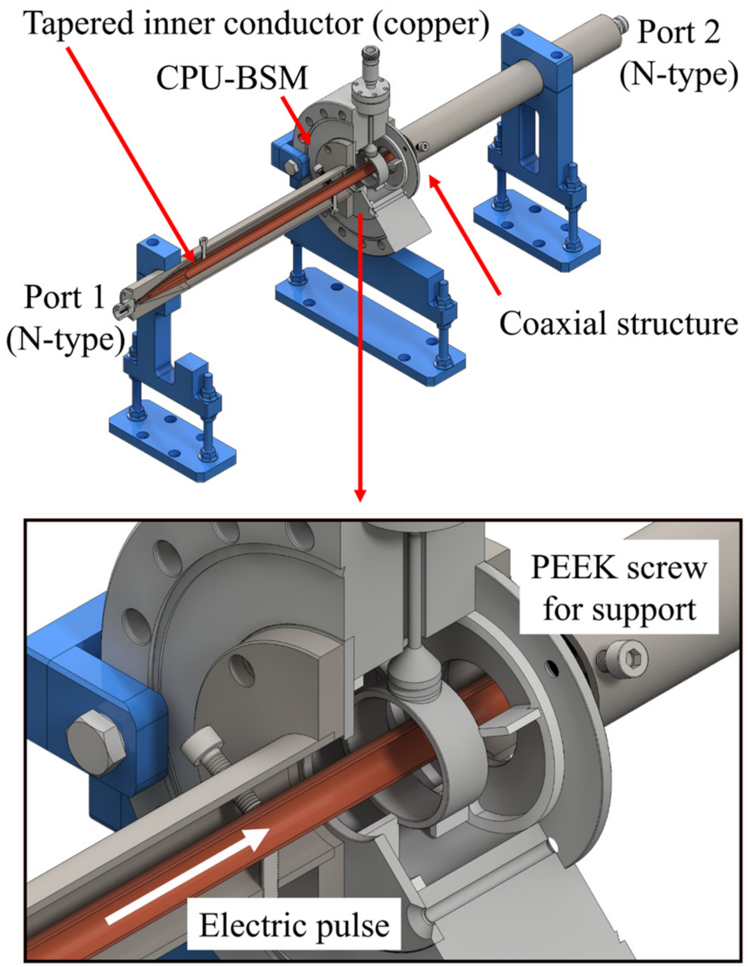
Simulation results between the CPU-BSM and various length beam bunches with a β of 0.1 and a 2 pC charge

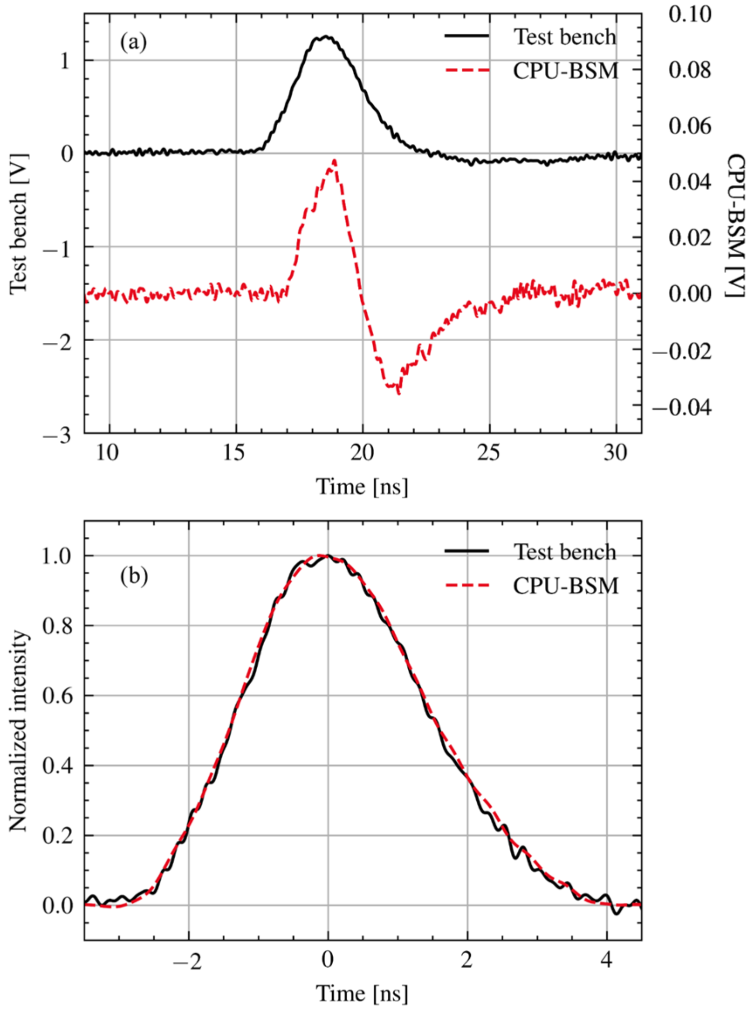


Estimated bunch shapes from the simulation results between the CPU-BSM and beam bunches, using the H(f) formula obtained from simulations with beam bunches having a σ of 0.1 ns

Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

Testbench for the fabricated CPU-BSM





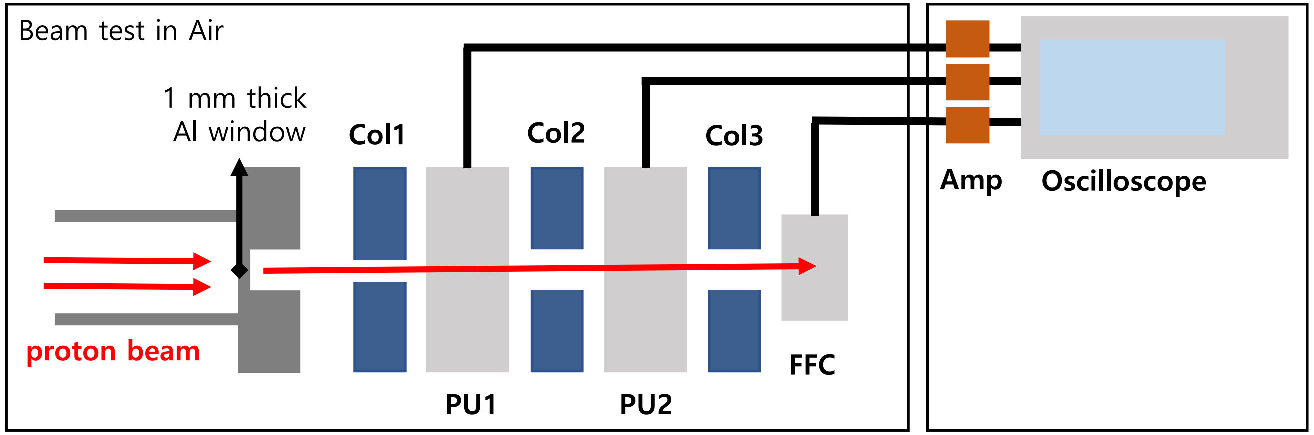
- ✓ To verify the operation of the fabricated CPU-BSM devices, a test bench imitating the electric field generated by beam bunches without an actual beam was developed
- ✓ The electric field of the pulsed signal is transmitted in TEM mode, emulating the conditions of beam bunches moving at close to the speed of light

Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

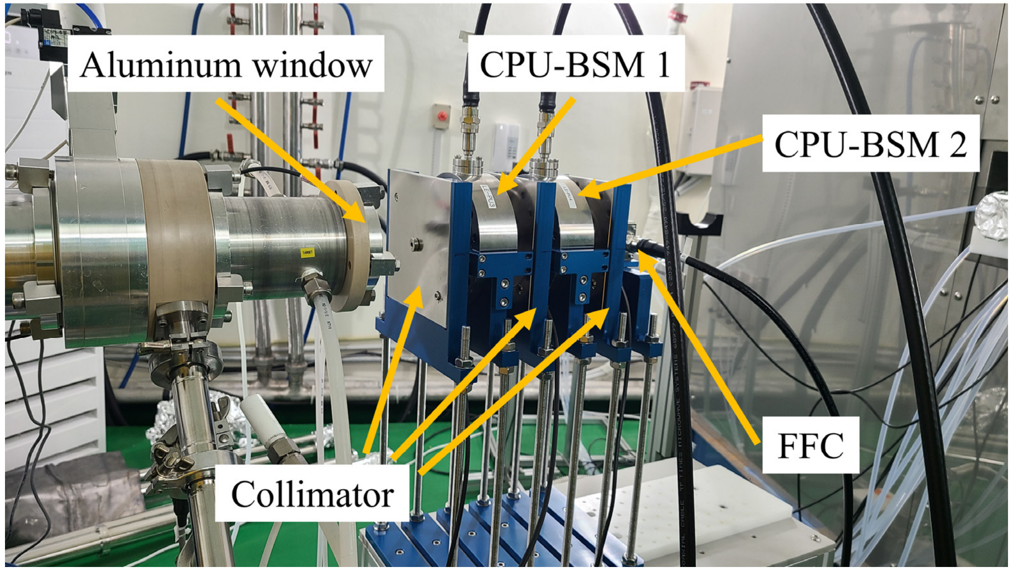
Experiment at RFT-30 cyclotron

Beam specification for experiment

Proton Beam energy	30 MeV
Beam current (avg)*	<10 μA
frequency	63.96 MHz
Repetition rate	100 Hz
Bunch length	1 ~ 4 ns (expectation)
Duty	5%
Thickness of Al window	1 mm
Diameter of collimator	5 mm



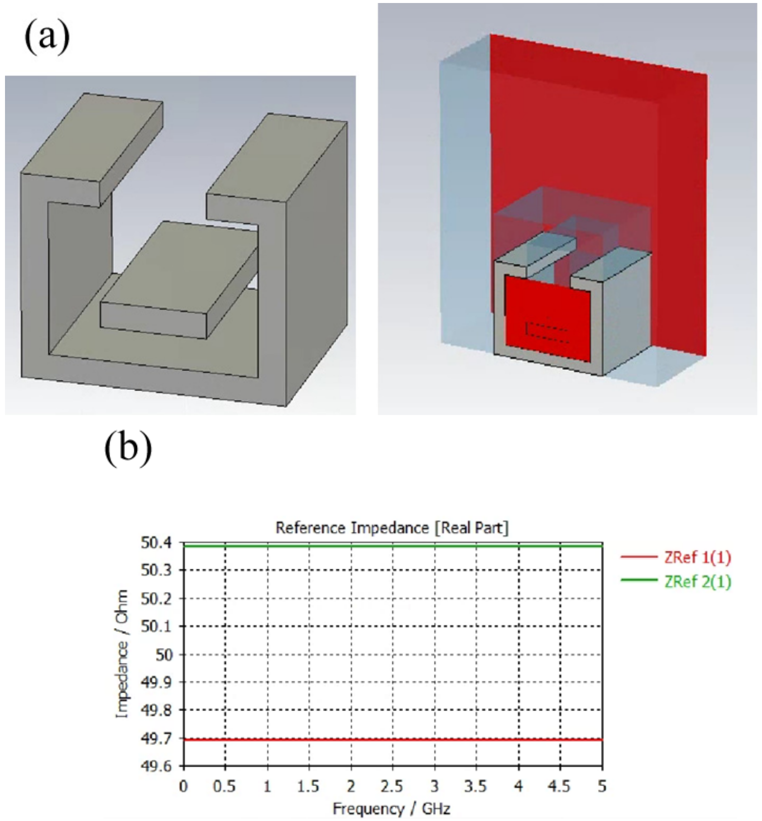
- ✓ Before we installed the CPU-BSMs in RAON beamline, experiments to validate the functionality of the CPU-BSM with non-relativistic beams were conducted using the RFT-30 cyclotron.

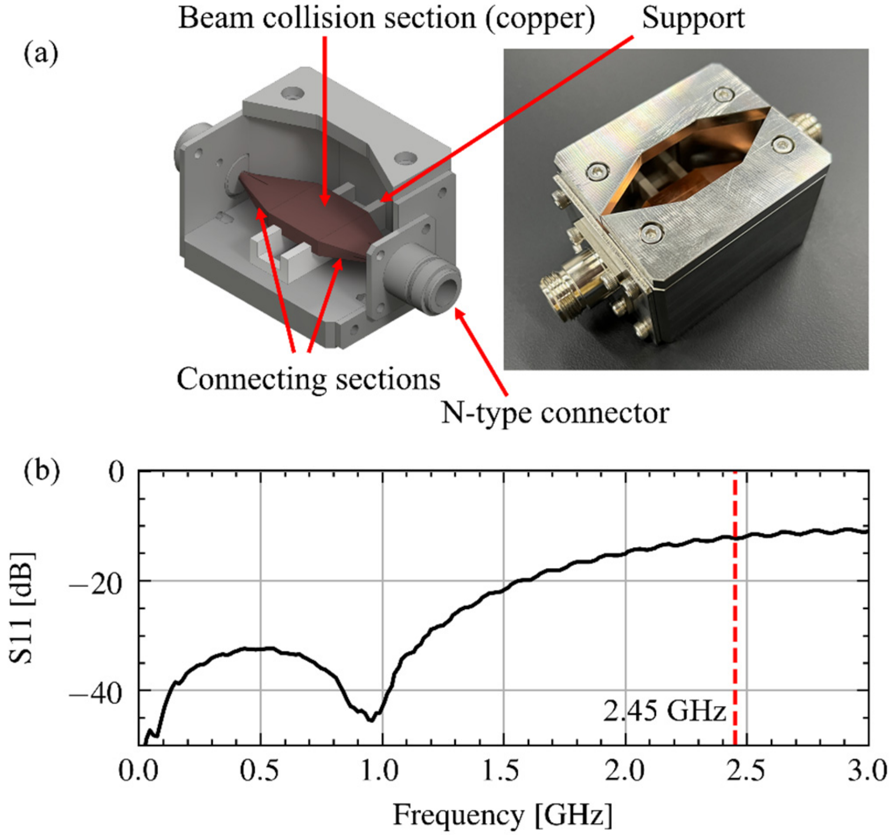


Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

Experiment at RFT-30 cyclotron

✓ A Fast Faraday Cup (FFC) was chosen as a control variable for measuring the beam bunch shape during the experiment

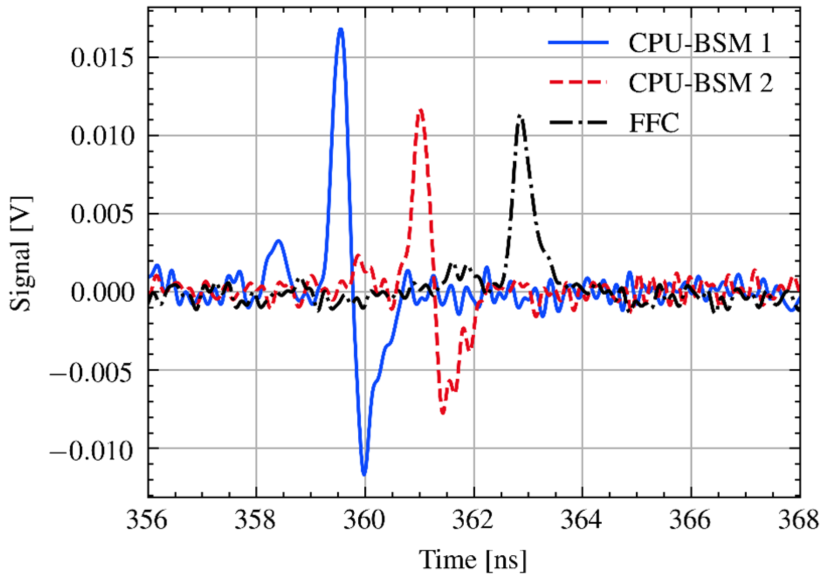


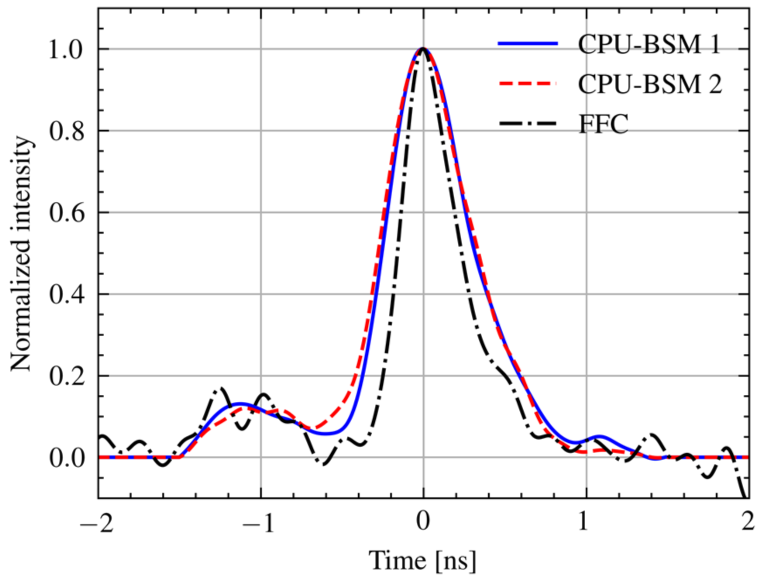


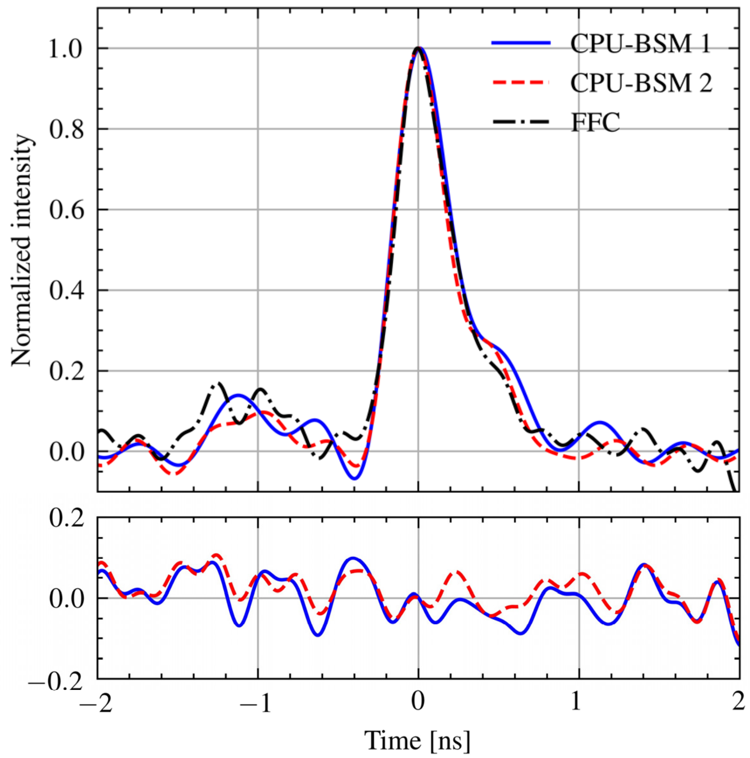
(a) Design and manufactured of the Fast Faraday Cup (FFC). (b) Measured S11 value at port 1 with a 50 Ω termination at port 2

Capacitive Pick-Up type Bunch Shape Monitors (CPU-BSM)

Experiment Result



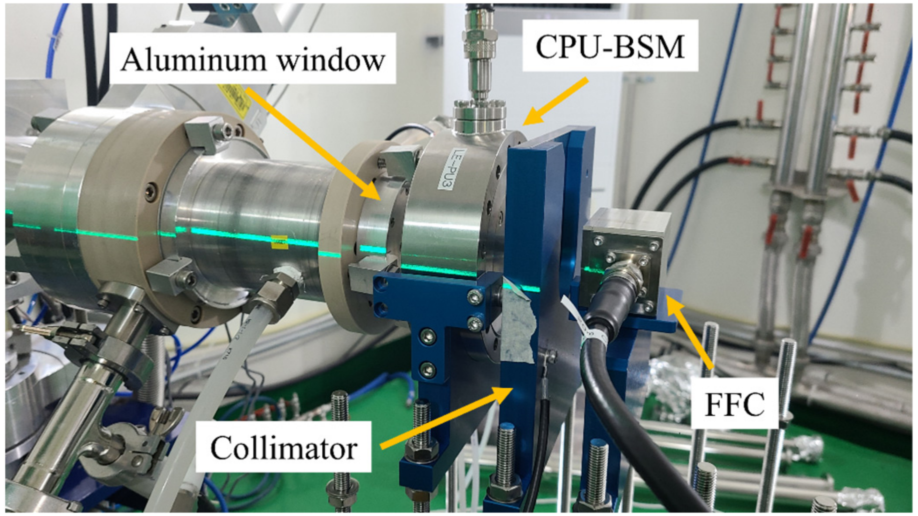


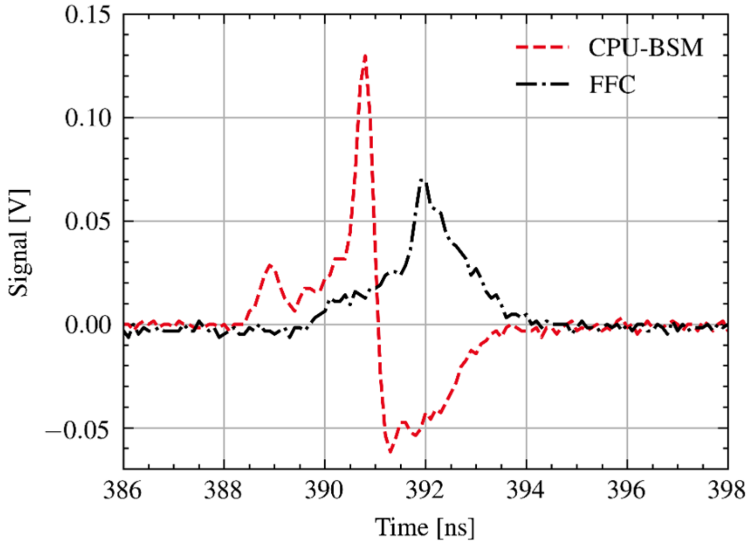


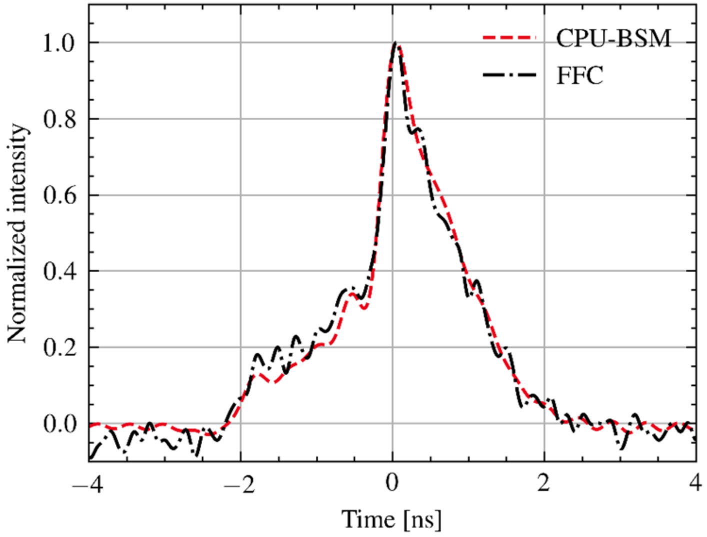
- ✓ The estimated results were compared with the adjusted signal measured by the FFC
- ✓ The experimental result demonstrates the operation of the CPU-BSM with approximately 1 ns bunch length beam

Capacitive Pick-Up type Bunch Shape Monitors (CPU-BSM)

Experiment Result



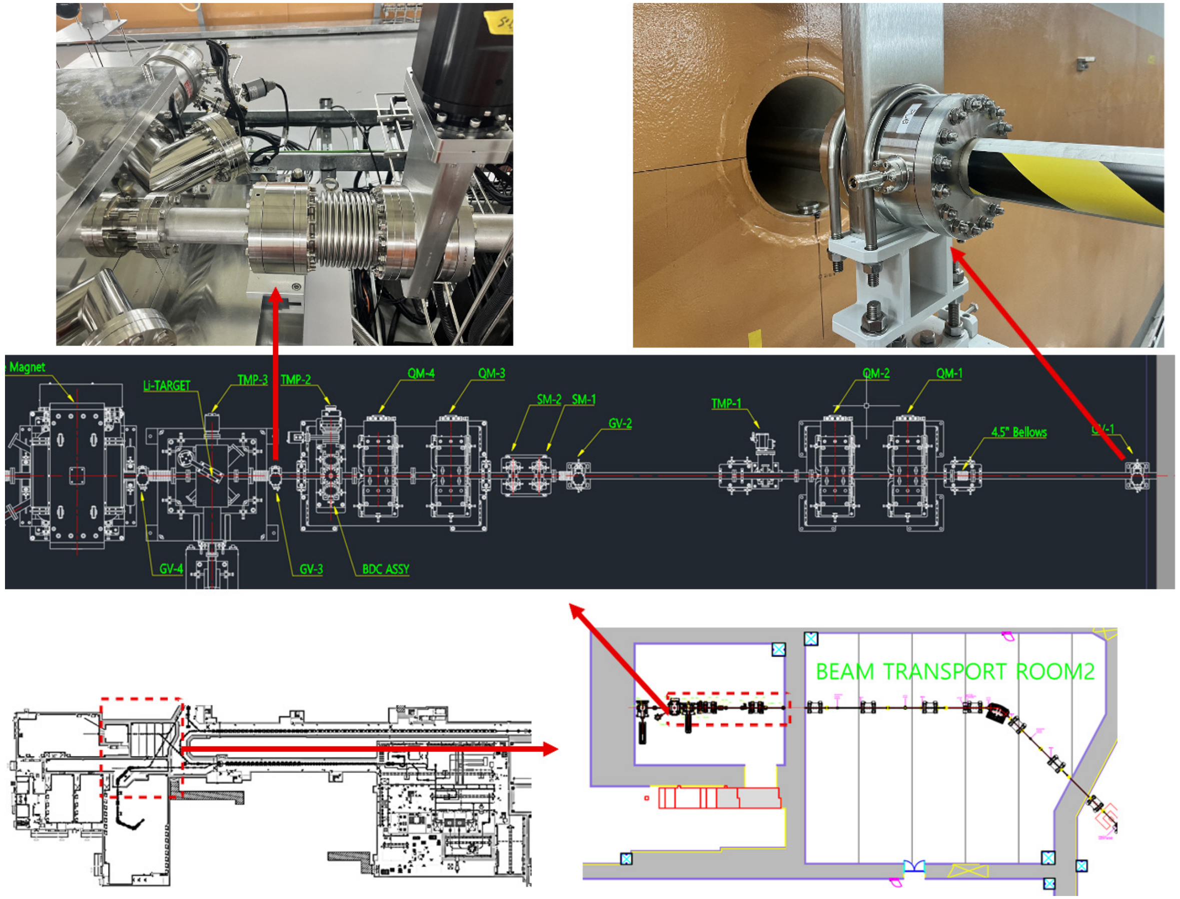




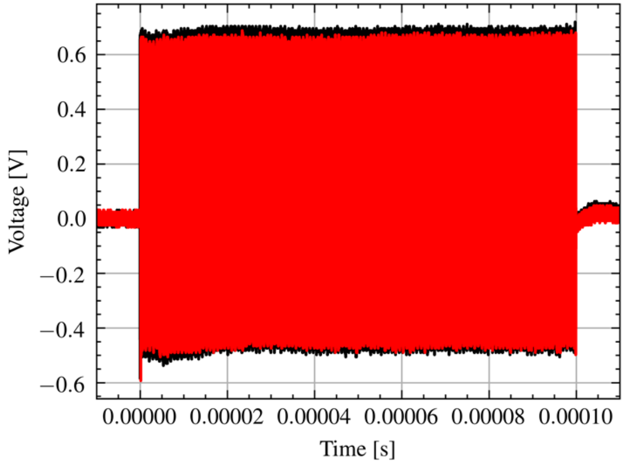
- ✓ During the experiment, the cyclotron was restarted, resulting in changes to the bunch shape
- ✓ The experiment result confirming its capability to monitor the longitudinal bunch shape of beams with non-Gaussian bunch shapes

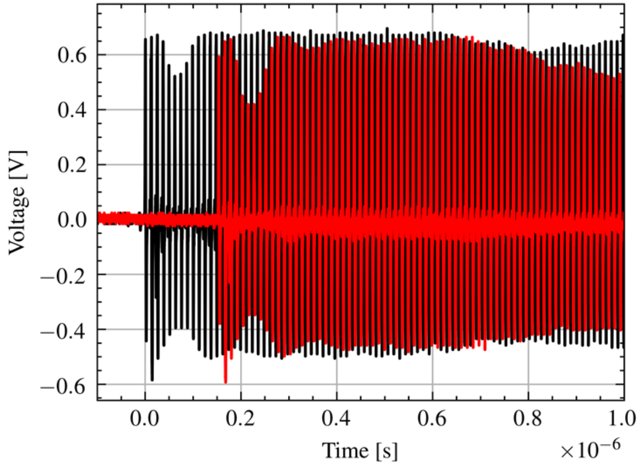
Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM)

Preliminary Results at RAON



Two CPU-BSMs in the SCL3-NDPS beamline

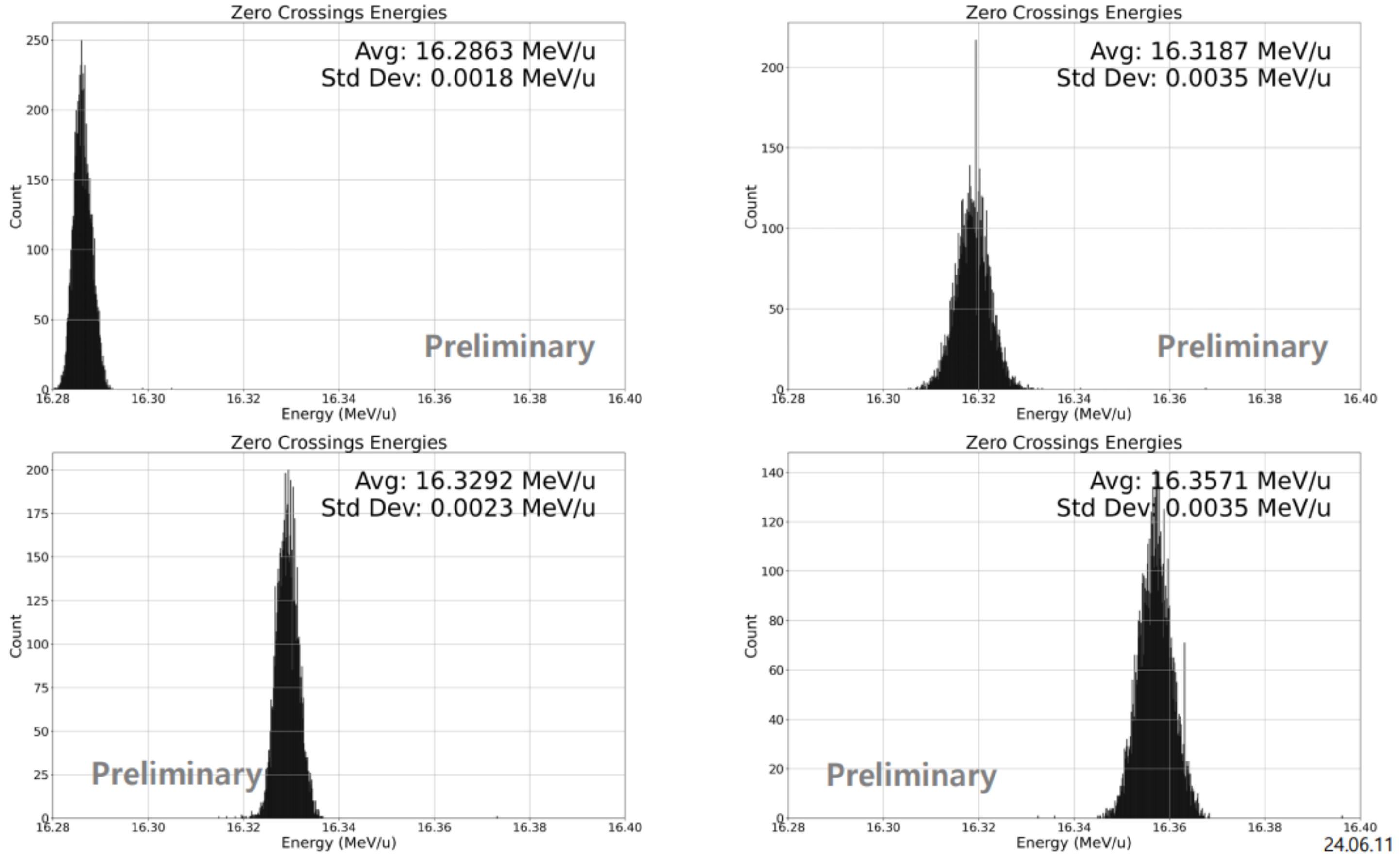


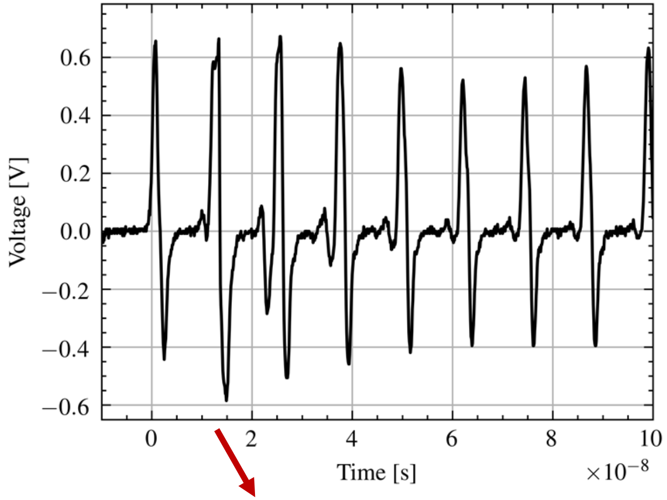


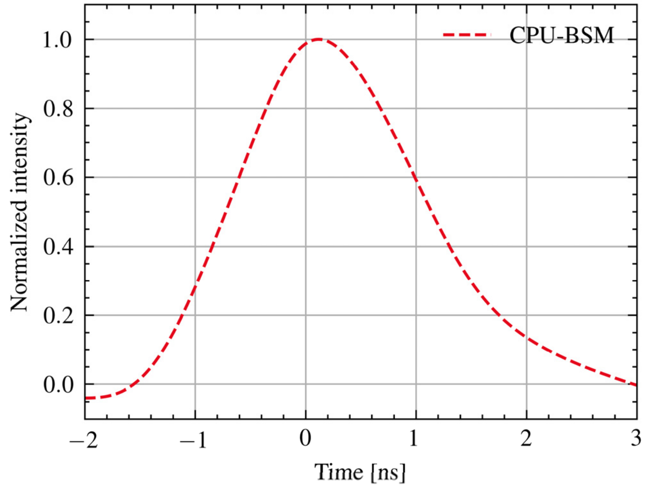
✓ Repetition rate: 81.25 MHz

Capacitive Pick-Up type Bunch Shape Monitors (CPU-BSMs)

Preliminary Results at RAON







✓ Beam energy: ~16.3 MeV/u

✓ FWHM: 1.8 ns ≈ Simulated value: 1.8 ns

Summary

Summary

- ✓ The Capacitive Pick-Up type Bunch Shape Monitor (CPU-BSM) was developed to provide non-destructive longitudinal bunch shape diagnostics, repetition rate diagnostics, and arriver time diagnostics at RAON.
- ✓ The simulation result with bunch shape reconstruction algorithm demonstrated the ability to reconstruct the bunch shape from the detected signals of the CPU-BSMs
- ✓ The performance of the CPU-BSM was validated through bunch shape measurement experiments using non-relativistic hydrogen ion beams, demonstrating its effectiveness.
- ✓ The CPU-BSMs have been installed in the RAON beamline.

Thank you!