

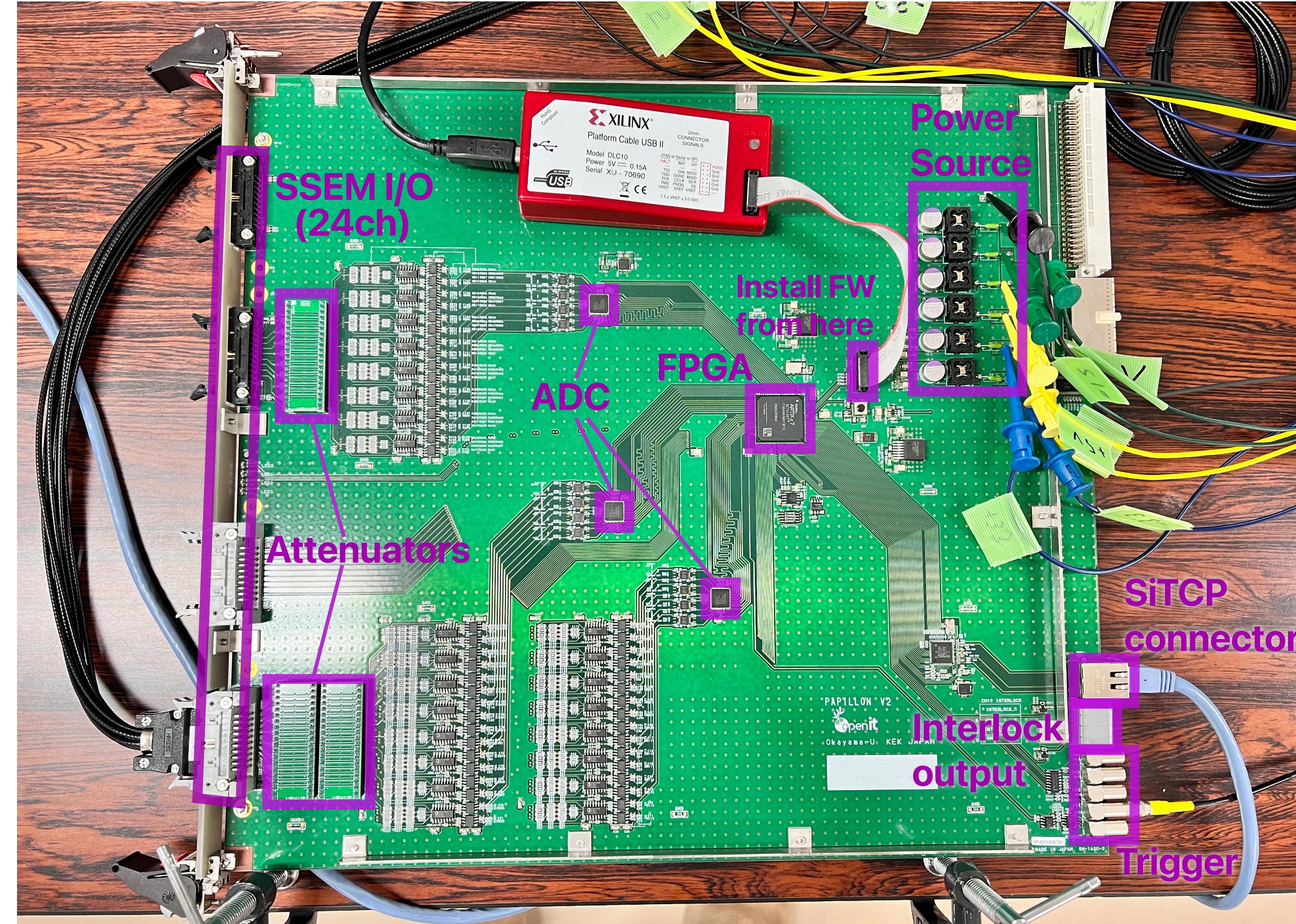
Development of PAPILLON module towards beam upgrade

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What is PAPILLON module?

■ PAPILLON is Beam interlock module towards beam upgrade to 1.3 MW.

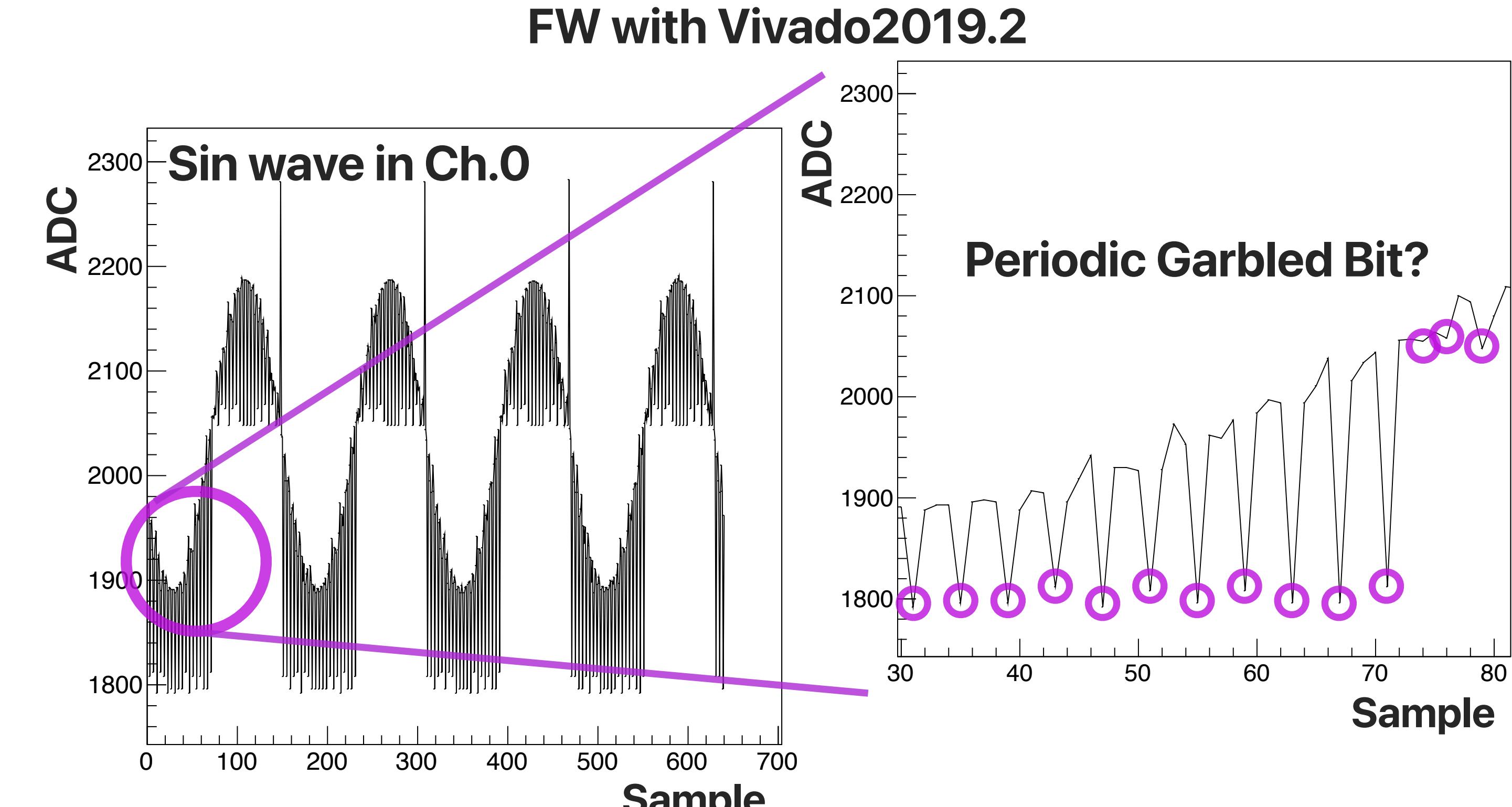
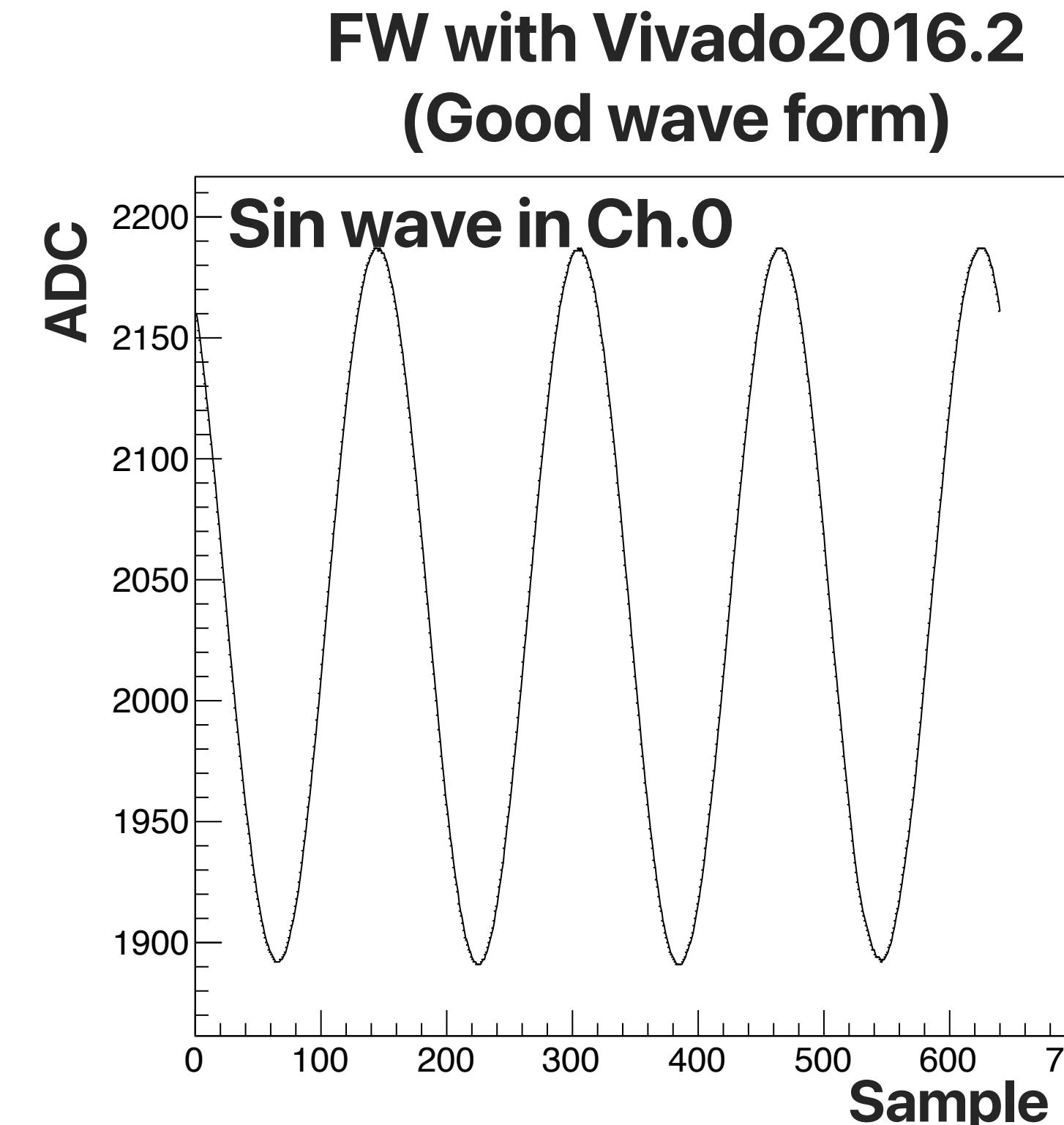
Beam position & width calculation take ~1 sec by offline analysis, but the repetition upgrades 2.48 → 1.16 sec.
→ Calculate position & width with shorter time by FPGA.



Debugging towards New Vivado Version

- The current PAPILLON FW was developed with Vivado ver2016.2 (by Yamasu-san at Okayama University).
The current development has been progressed with Vivado 2019.2.
→FW with Vivado ver2019.2 works well?

- The answer is NO... (Tested with simple sin waveform; 500kHz, 500mVpp)
Timing of ADC→FPGA or FPGA→PC(SiTCP connection) should be strange.



Debugging towards New Vivado Version

■ Debug point: Critical warning of timing constraint

PAPILLON uses multiplier, divider and RMS etc for beam position & width calculation.

Numerical calculation in FPGA(e.g. multiplier, divider) should be done at the dedicated blocks -DSP(Data Signal Processor) rather than common blocks.

(Otherwise, it takes time due to relatively complicated procedure)

Adder(+), subtractor(-)

→ Combination of AND, OR, 2's complement

Relatively easier

Multiplier(×)

→ Iteration of adder and shift operation

Divider(÷)

→ Iteration of subtractor and shift operation

Use them for beam position & width calculation

Beam position:

$$X[\text{mm}] = \frac{\sum_{\text{strip}=0}^{23} Q_{\text{strip}} \times x_{\text{strip}}}{\sum_{\text{strip}=0}^{23} Q_{\text{strip}}}$$

Beam width:

$$\sigma_X[\text{mm}] = \sqrt{\frac{\sum_{\text{strip}=0}^{23} Q_{\text{strip}} (x_{\text{strip}} - X)^2}{\sum_{\text{strip}=0}^{23} Q_{\text{strip}}}}$$

■ Comment out the beam position and width calculator, for the moment. → Critical warning was vanished.
Redevelop this module with above advice again (it includes next tasks; pedestal calculation or etc).

Debugging towards New Vivado Version

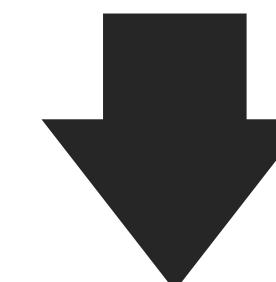
- Timing of ADC→FPGA is also adjusted.
→ADC output the expected pattern at the ADC test mode.

ADC output 0aaa, 0555... with 24ch.

24ch data (event 1)

0000 05550555 05550555 05550555 05550555 05550555 0aaa0aaa 0aaa0aaa 0aaa0aaa 0aaa0aaa 05550555 05550555 05550555 05550555
0030 0aaa0aaa 0aaa0aaa 0aaa0aaa 0aaa0aaa 0aaa0aaa 05550555 05550555 05550555 05550555 0aaa0aaa 0aaa0aaa 0aaa0aaa 0aaa0aaa

Timing is strange.



Adjusted phase of strange ADC ch.(ch8-ch15)

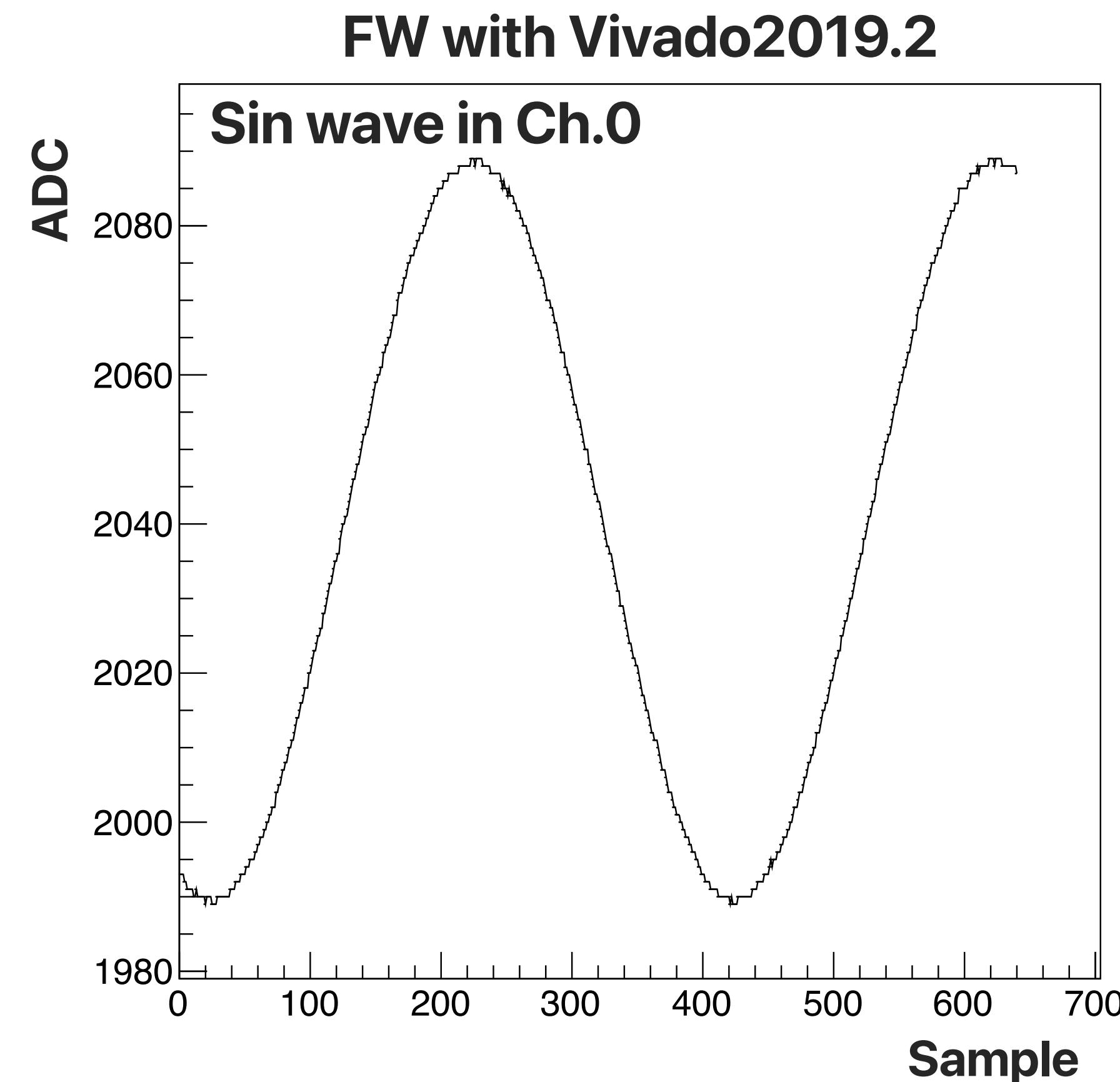
24ch data (event 1)

0000 0aaa0aaa
0030 05550555 05550555 05550555 05550555 05550555 05550555 05550555 05550555 05550555 05550555 05550555 05550555 05550555

Good!

Defeated the Bug!

- Input the simple sin wave (200 kHz, 200 mVpp)
→ Beautiful wave form could be confirmed!
- As the next step, we can move on development of beam position and width calculator.



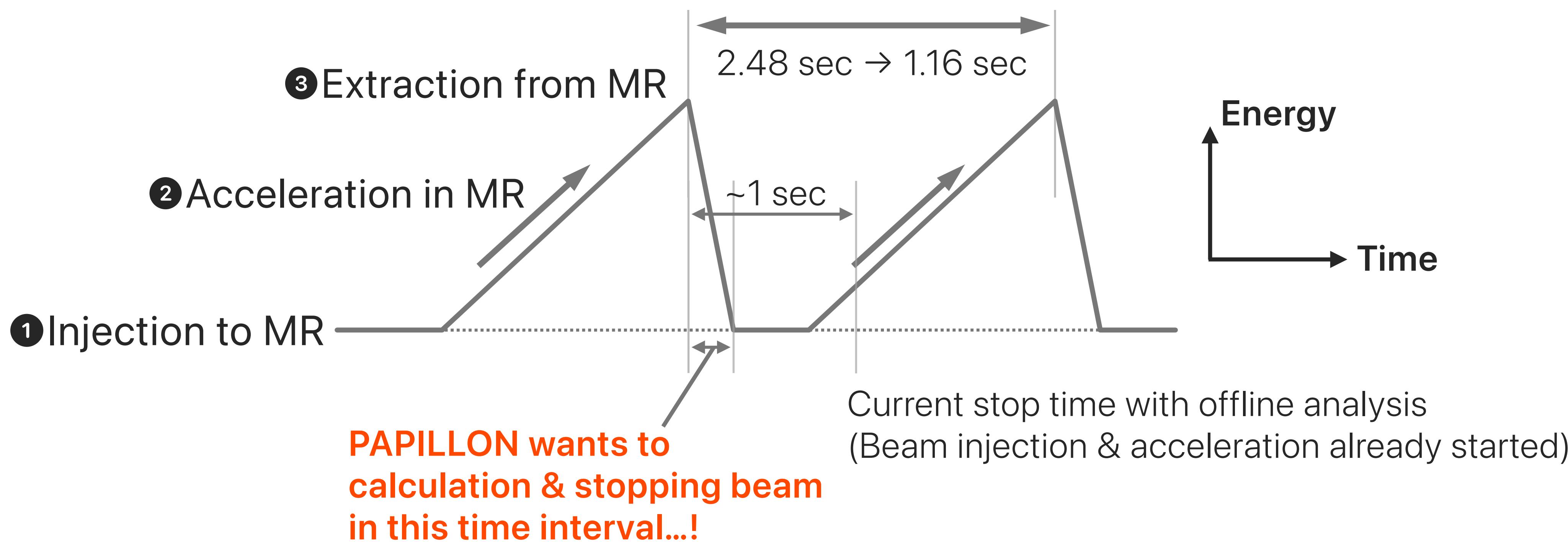
Summary and Next step

- PAPILLON is a new module that performs faster beam position & width calculation with FPGA towards T2K beam upgrade
Development is progressing towards to install into T2K
- We have two items for this development:
 1. Implementation of beam width calculation and its criterion.
 2. Implementation of pedestal calculation.
- We transferred Vivado 2016.2 → 2019.2 in this development, but we had bug.
→ Bug is fixed by “proper solution” for timing violation and ADC phase adjustment.
- We can move on development of the module that calculates beam position and width.
(It includes above two next tasks.)

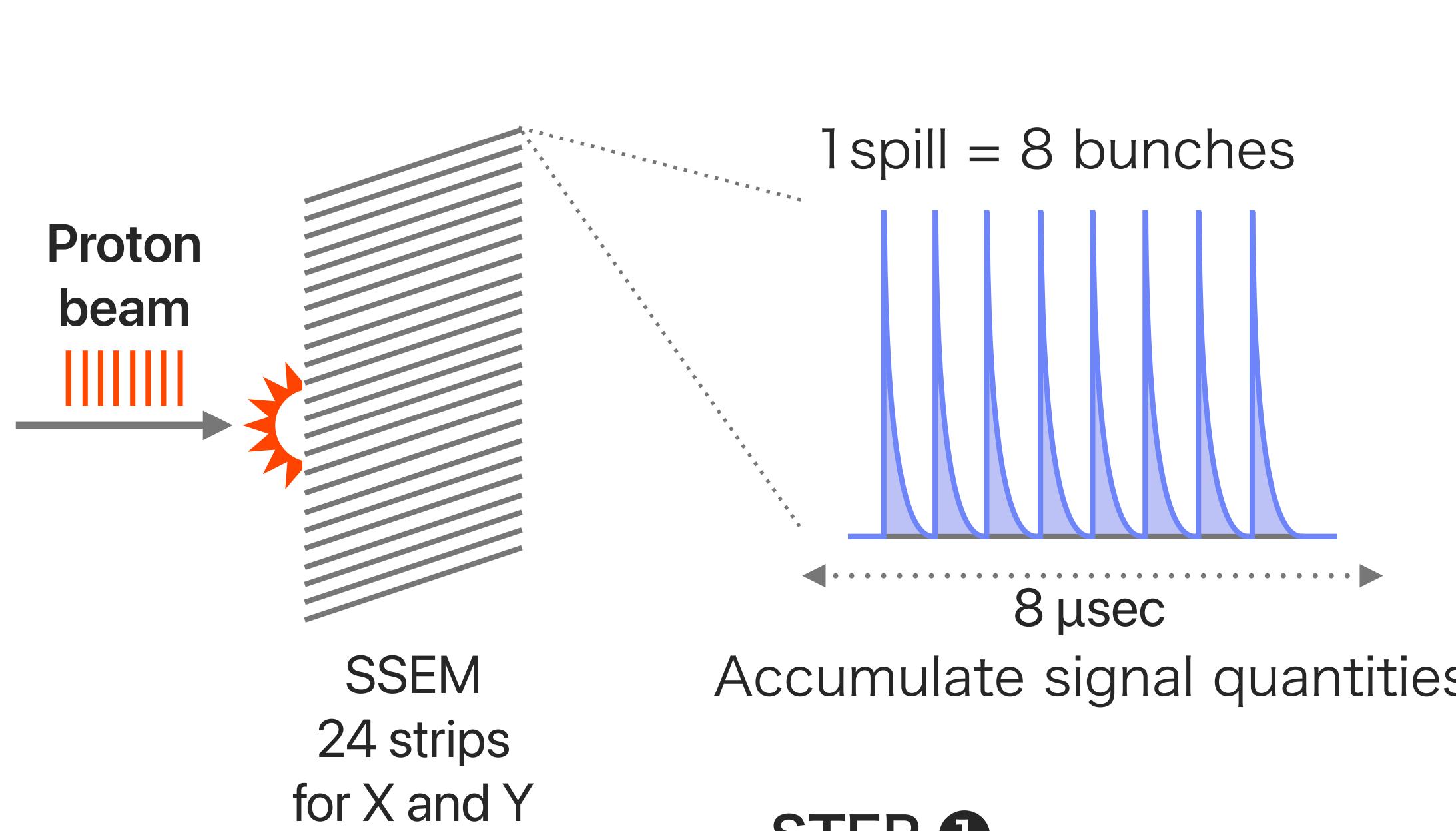
Back up

Remind: Motivation of PAPILLON

- How to upgrade proton beam?
→ Increasing of proton density per a spill & **shortening of spill interval ($2.48 \text{ sec} \rightarrow 1.16 \text{ sec}$)**
- Beam position calculation with offline analysis takes $\sim 1\text{sec}$
→ It will be able not make it in time of next beam injection
PAPILLON performs faster calculation with FPGA (motivation of development)

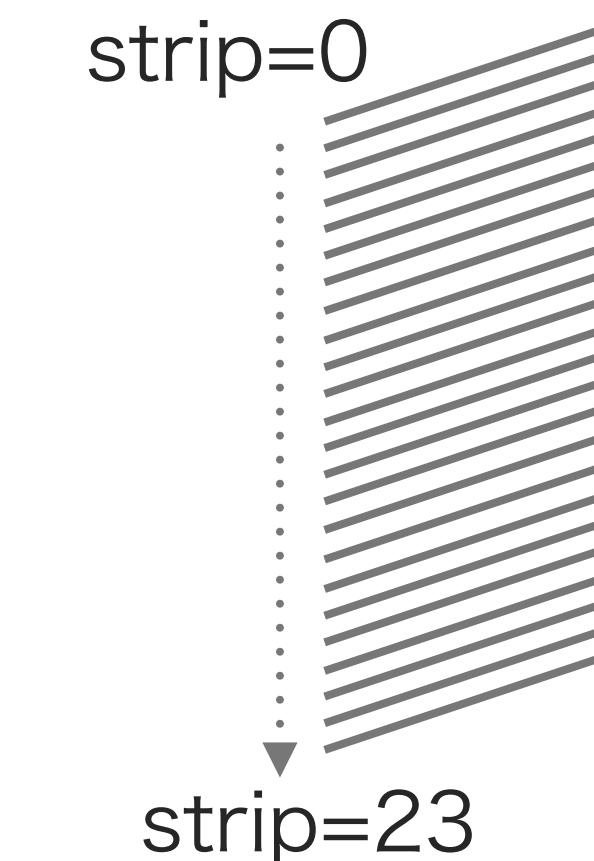


Beam Calculation in PAPILLON



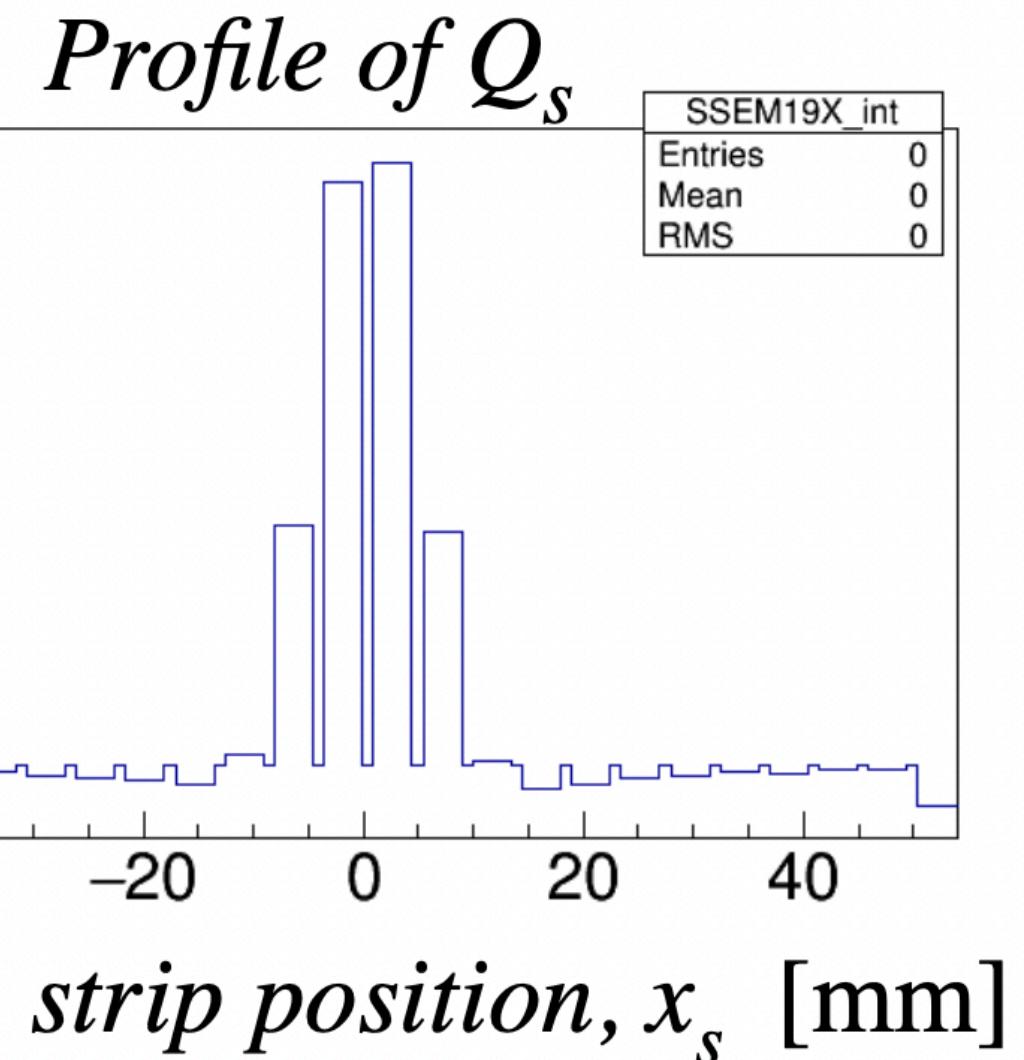
STEP ①

Accumulate signal quantities
with 8 μ sec window = Q_{strip}
(1spill interval is $\sim 5 \mu$ sec)



STEP ②

Obtain accumulated signal
quantities for each 24 strips



STEP ③

Calculate beam position as
weighted average

$$X[\text{mm}] = \frac{\sum_{strip=0}^{23} Q_{strip} \times x_{strip}}{\sum_{strip=0}^{23} Q_{strip}}$$

x_{strip} : position of each strip

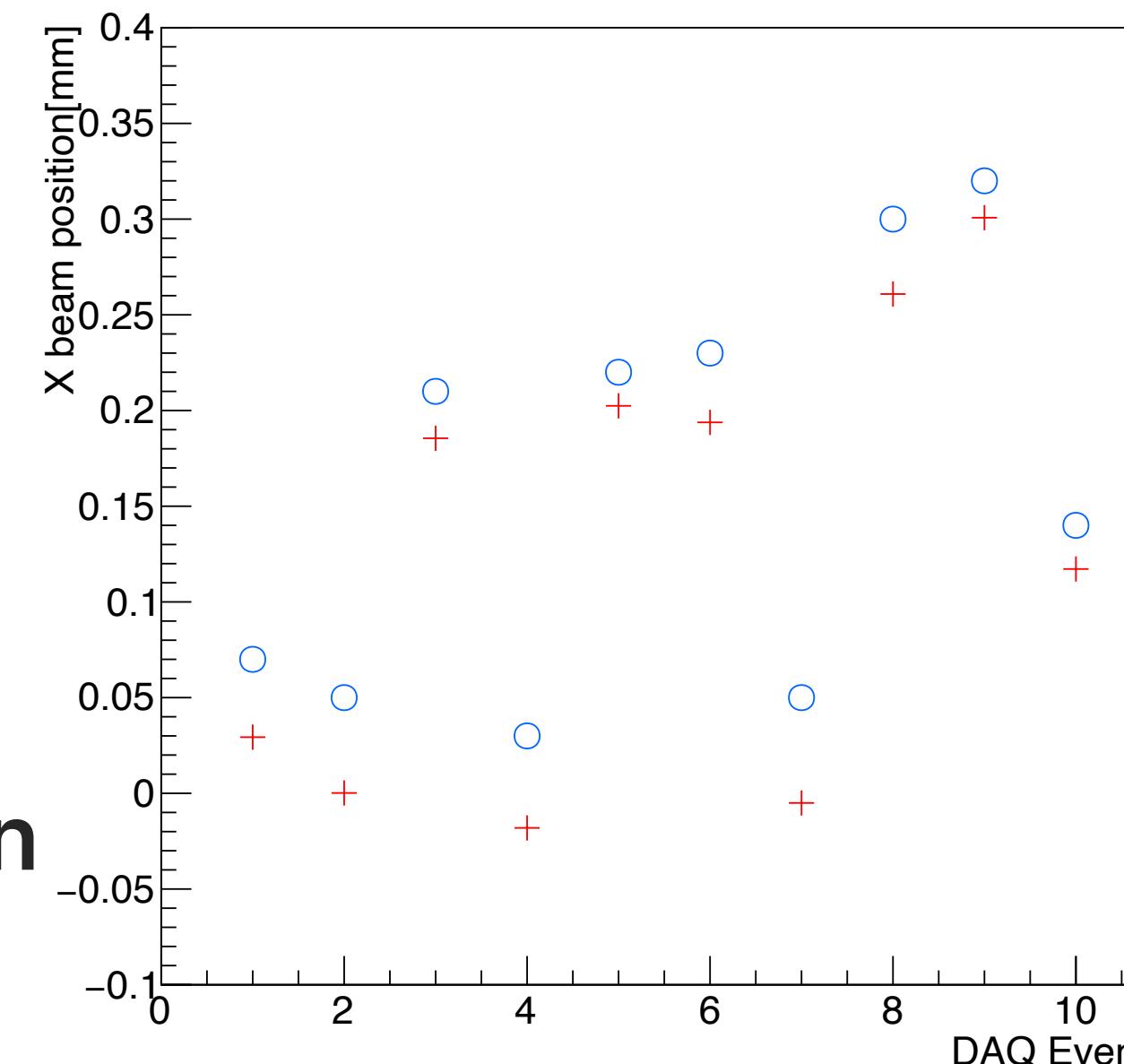
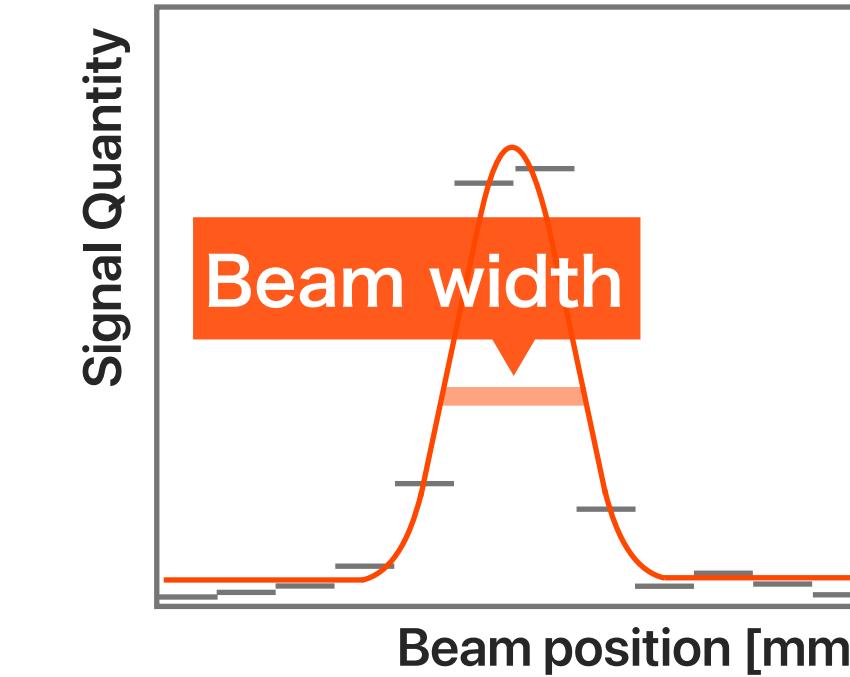
Q_{strip} : Signal Quantity for each strip

X : beam position

Beam Width Calculation Test

- Beam position and width event by event checked in beam test in April 2021.
→ We can see the strong correlation btw PAPILLON and offline analysis.

T2K offline analysis:



PAPILLON (tentative):

$$\sigma_X[\text{mm}] = \sqrt{\frac{\sum_{\text{strip}=0}^{23} Q_{\text{strip}} (x_{\text{strip}} - X)^2}{\sum_{\text{strip}=0}^{23} Q_{\text{strip}}}}$$

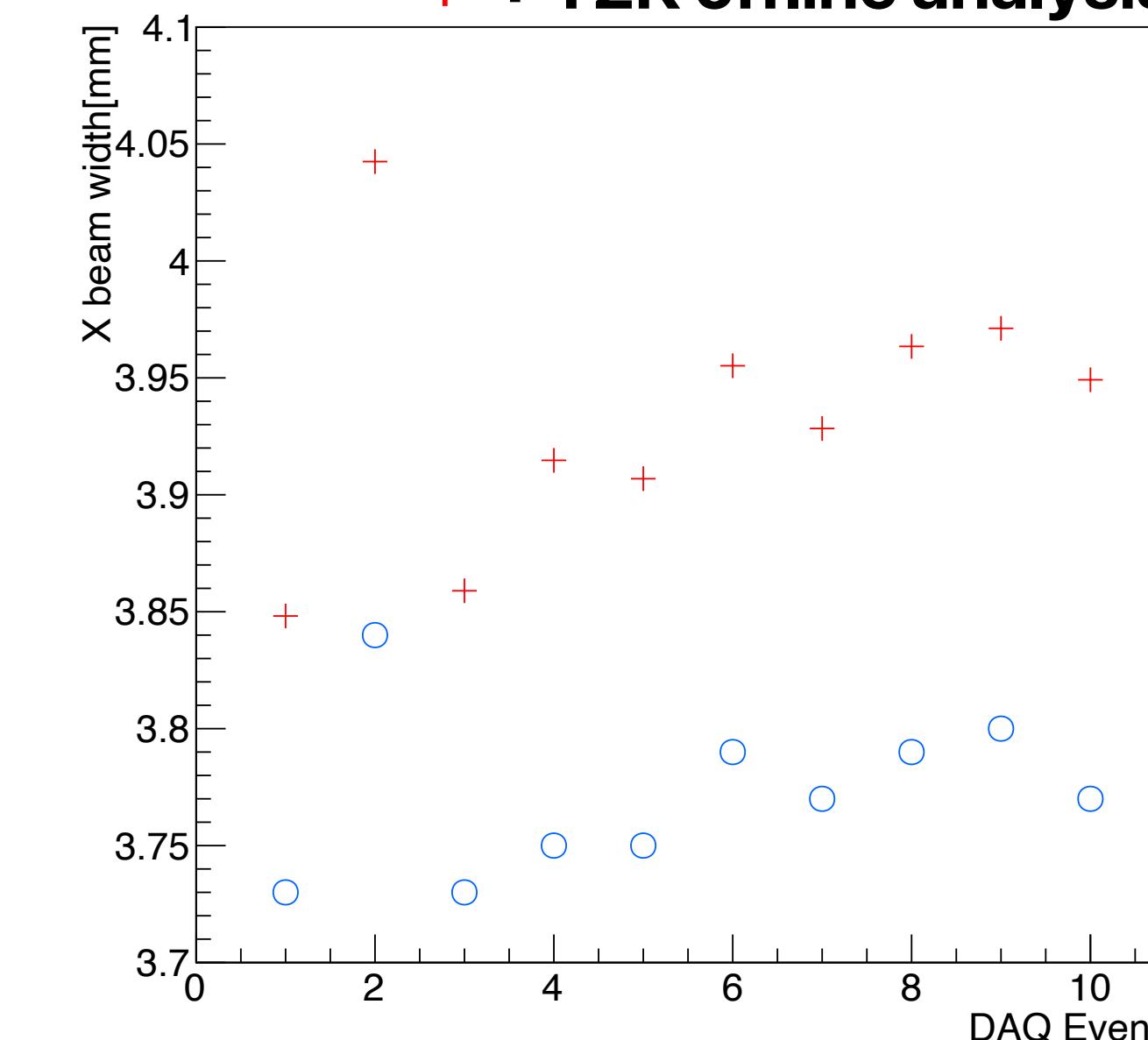
x_{strip} : position of each strip

Q_{strip} : Signal Quantity for each strip

X : beam position

○ : PAPILLON

+ : T2K offline analysis

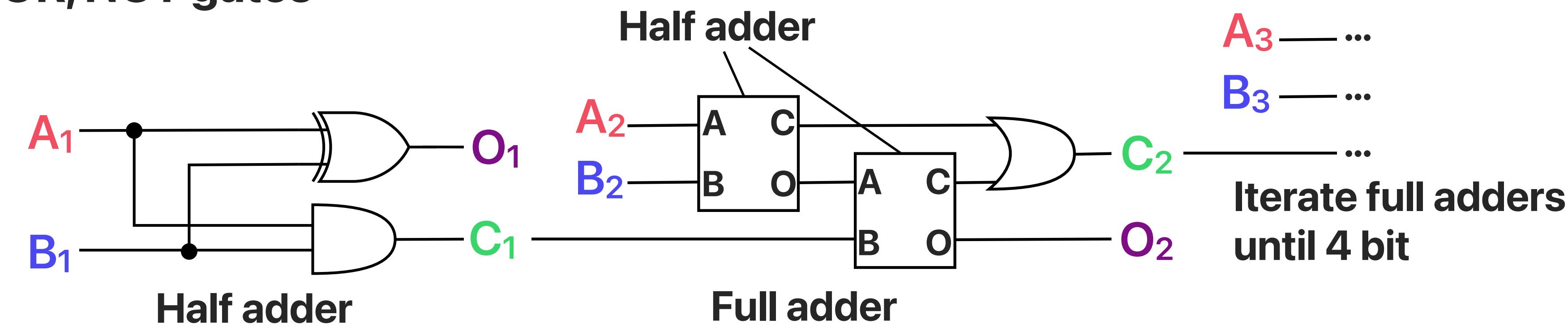


Bit Calculation

Adder(+): Combination of AND, OR, NOT gates

$$\begin{array}{r}
 & 0 & 1 & 0 & 1 \\
 +) & 0 & 0 & 1 & 1 \\
 \hline
 \text{Carry-up} & 1 & 1 & 1 & -
 \end{array}$$

1 0 0 0



Multiplier(\times): Iteration of 1 bit shift & adder

$$\begin{array}{r}
 & 0 & 1 & 0 & 1 \\
 \times) & 0 & 0 & 1 & 1 \\
 \hline
 & 0 & 1 & 0 & 1 & \text{copy 0101} \\
 & 0 & 1 & 0 & 1 & \leftarrow \dots \text{1 bit shift and copy 0101} \\
 & 0 & 0 & 0 & 0 & \leftarrow \dots \text{1 bit shift and add 0000} \\
 & 0 & 0 & 0 & 0 & \leftarrow \dots \text{1 bit shift and add 0000} \\
 \hline
 & 1 & 1 & 1 & 1
 \end{array}$$

Adder
↓

Subtractor and divider are need 2's complement, but basically similar with adder and multiplier.