MOZZPLM2

A Bunch Structure Measurement of Muons Accelerated by RFQ using A Longoitudinal Beam-Profile Monitor with Hight Time Resolution

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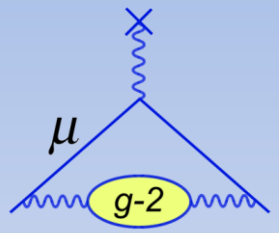
Dipole Moments of Muon

Muon is more sensitive and good prove to look for the Beyond Standard Model!
High intensity muon beam leads to MORE high precision measurement!

Anomalous magnetic moment: *g*-2

> 3 sigma discrepancy between the measured value and the Standard Model prediction.



$$\vec{\mu} = g\left(\frac{q}{2m}\right)\vec{s}$$

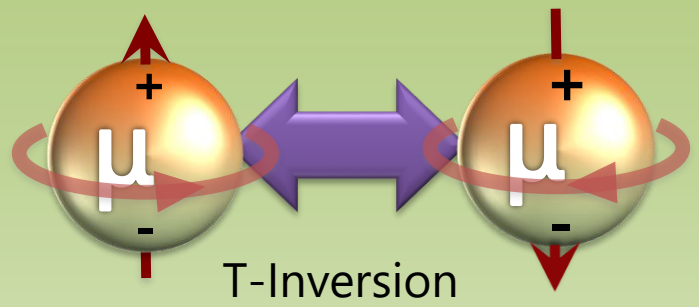
$$\alpha_\mu = \frac{g-2}{2} = \alpha_\mu^{\mathrm{QED}} + \alpha_\mu^{\mathrm{EW}} + \alpha_\mu^{\mathrm{QCD}} + \alpha_\mu^{\mathrm{BSM?}}$$

540 ppb (BNL)

460 ⇒100 ppb

Electric Dipole Moment: EDM

Time-reversal violation observation
if we can see EDM ≠ 0 in this sensitivity.



$$\vec{d} = \eta\left(\frac{q}{2mc}\right)\vec{s}$$

$<1.8\times10^{-19}$ e·cm (BNL)

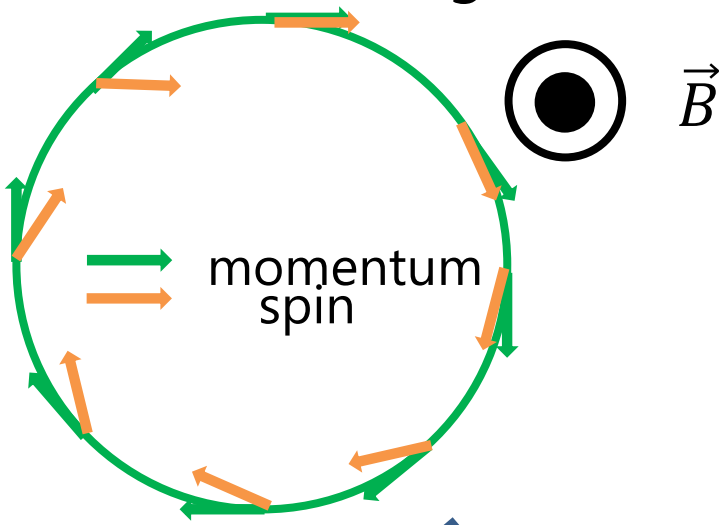
1×10^{-21} e·cm

Precision / Sensitivity

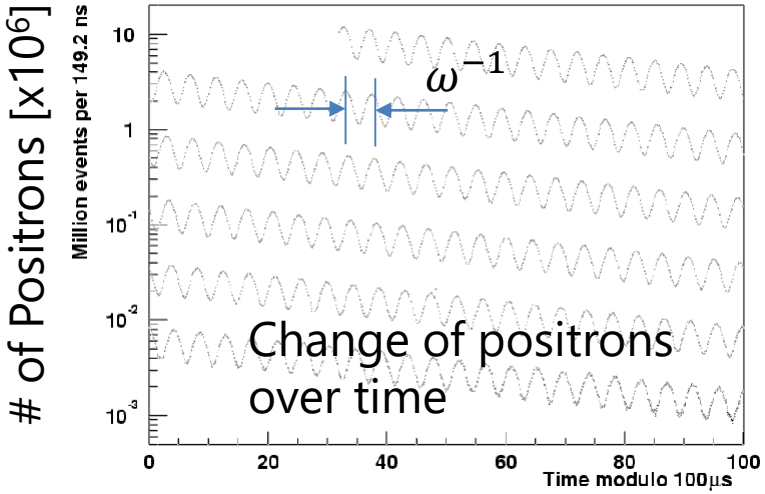
J-PARC muon *g*-2/EDM Experiment

Precise Measurement of Spin Precession

Circulate muon beam in magnetic field

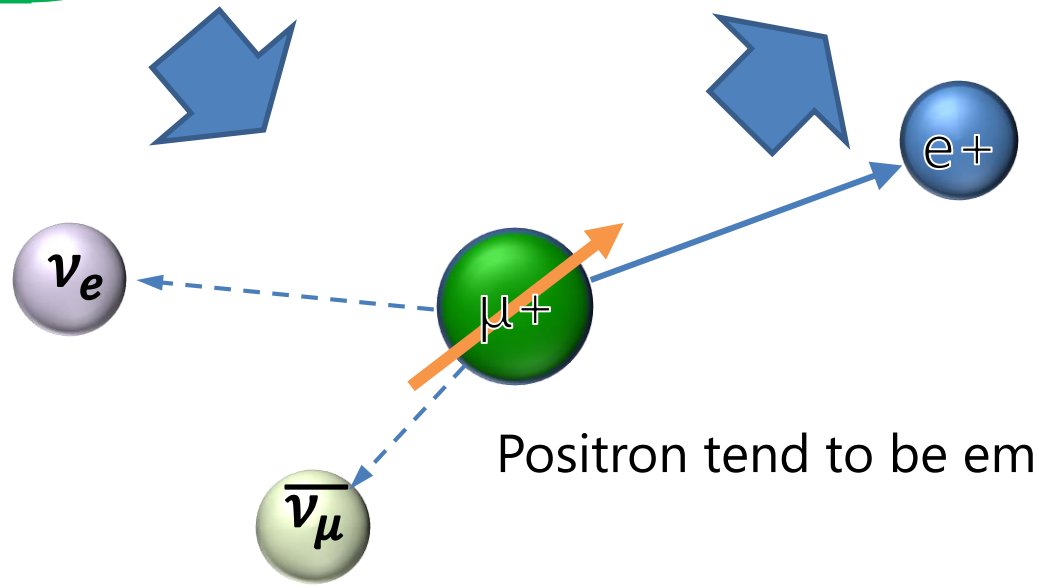


Measure the spin precession



Elapsed time[μs]

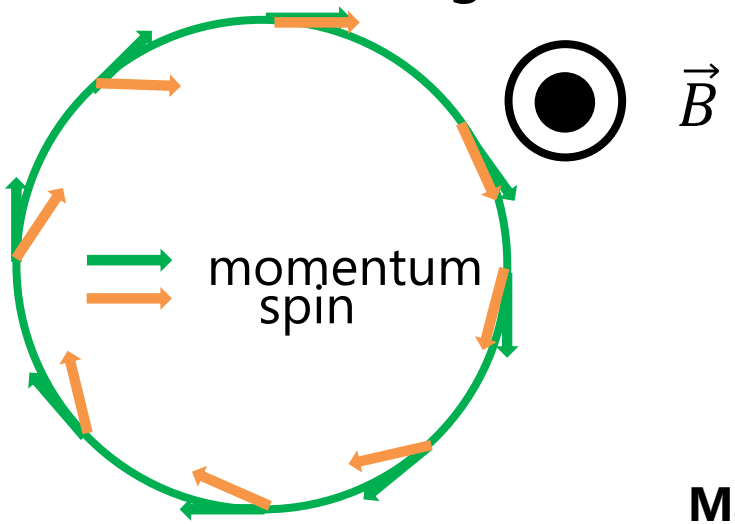
$$\omega = (g-2)\frac{eB}{2m_\mu}$$



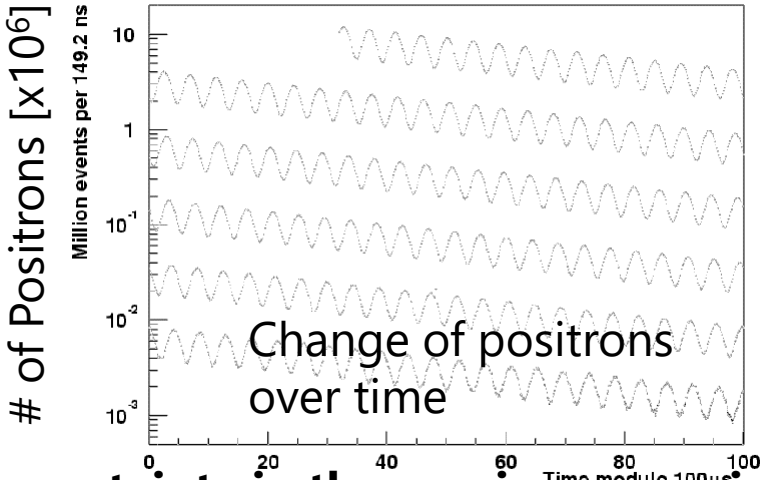
Positron tend to be emitted for a muon spin direction

Precise Measurement of Spin Precession

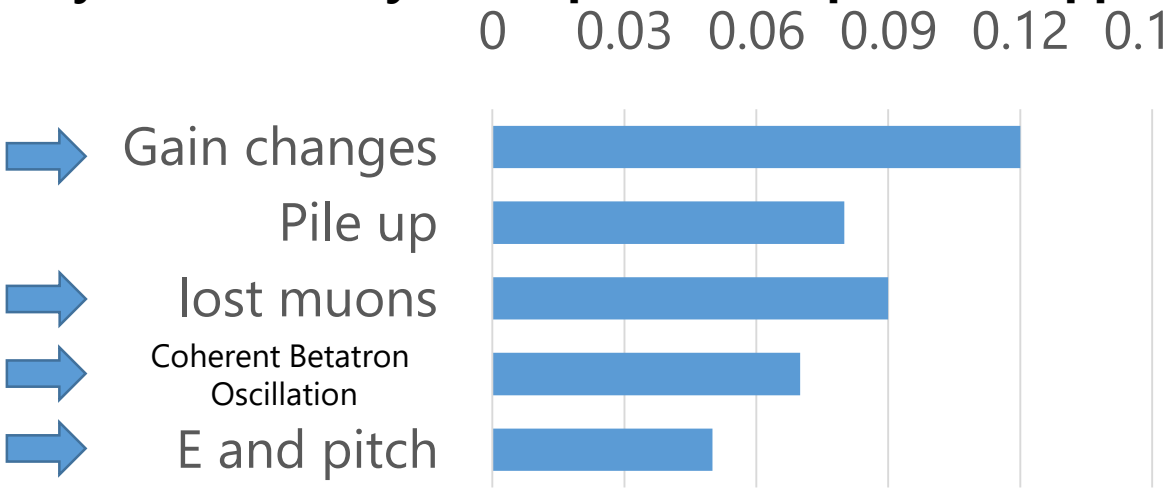
Circulate muon beam in magnetic field



Measure the spin precession



Major uncertainty in the previous experiment [ppm]

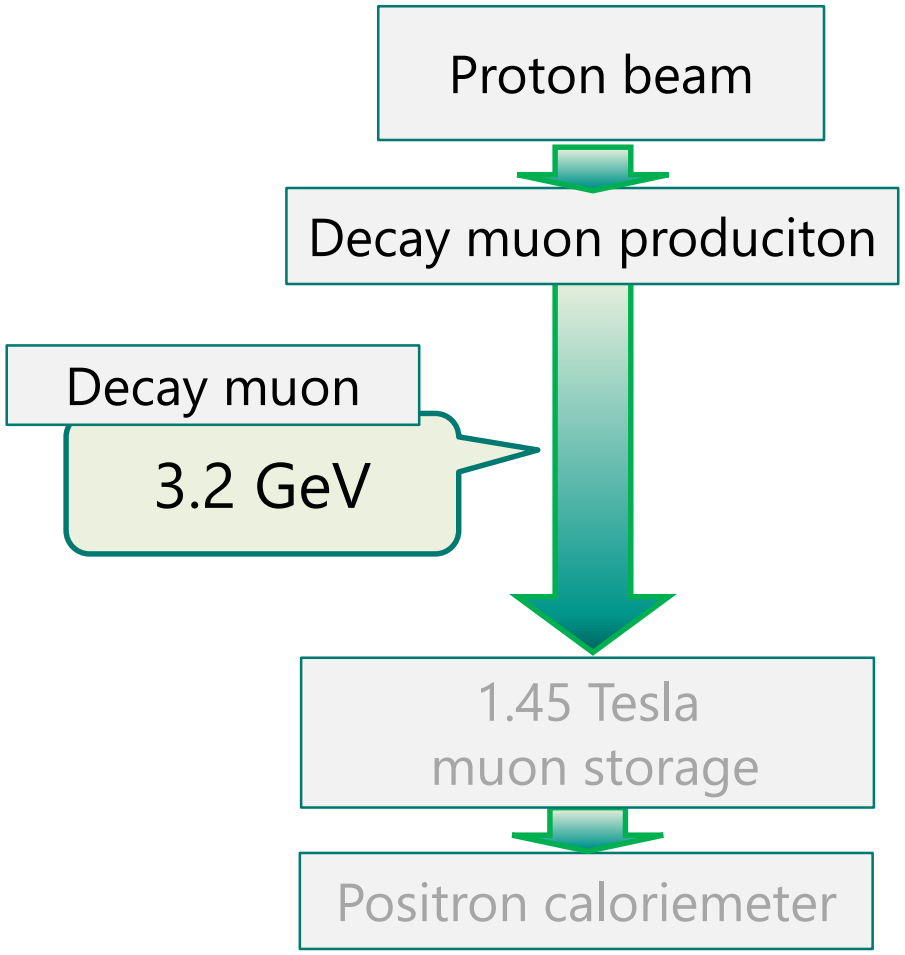


Derive from
the emittance of muon beam

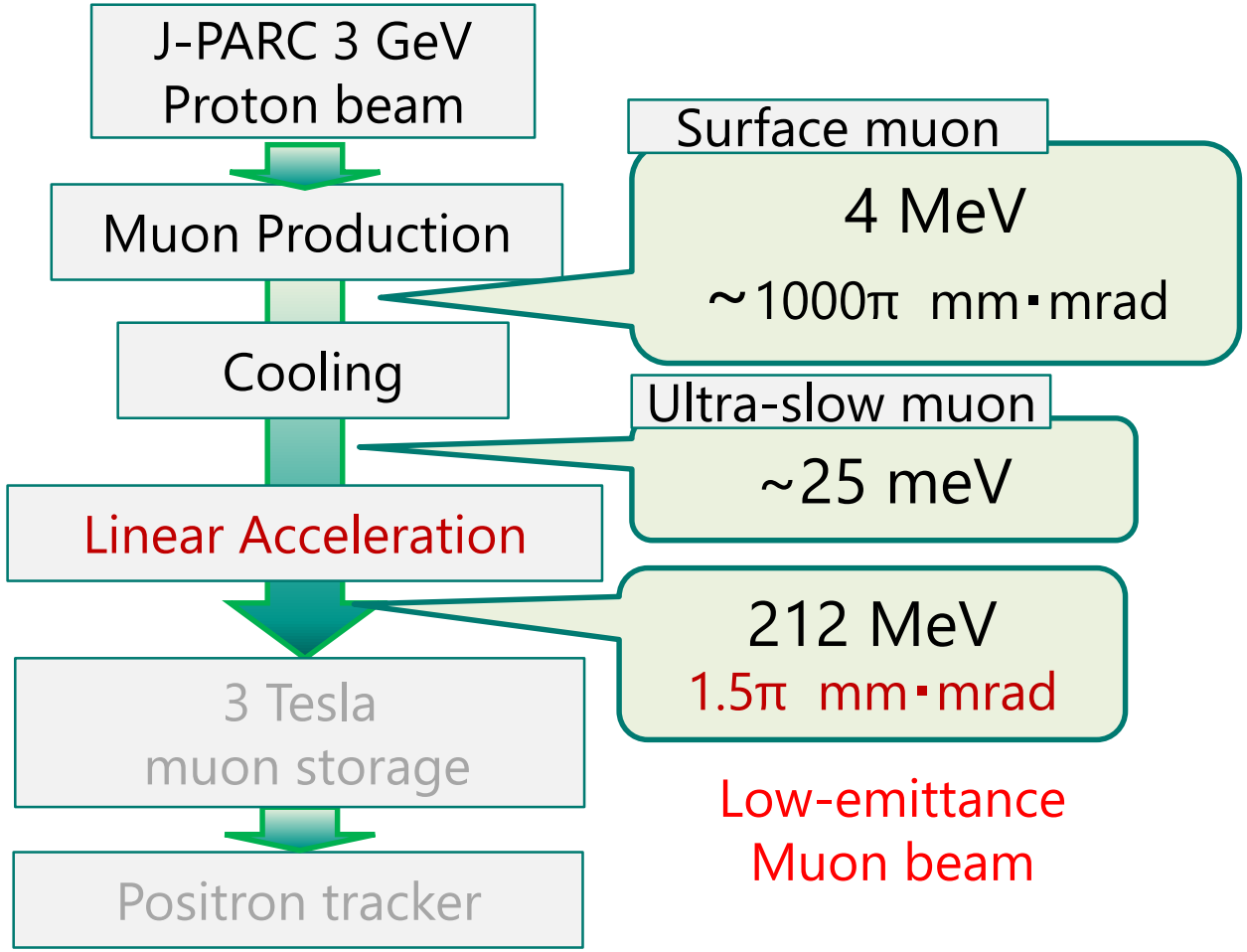
⇒ **Aim to reduce the uncertainties by low-emittance muon beam**

Muon Beam Production in Muon g-2/EDM Experiment

BNL / FNAL



J-PARC



Muon linac is necessary to provide low-emittance muon beam.

Status of Muon Linear Acceleration

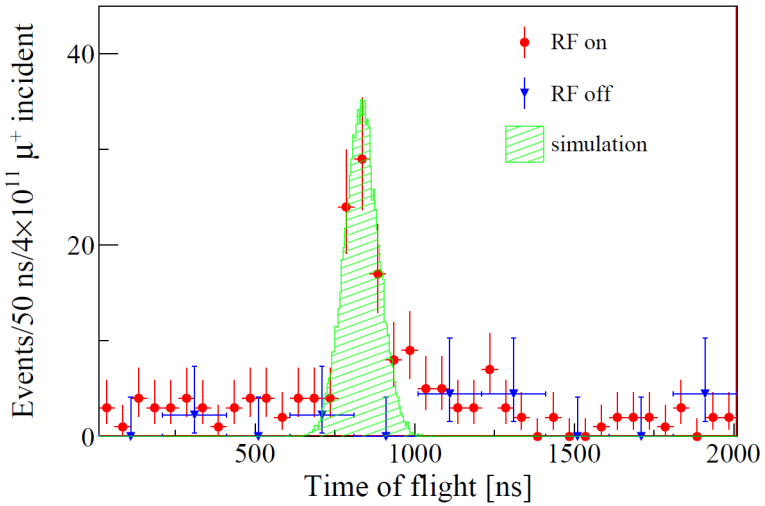
Issue

- Unprecidented muon RF acceleration
- Unestablished the way to diagnostic low-energy and low-intensity

Status=demonstration

Oct. 2017: First muon acceleration
Dec. 2017: Meas. transverse profile

⇒Reported in IPAC'18



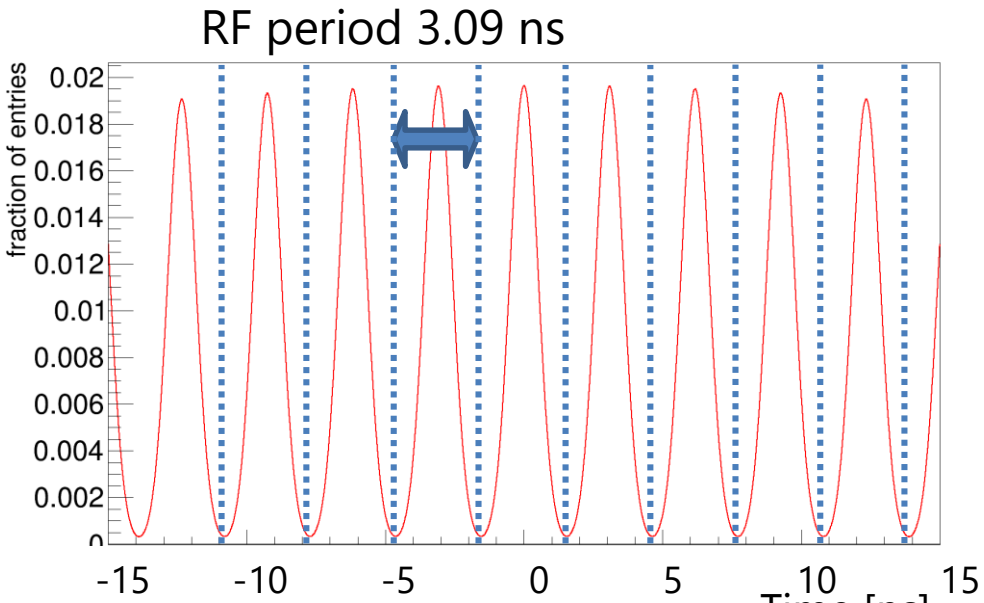
Remaining issue and this work

Beam intensity is too low to use a conventional phase monitor
→Develop a longitudinal beam profile monitor
→Demonstrate the measurement of low-energy muon bunch

Expected Structure and Monitor Concept

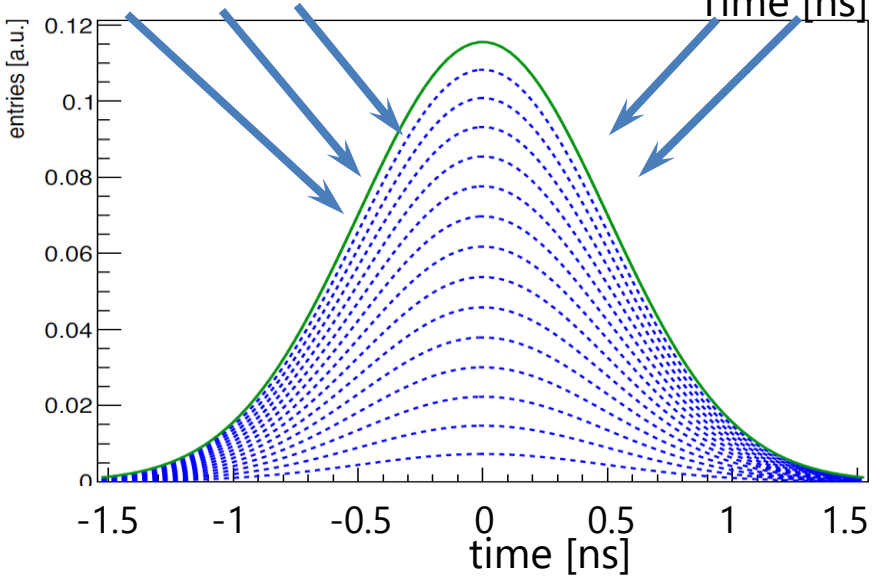
Requirements

- For 324 MHz accelerators.
- Beam intensity is about 0.5 mHz in the demonstration phase.
- Phase resolution of 1%, 30-40 ps

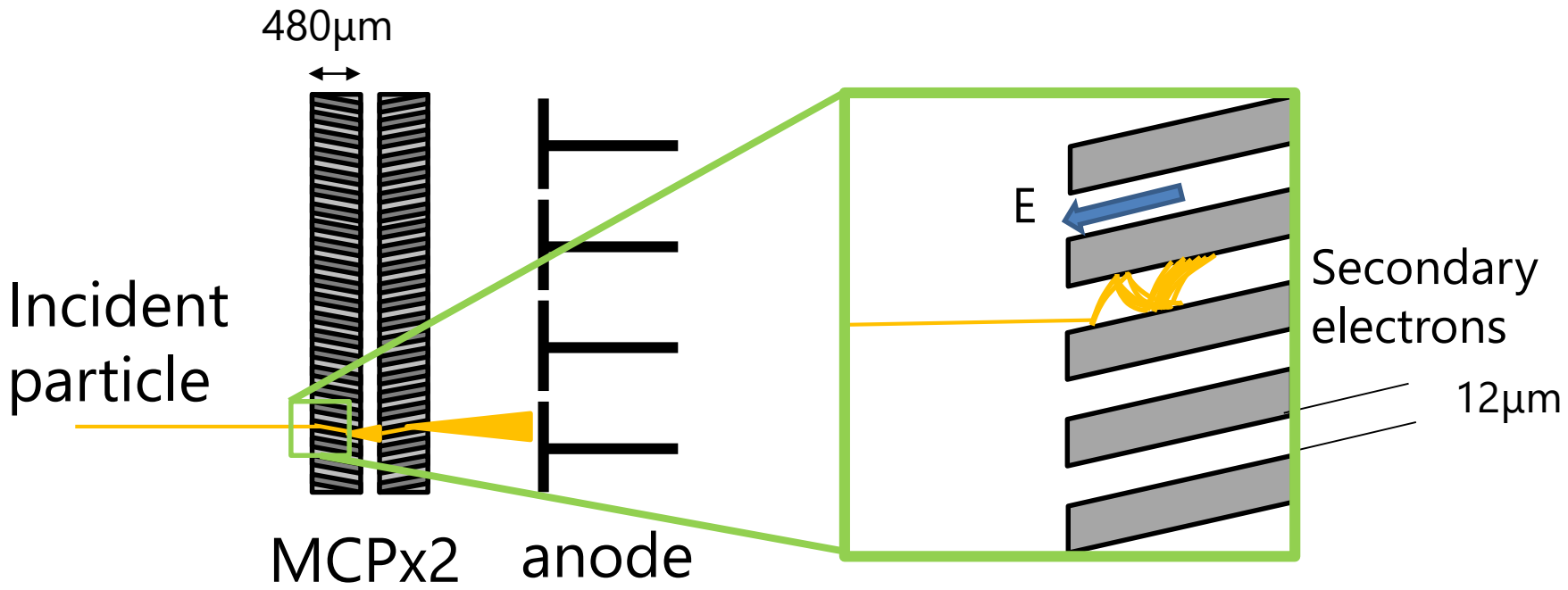


Superpose muon one by one to deal with long time data and other bunches in a batch.

- Measure the time difference btw the signal and RF synchronized signal.
- Take the remainder of RF period.



Longitudinal Beam Profile Monitor



Measure <u>time of muon arrival</u> with <u>high time resolution</u> using MCP

☺ Sensitivity to low-energy single muon

☺ Good time resolution

☹ Need to limit the beam power

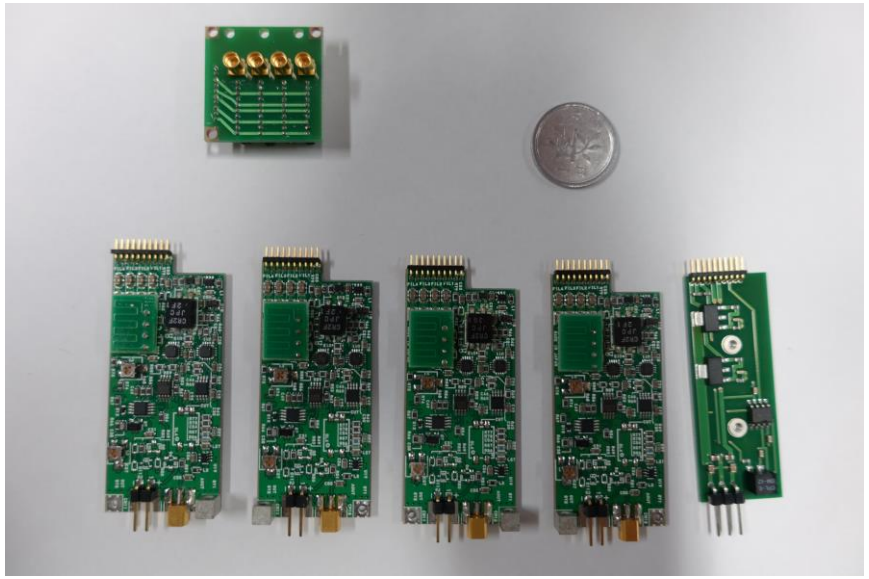
→ No problem in commissioning stage

Adopt four-separated multi-anode to avoid deterioration of the time resolution depending on spread of transverse profile.

Electronics and DAQ

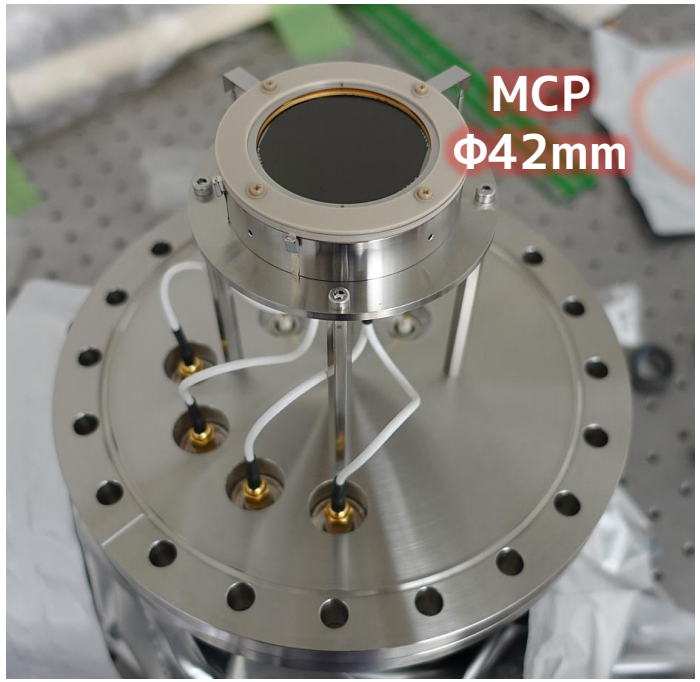
- Constant-Fraction Discriminator
  - Suppress a time-walk effect
  - time jitter: < 5 ps

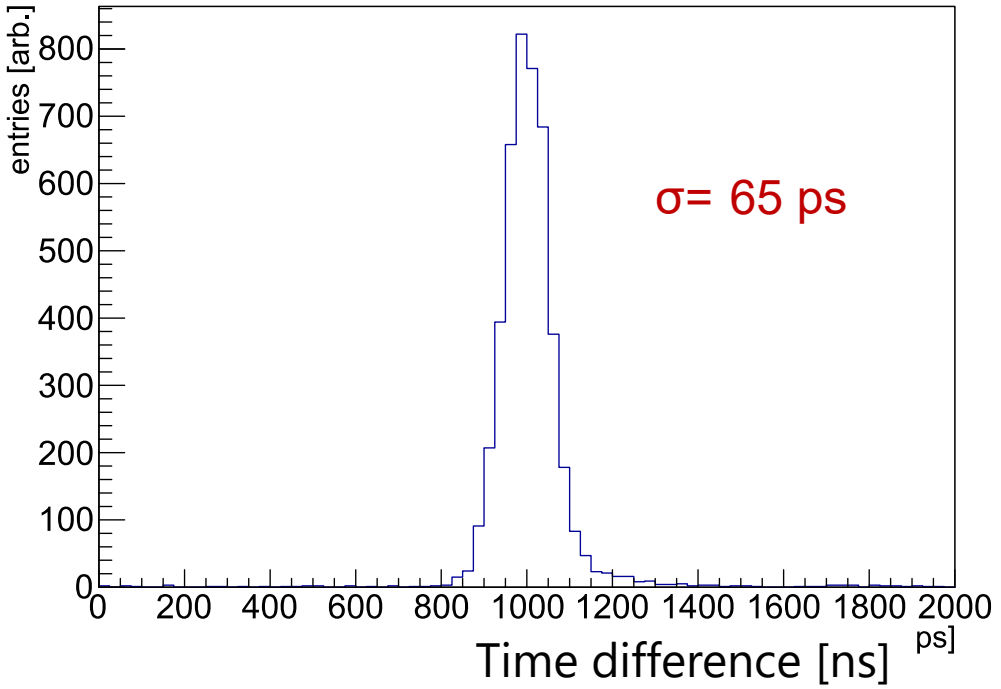
K. Inami *et. al.*, "A 5 ps TOF-counter with an MCP-PMT". *NIM* A560(2), pp. 303–308. (2006). https://doi.org/10.1016/j.nima.2006.01.027



- TDC: CAEN V1290
  - LSB: 25ps
  - Time resolution: 35ps
- FADC: CAEN V1720
  - Sampling signal voltage every 4 ns
  - Dynamic range: 10μs

Time Resolution Measurement

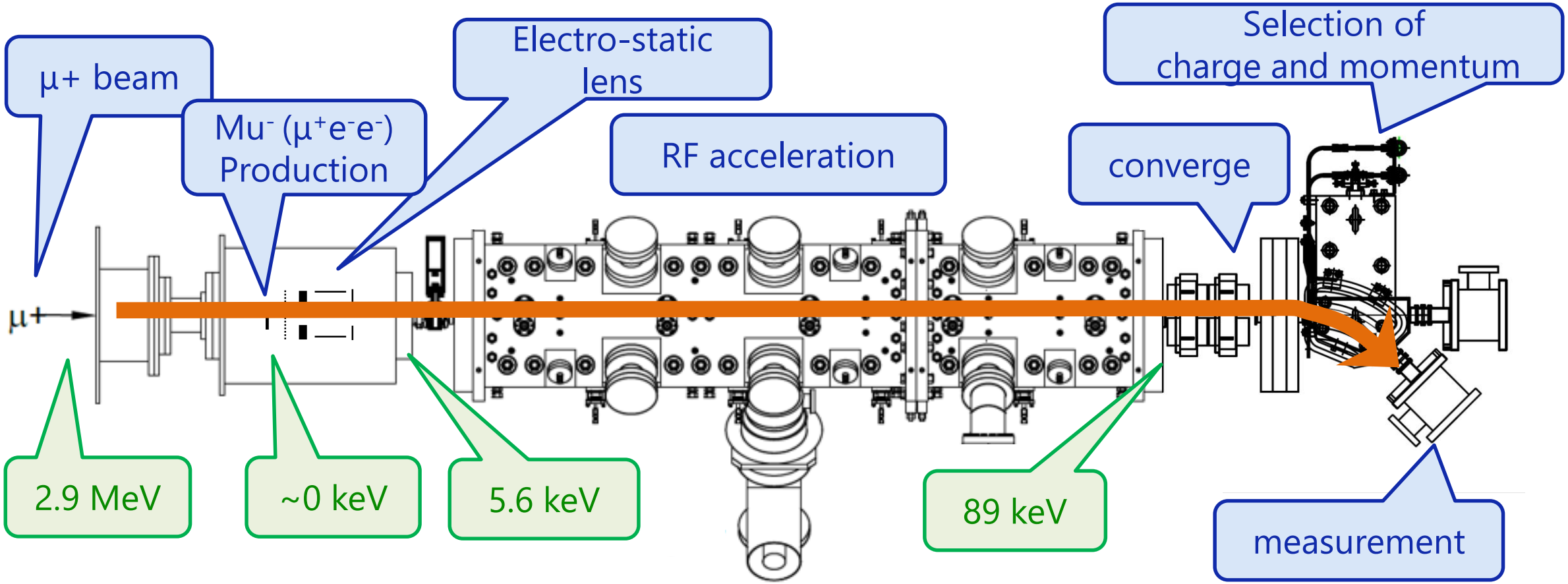




Evaluate the time resolution of the monitor using photo-electron.
Achieve the time resolution of 65 ps
= phase resolution of 2%

⇒ For the details, WEPGW042 (M.Yotsuzuka)

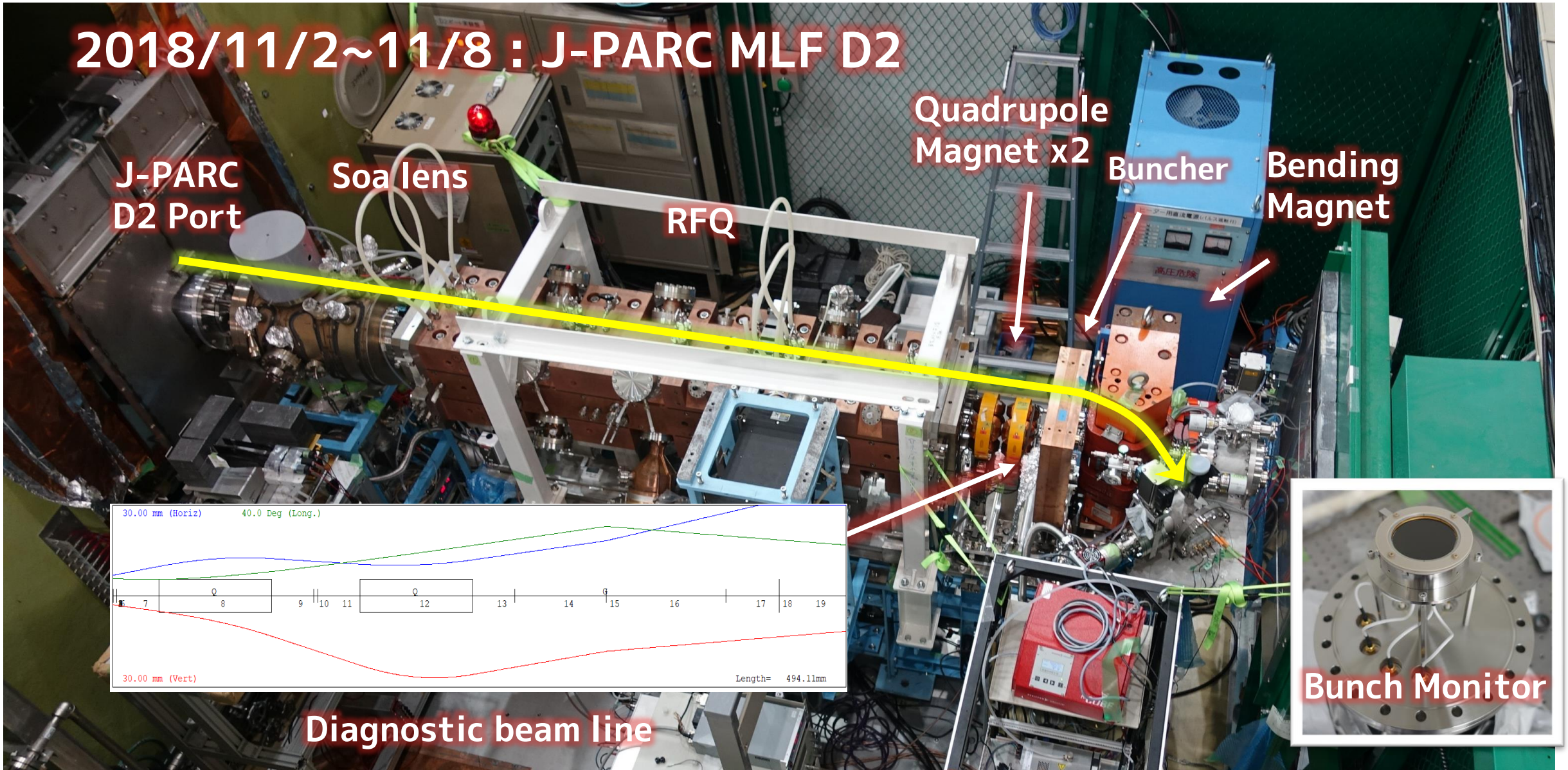
Experimental Setup for Bunch Size Measurement



Produce bunches of the accelerated 89keV $Mu^-(\mu^+e^-e^-)$

- μ+ cooling and energy monochromatizing
- Separation from background (penetrate μ+)

Experimental Setup for Bunch Size Measurement



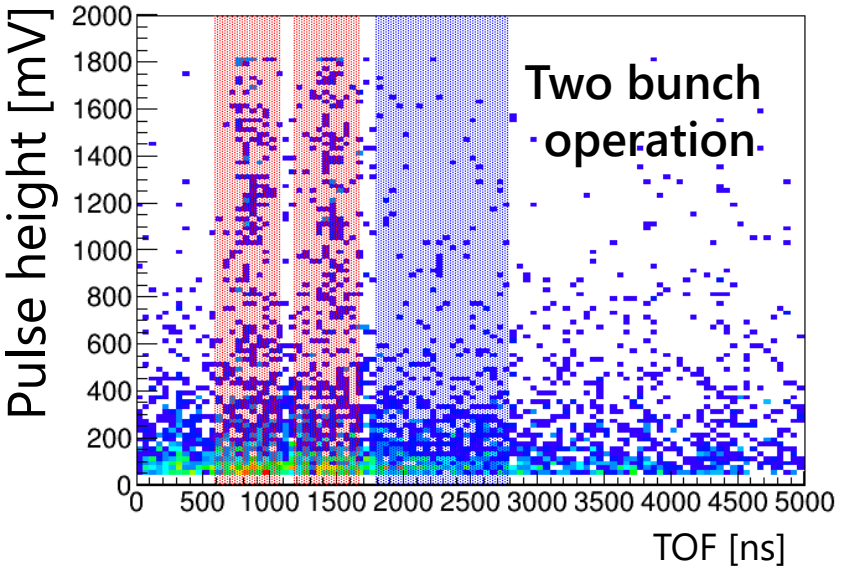
Signal Selection

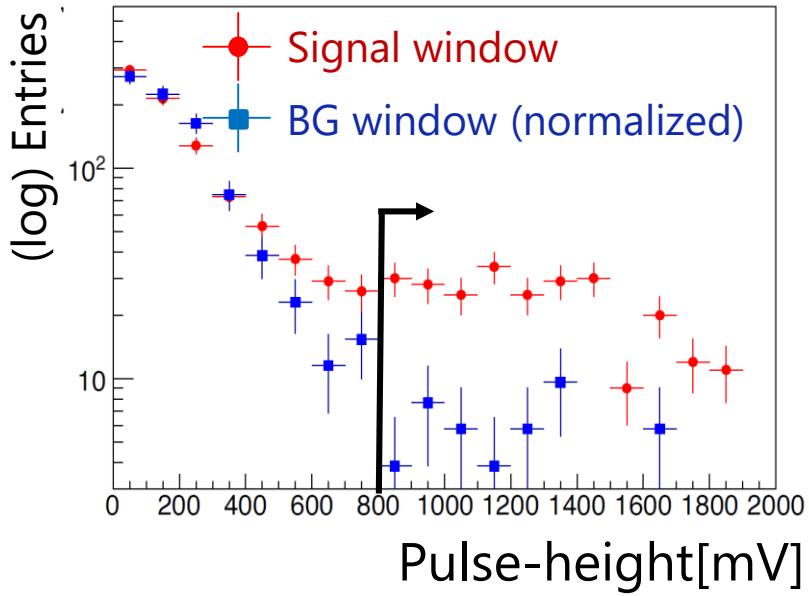
The data contain a lot of background data of positrons from muon decay.

Extract the accelerated Mu- from the beam test data.

1. Extract by Time-Of-Flight from μ+ arrival at Mu- production target.
2. Pulse-height distribution of accelerated Mu- become higher.

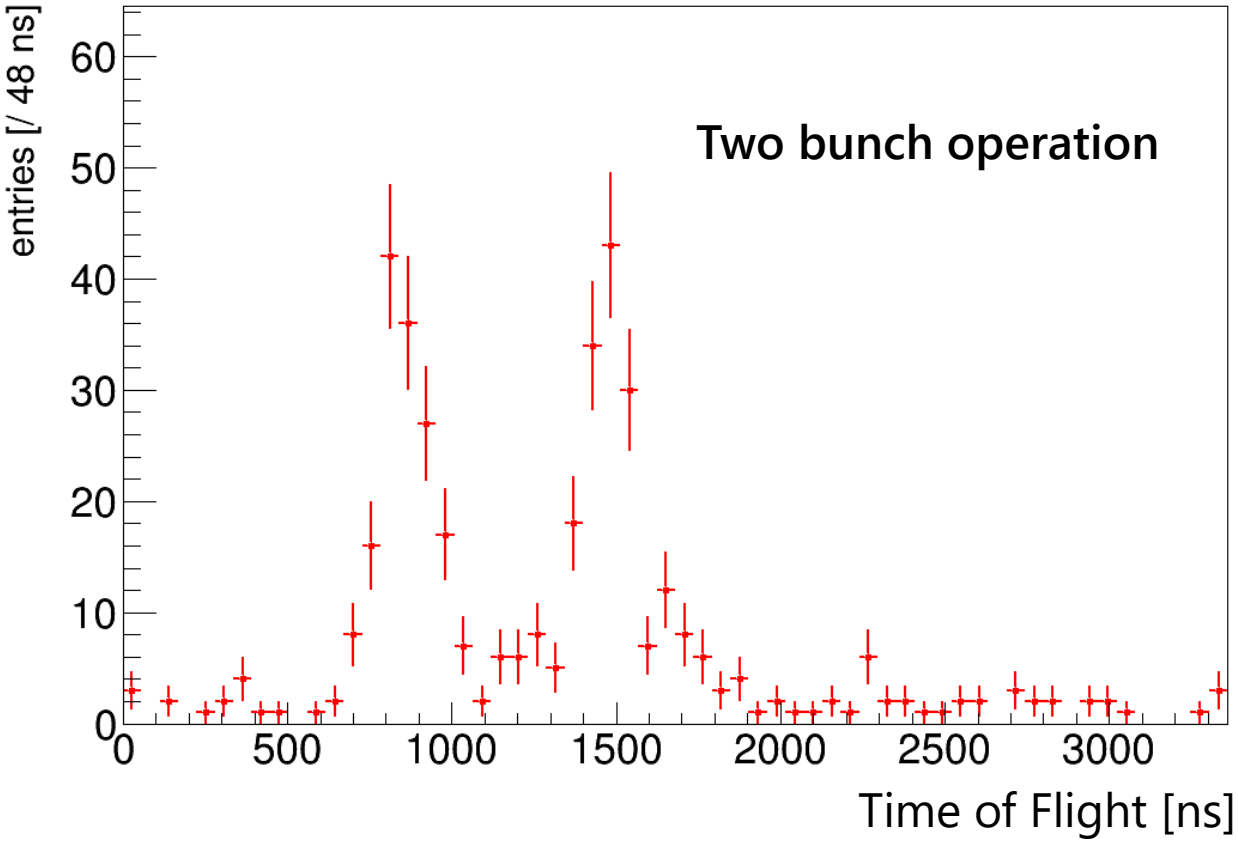
⇒extract the signal having higher pulse-height.



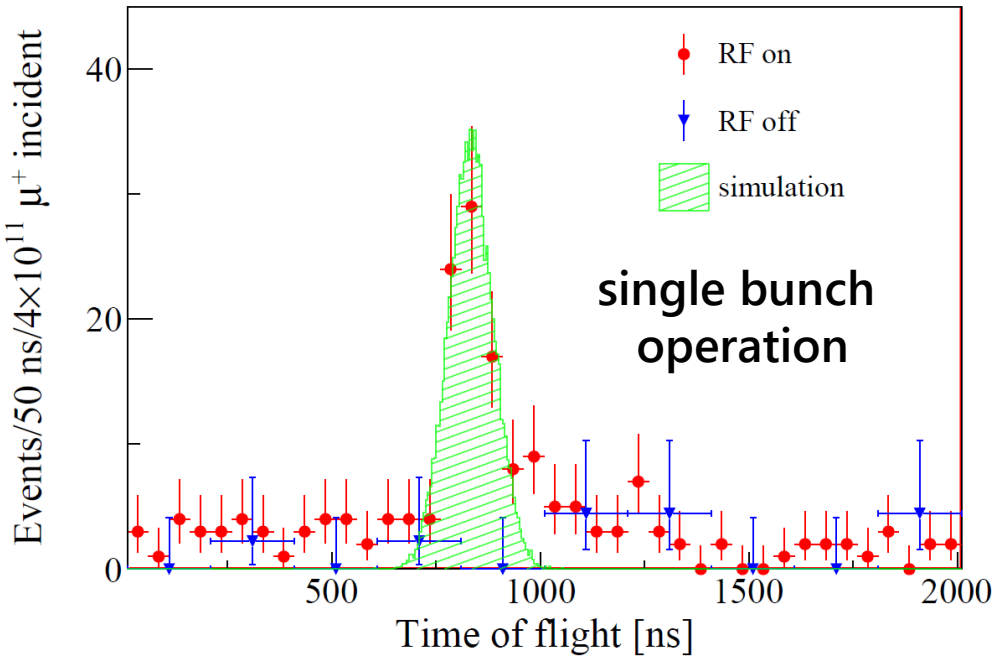


Signal Selection

result after signal selection

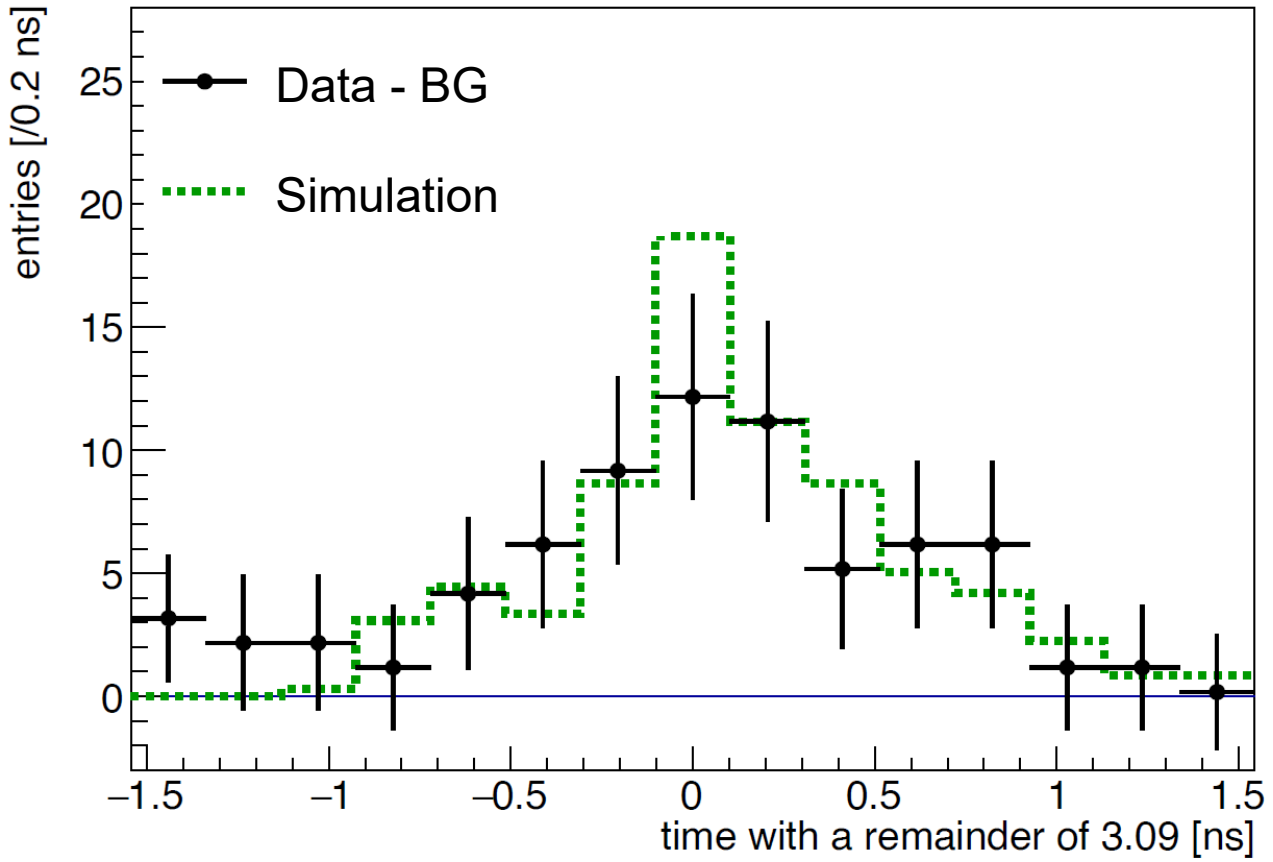


2017 demonstration of muon RF acceleration



Succeed in muon acceleration and BG reduction.

Result of The Bunch Measurement

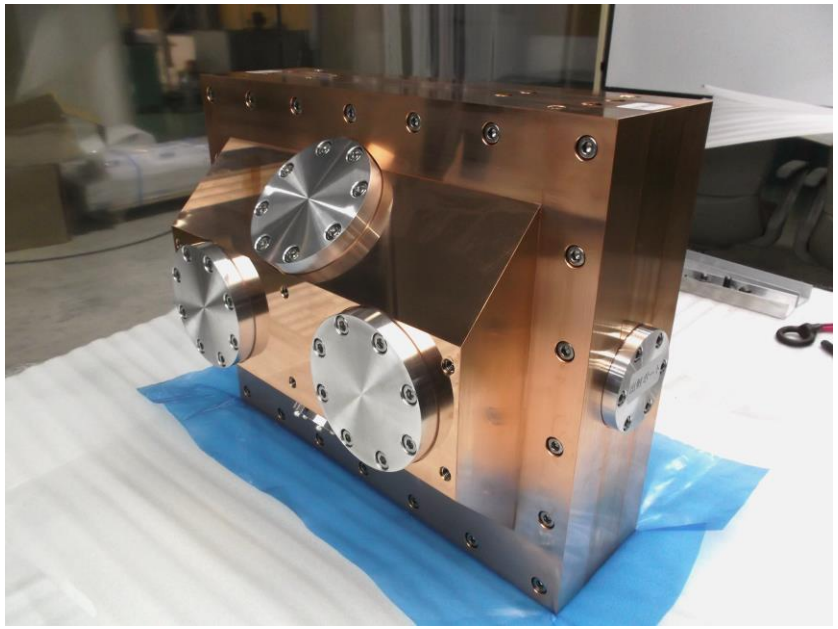


The result of measurement of the bunch size is 0.54±0.13 ns

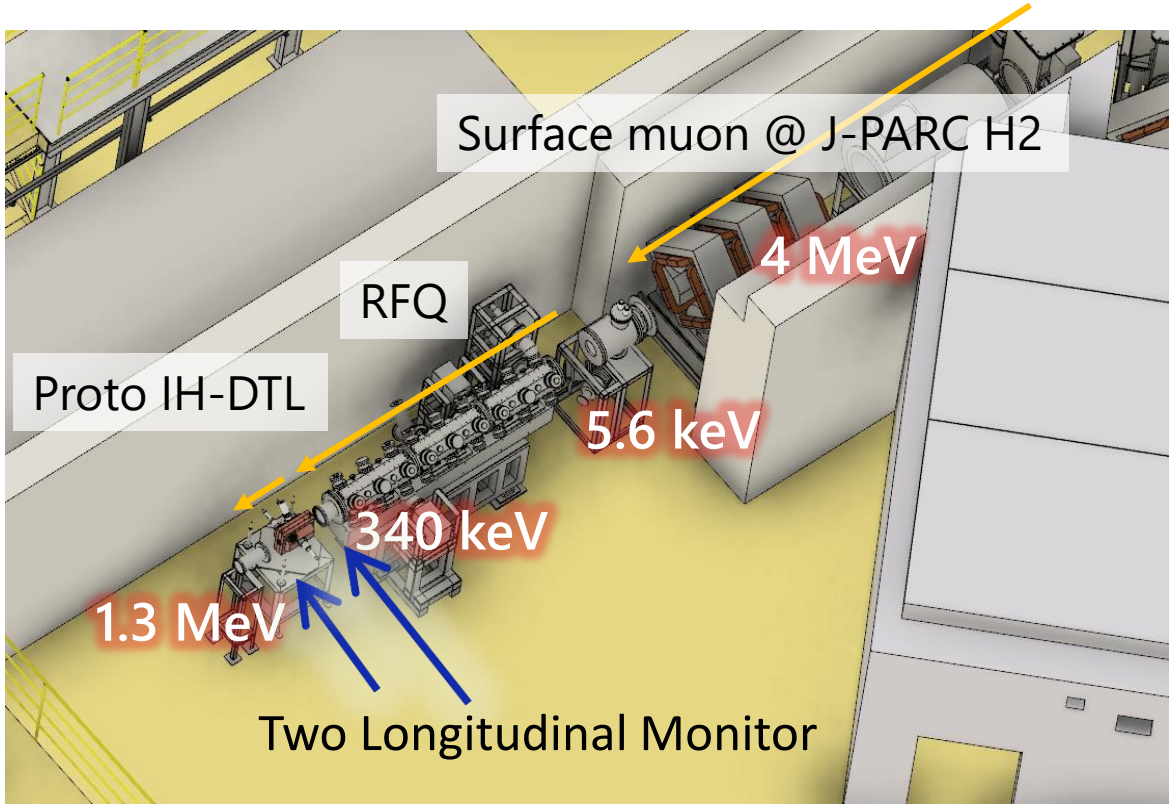
- This method to low-energy and low-intensity beam is effective.

Next Step…

- Acceleration up to 1.3 MeV by IH-DTL, 2nd accelerator.
- Measure the bunch size back and forward IH-DTL.



Proto-type IH-DTL ⇒MOPRB017 (Y.Nakazawa)



Summary

- The muon linear accelerator is under development at the J-PARC for the precise measurement of muon's g-2/EDM.
- The longitudinal beam profile monitor for low-energy muon with MCP is designed and developed.
  - aim to the time resolution of 30-40 ps for 324 MHz accelerator.
  - Achieved 65 ps
- Measured of bunch size of Mu^- accelerated up to 89 keV with RFQ.
  - The bunch width is $\sigma=0.54\pm0.13$ ns, which is consistent with the simulation.
  - This result means effectiveness of the method to measure the bunch size of low-beta and low-intensity muon beam.

- The adjust operation using the next-stage accelerator is planned.