Time determination method using digital waveform processing with RFSoC for RI beam experiments

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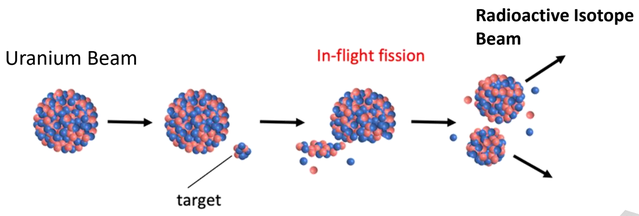
Rikkyo U.[A], RIKEN Nishina Center[B], Kyoto U.[C]

① RIKEN RI Beam Factory(RIBF)



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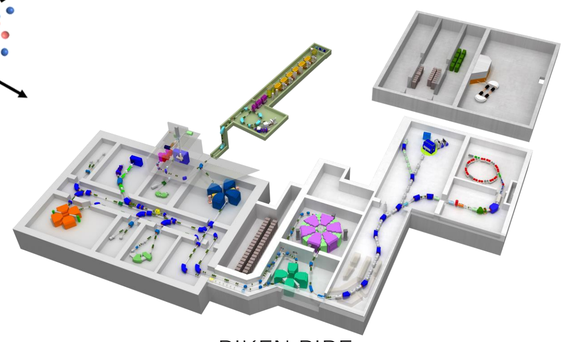

RIKEN RIBF

② Xilinx RFSoC

RFSoC

- 4GHz ADC x8
- FPGA
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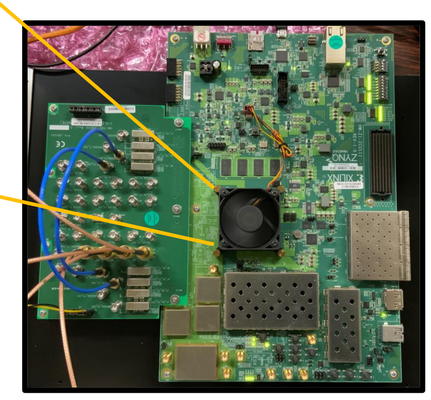
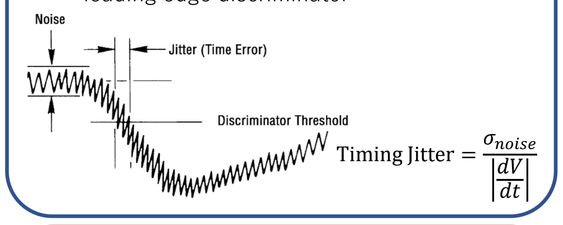


ZCU111 Evaluation kit

③ Timing Resolution

- In general, Timing determined by leading edge discriminator



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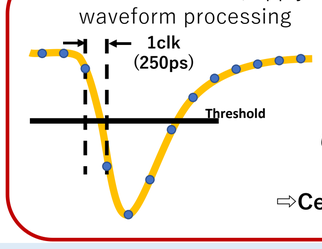

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$$G = \frac{\sum_i^n v_i \times i}{\sum_i^n v_i}^g \qquad v_i: i \text{ th signal value}$$

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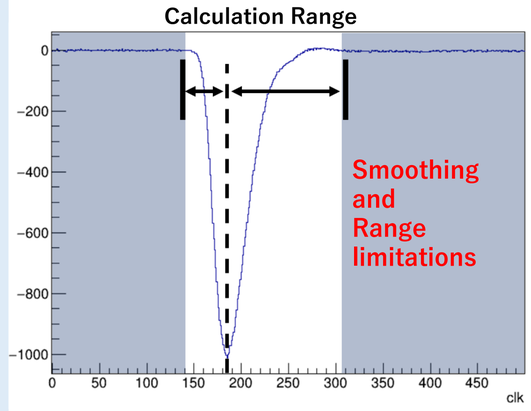
error of g



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To minimize effect of noise,
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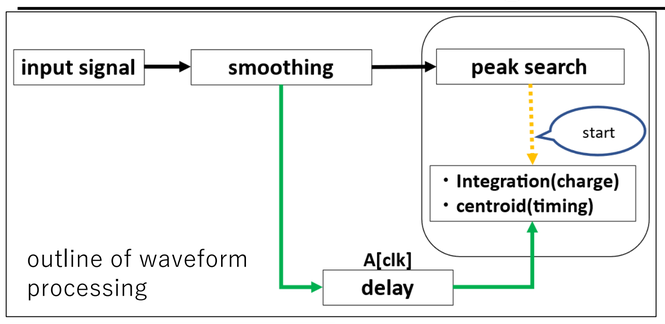
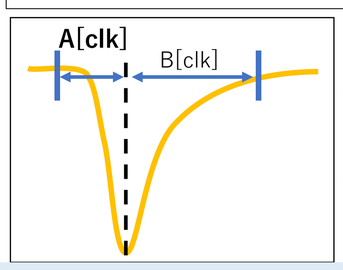
In addition, by **limiting the calculation range**, low-frequency noise that cannot be removed by smoothing is reduced.

⑤ Waveform processing



outline of waveform processing



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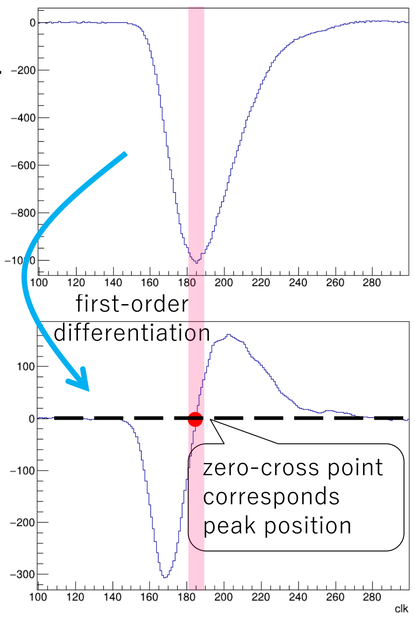
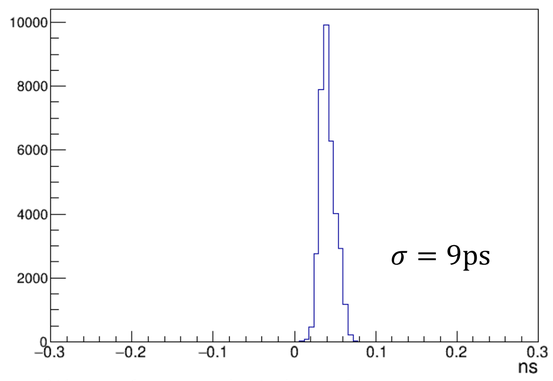
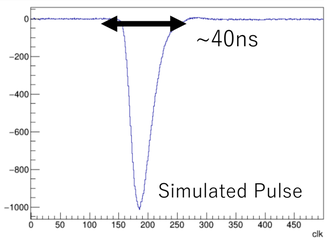


⑥ Timing resolution with centroid calculation



※waveform analysis by software (C language)



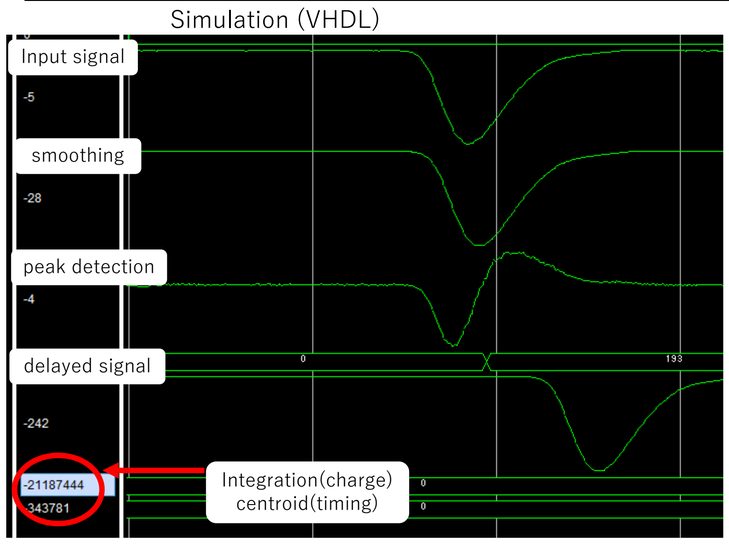
The time resolution obtained by centroid calculations is shown.

In this case, a pulse that simulated a plastic scintillator signal was used.

The result was **9 ps in σ**.
Very good time resolution was achieved.

⑦ Algorithm of centroid calculation ~Simulation

Simulation (VHDL)



Now, we are developing VHDL code to implement real-time waveform processing in FPGA.

This picture shows the simulation.

Here you can see calculation results using delayed signal.

Summary

- Developed waveform processing system without dead time using RFSoC devices.
- Adopted centroid calculation for waveform analysis method
  → ・A very good timing resolution of σ = 9ps was obtained
  ・Successfully developed waveform processing algorithm.
  ・Development of the VHDL code is in progress.

Thanks for your attention!

Appendix

Appendix

Algorithm of centroid calculation

- Calculate with FPGA without dead time
  →development recurrence relation

numerator : $g_n = g_{n-1} + q_n$

denominator : $q_n = q_{n-1} + v_n$

※The starting point of the calculation is n=1

v_i : i (clk)th signal value
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g_i : i (clk)th numerator value

$$G = \frac{\sum(v_i \times i)}{\sum v_i}$$

$$g_1 = 0 + q_1 = v_1$$
$$g_2 = g_1 + q_2 = v_1 + (v_1 + v_2) = 2v_1 + v_2$$
$$\vdots$$
$$g_n = g_{n-1} + q_n = nv_1 + (n-1)v_2 + \cdots + v_n$$

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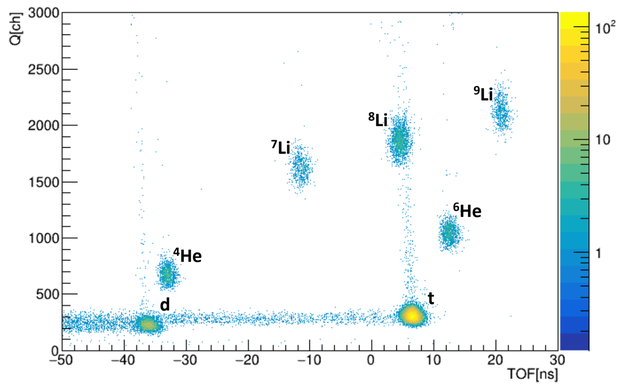
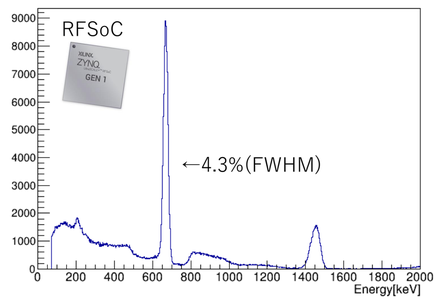
Particle identification

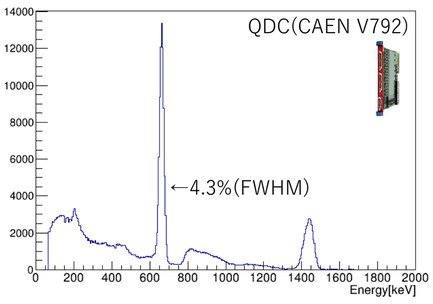
particle identification at RI beam experiment with RFSoC



Energy resolution

- Comparison energy spectrum
  662keV γ-ray(^{137}Cs) measurement using LaBr3(Ce) scintillator +PMT





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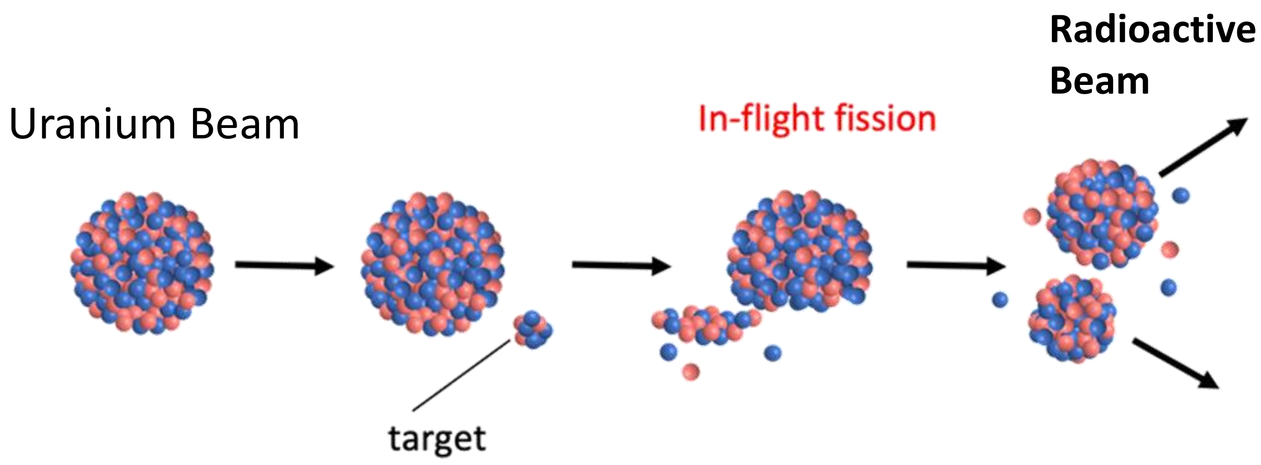

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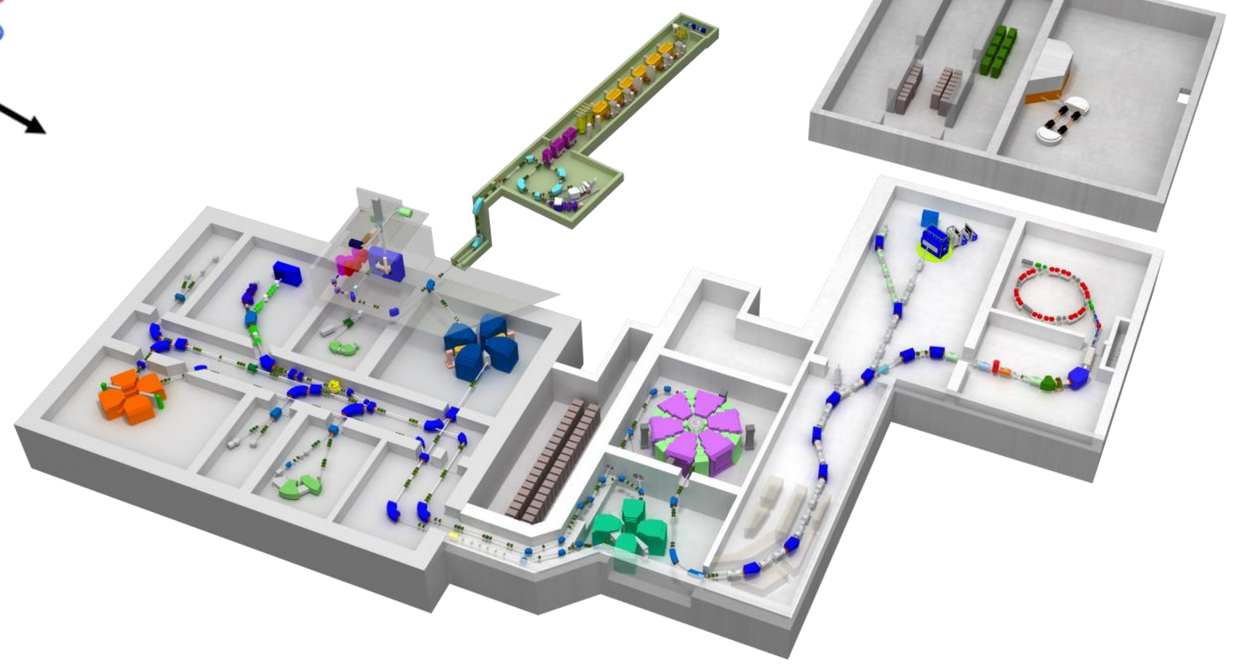

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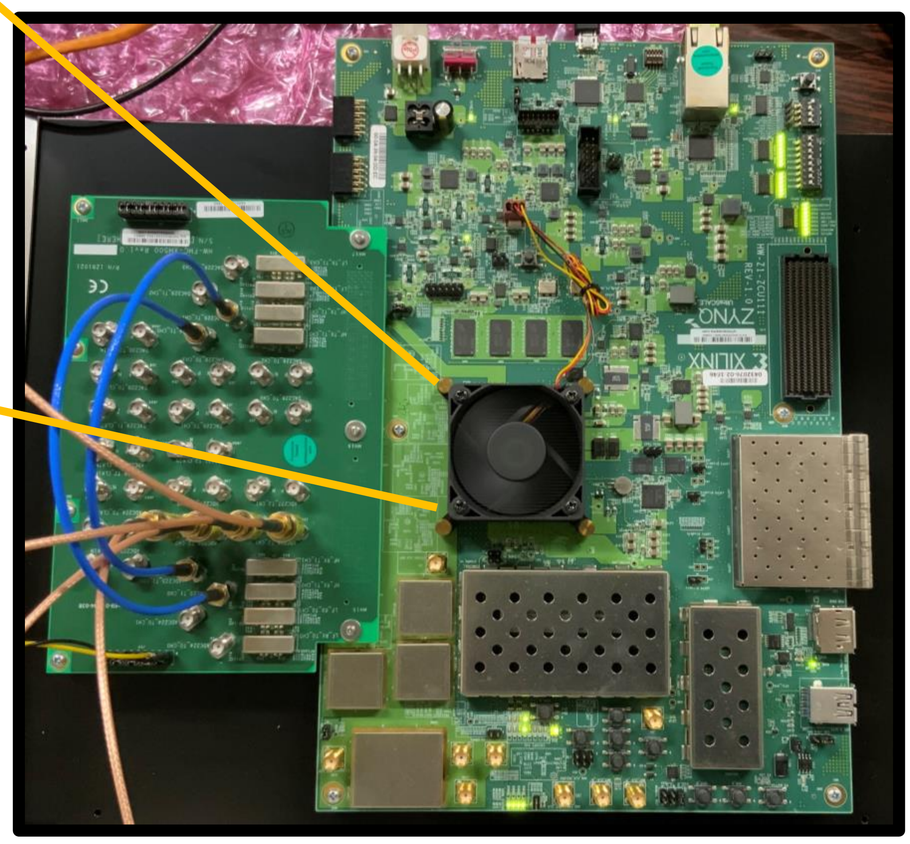

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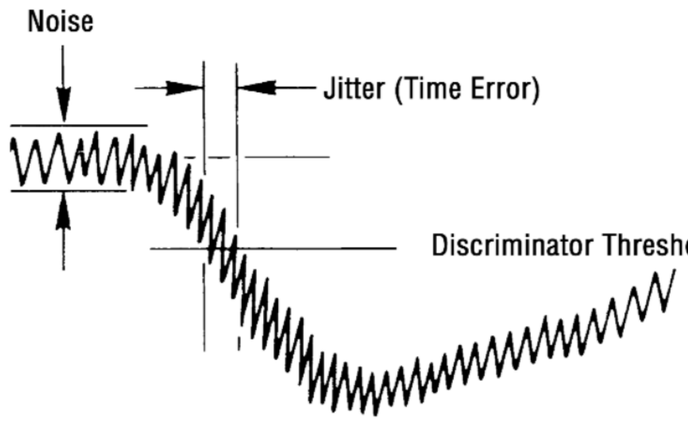

$$\text{Timing Jitter} = \frac{\sigma_{noise}}{\left|\frac{dV}{dt}\right|}$$

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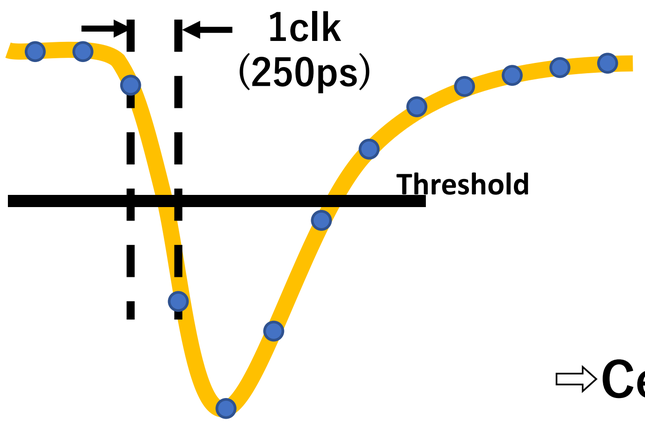

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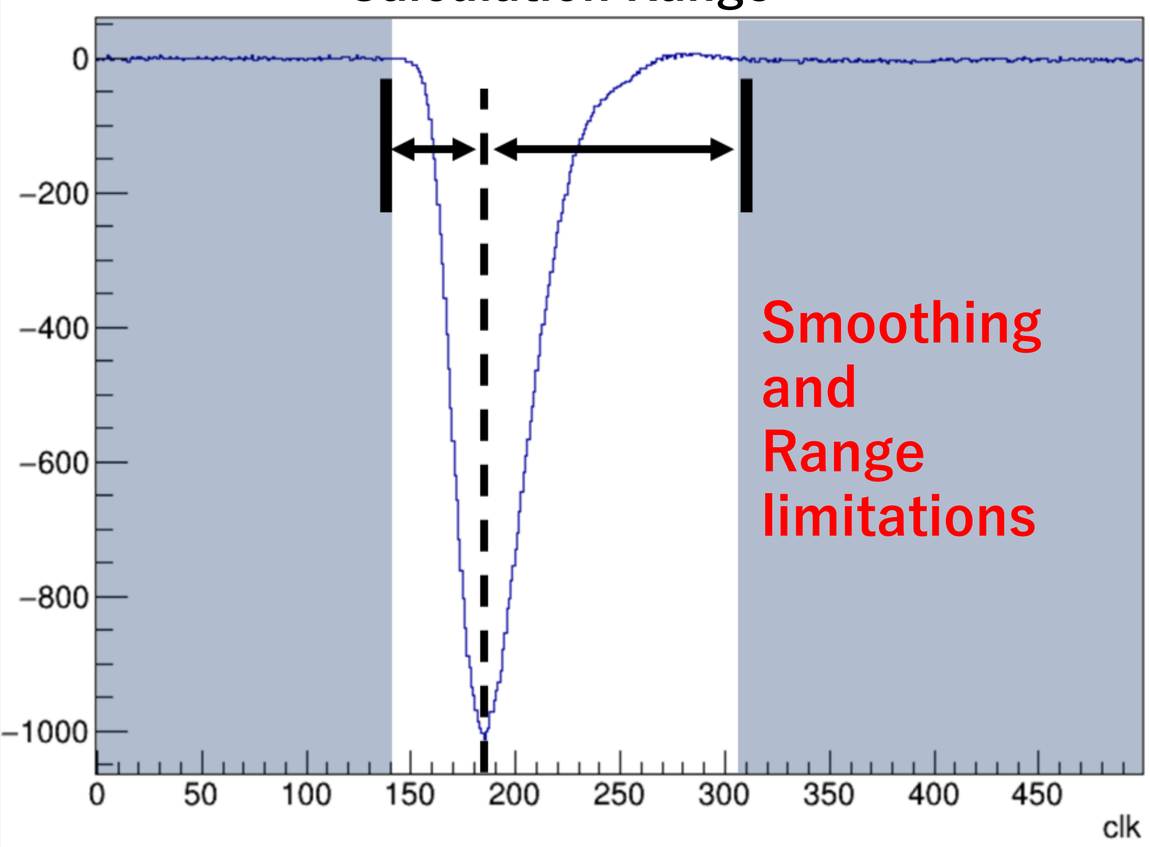

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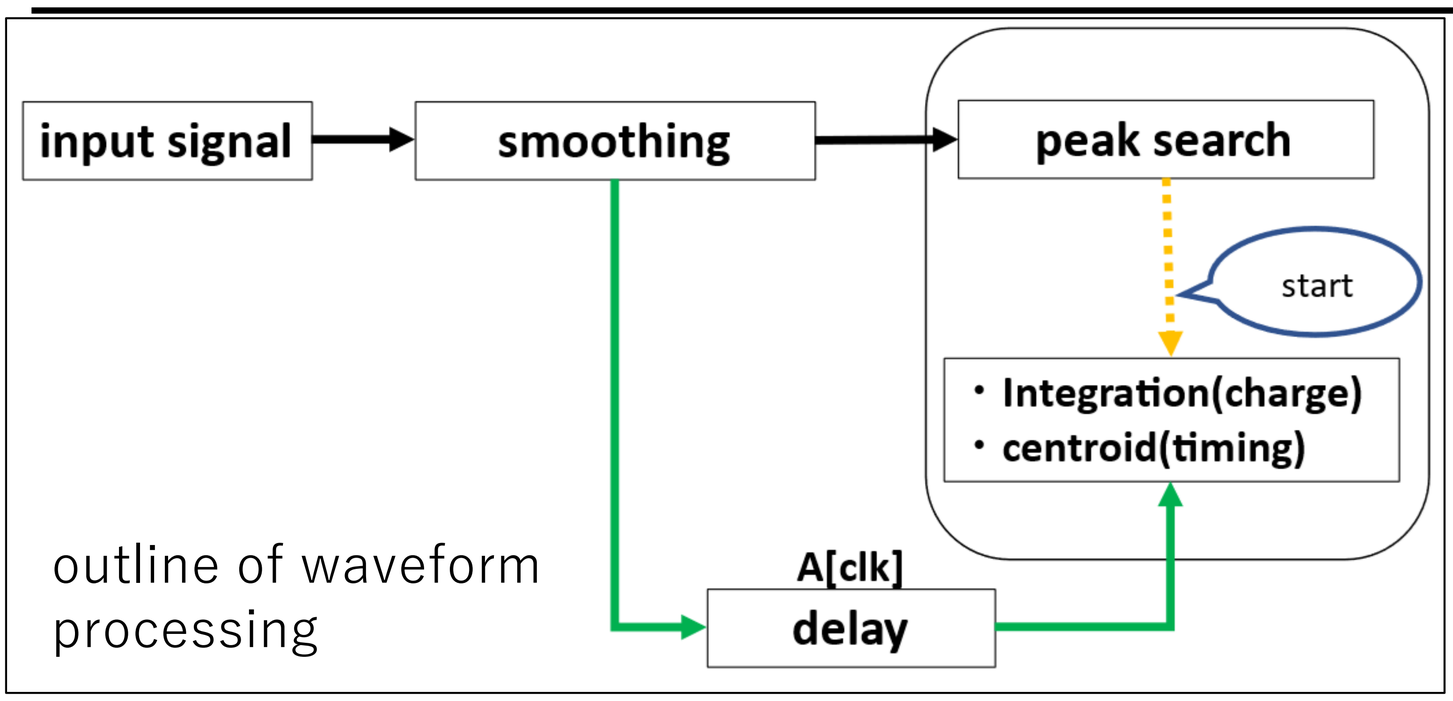

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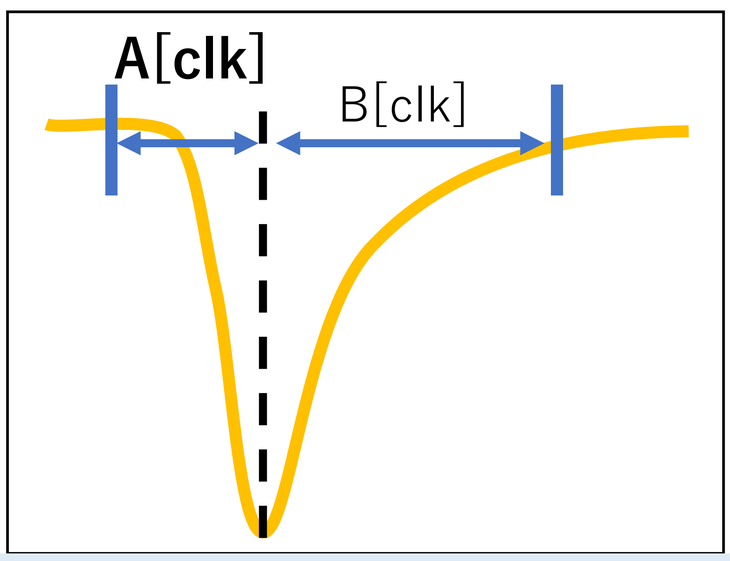

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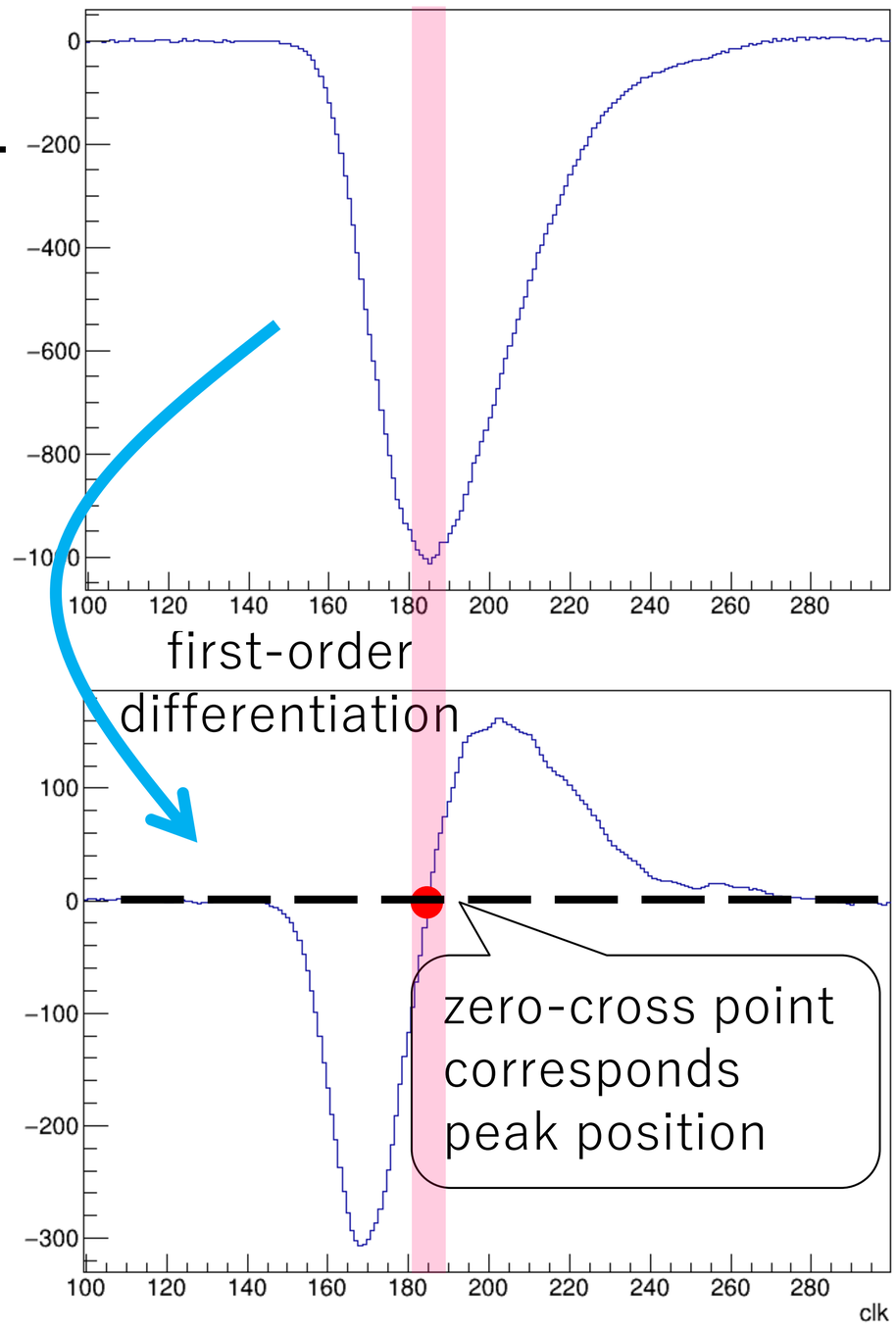

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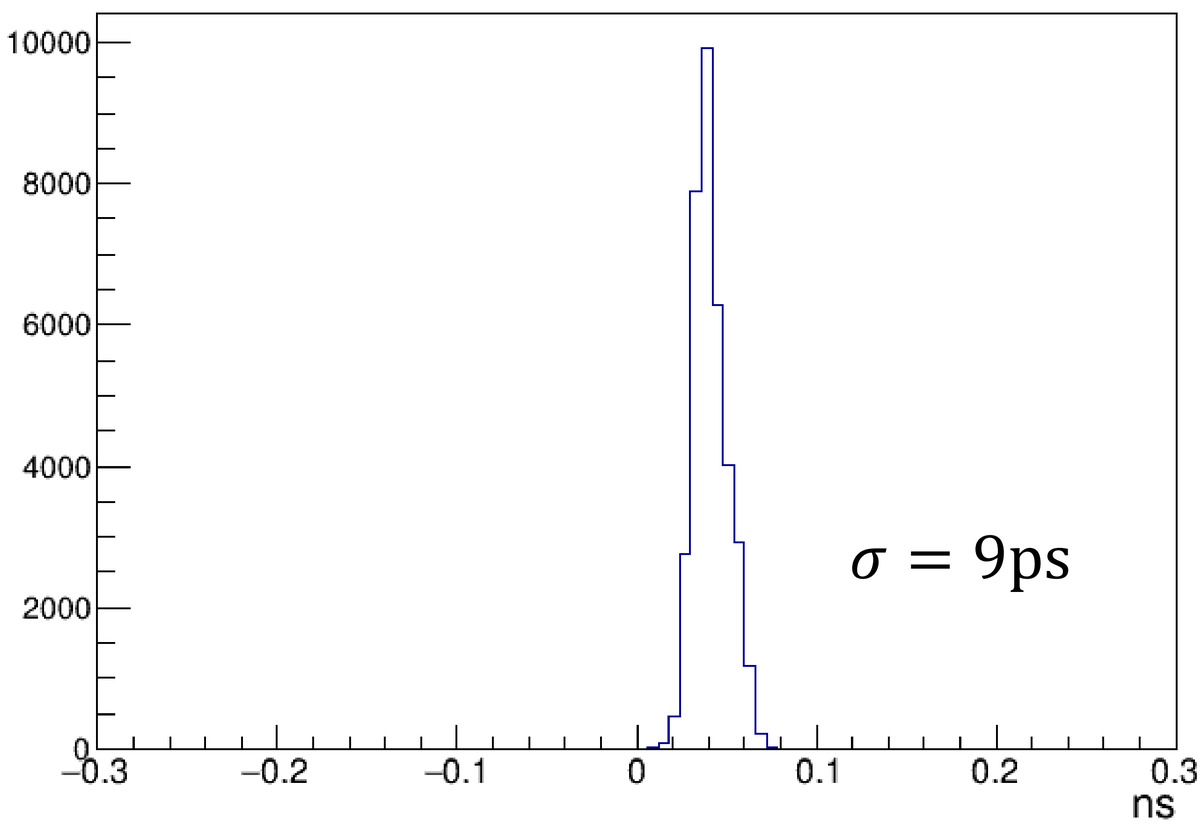

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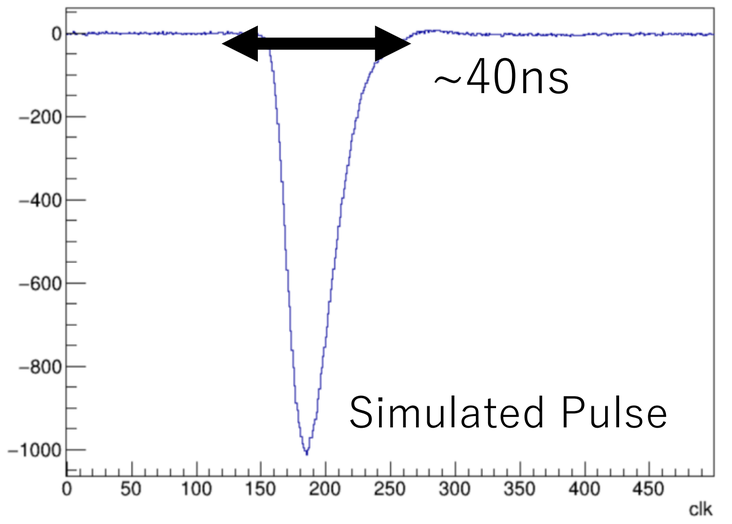

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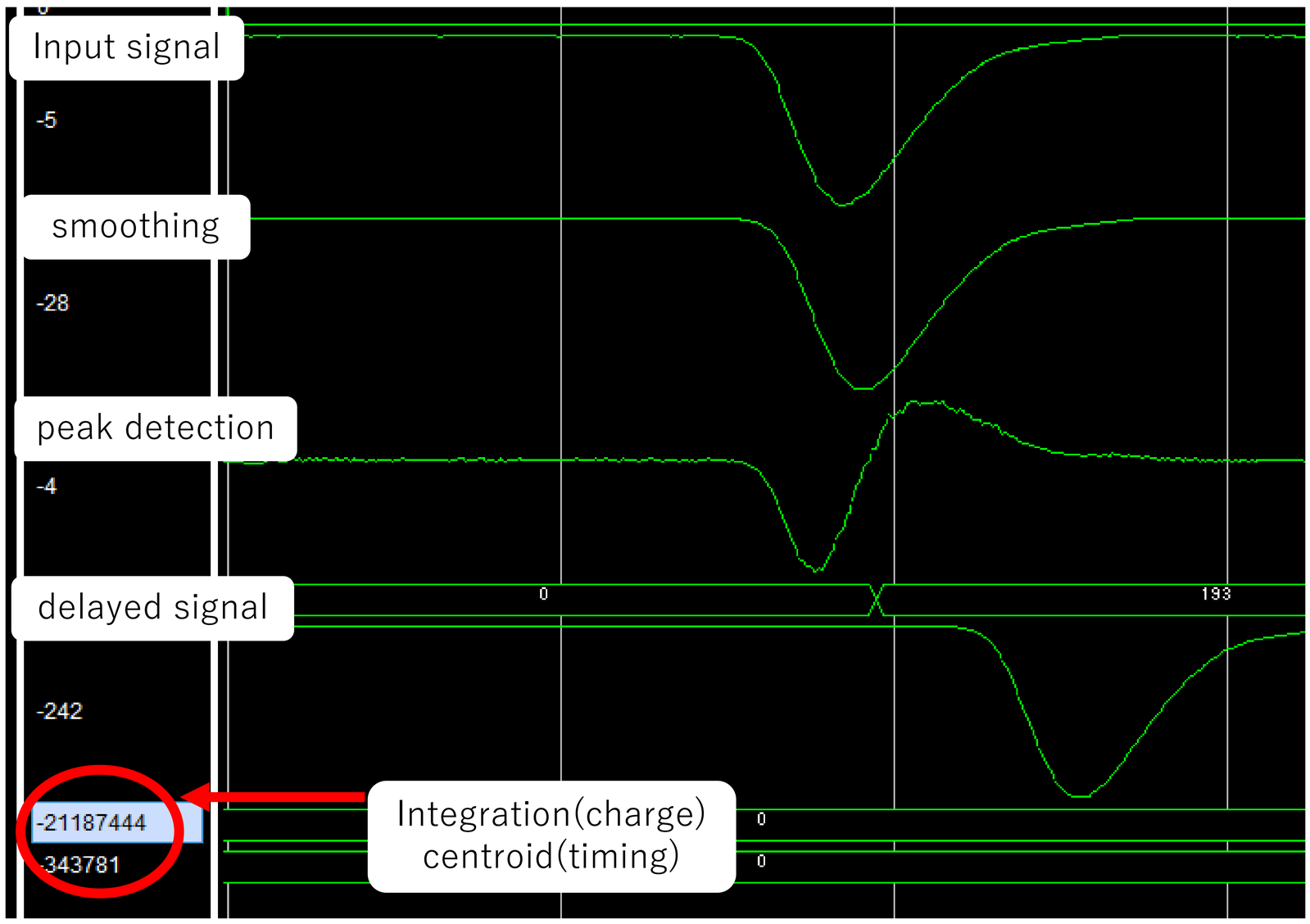

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Particle identification & Energy resolution

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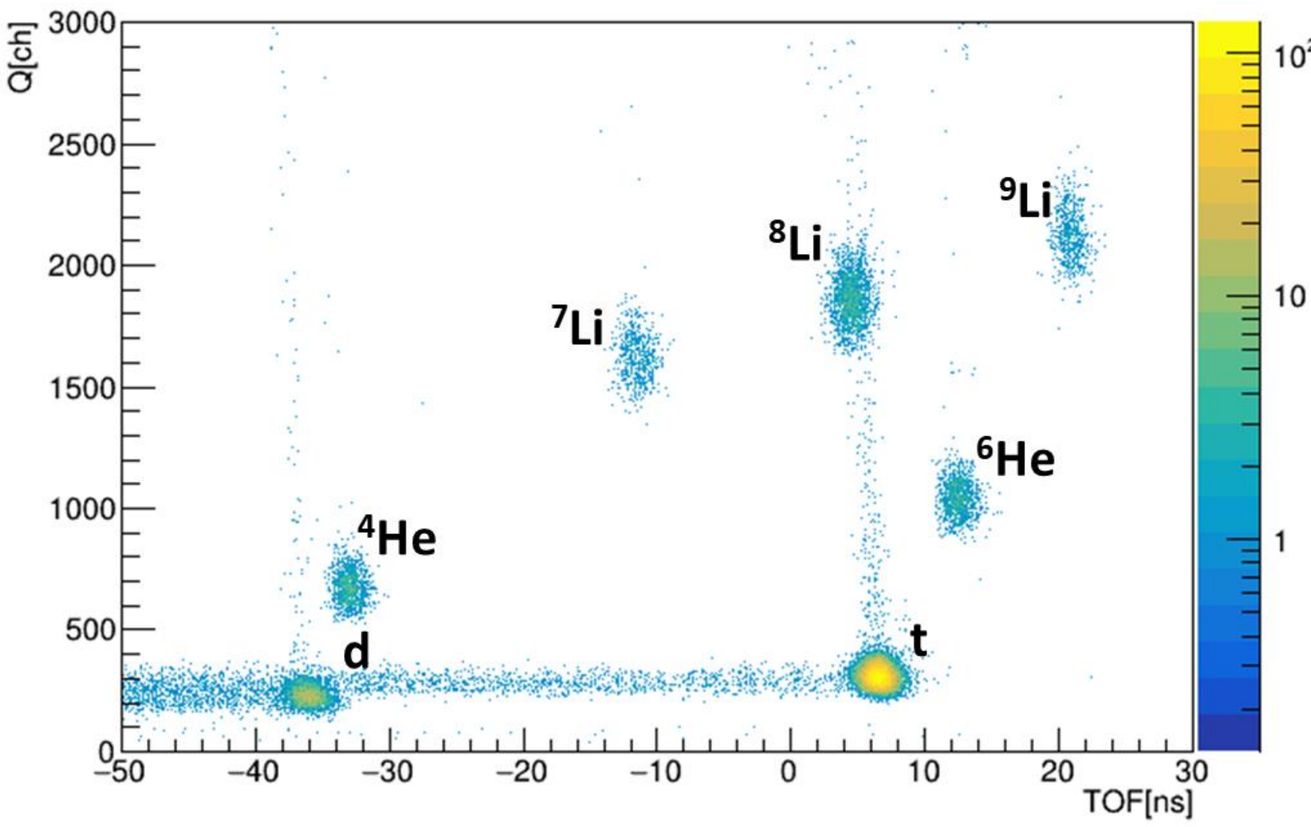

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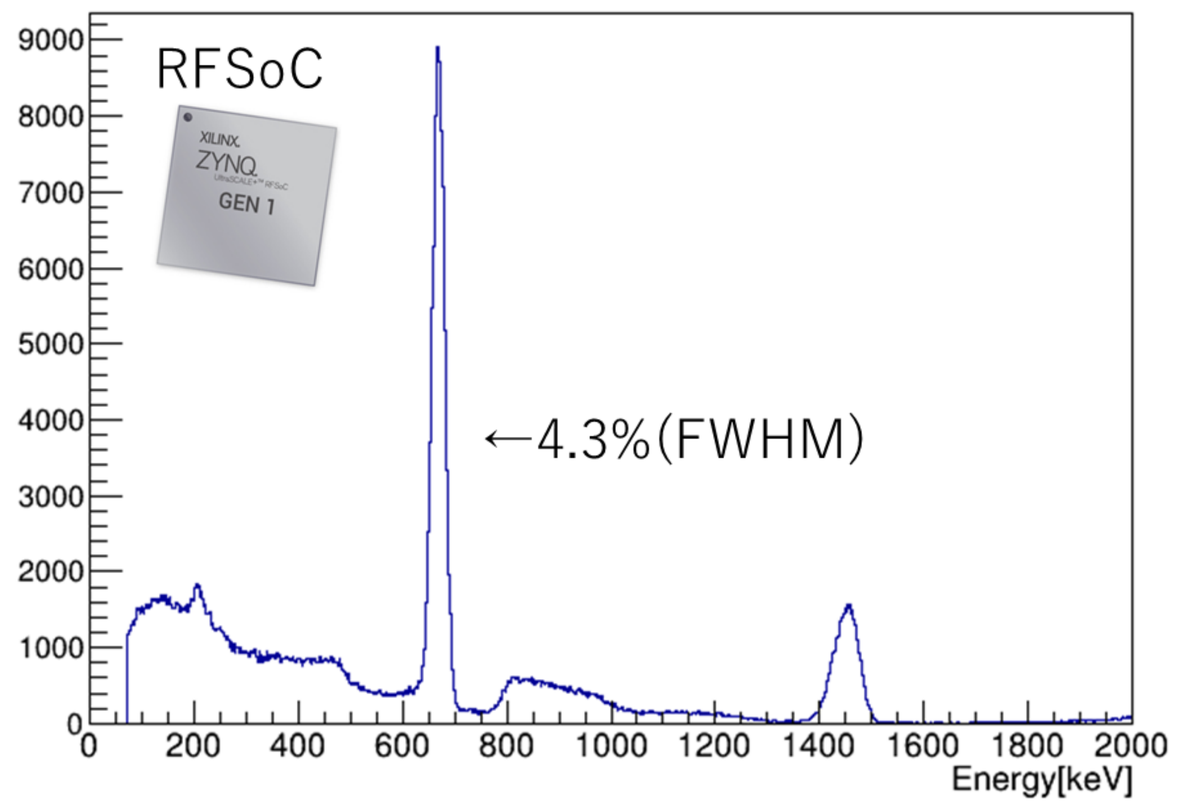

cf.) CAEN V792 : 4.3%(FWHM), under the same condition.