Pulse Identification Method for Overlapped Pulses

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J-PARC KOTO experiment

Physics Motivation

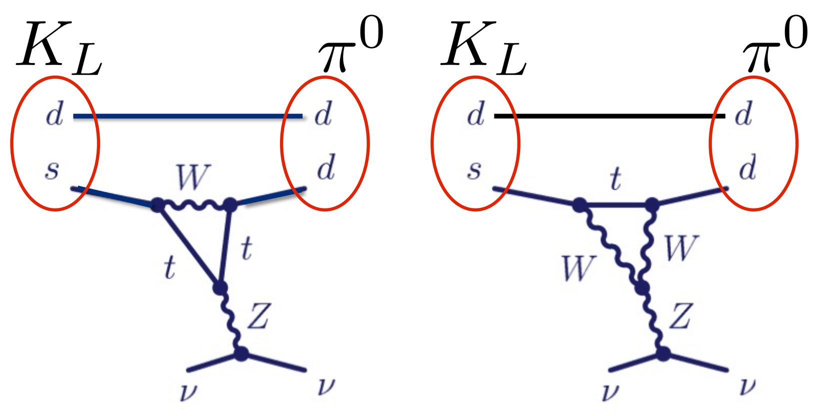
Search for $K_L^0 \rightarrow \pi^0 \nu\overline{\nu}$

- Rere Decay: BR=2.4x10^{-11} (theoretical prediction)
- Direct CP violation process.
- Br($K^0_L \rightarrow \pi^0 \nu\nu$)∝$\eta^2$
- Small theoretical uncertainty : 1~2%

→ **Golden Mode to Test Standard Model**

- Sensitive to new Physics through loop diagrams

→ **Good Probe for New Physics**



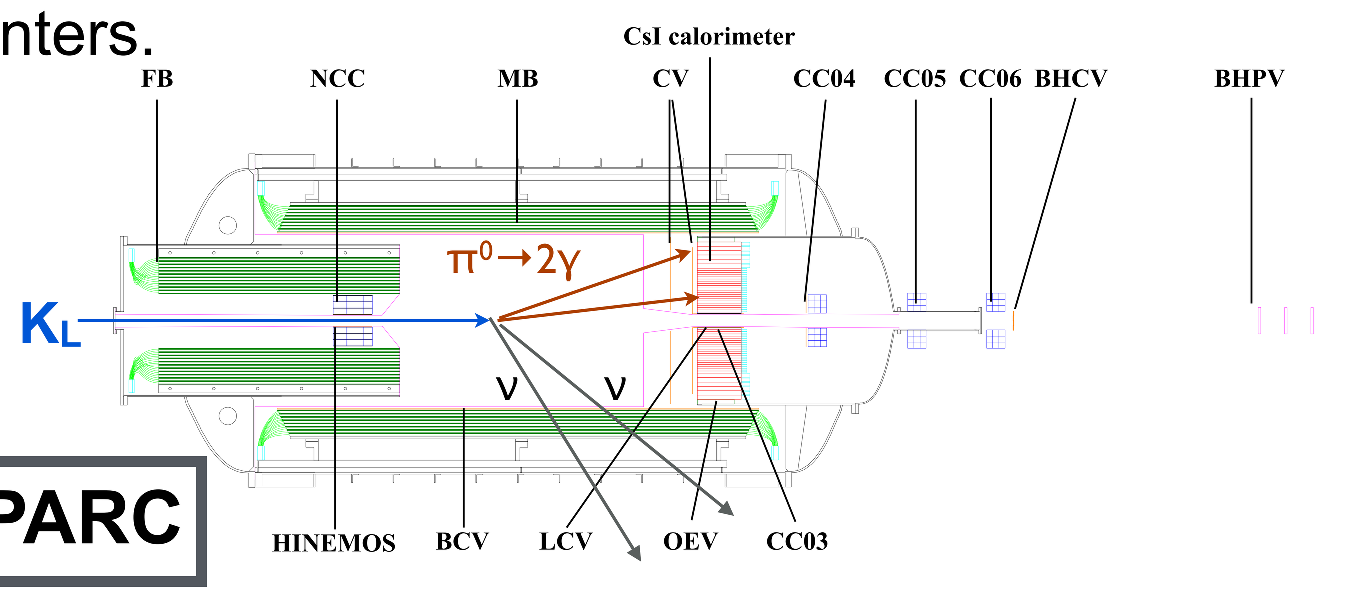
Feynman diagrams

First Physics Run in May 2013 @J-PARC

Experimental setup and method

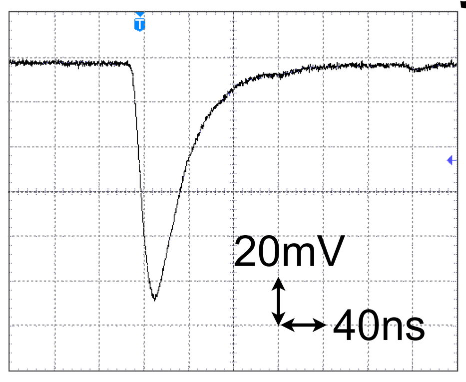
Detect 2γ ($\pi^0 \rightarrow 2\gamma$) and nothing else

- **detect 2γ by CsI Calorimeter**
  - reconstruct the π^0 decay vertex from energy and timing.
- **Confirm nothing else from the decay.**
  - Cover the decay region with **high efficiency** hermetic veto counters.

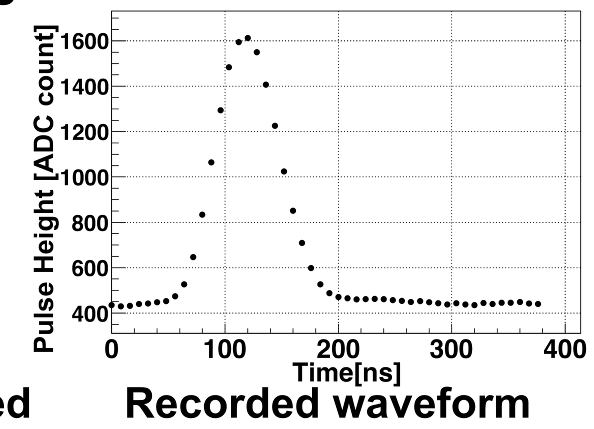


Requirement for pulse identification method

- Low inefficiency for particle detection is required for veto.
- **Multiple pulses in the veto timing window can be a source of inefficiency.**
  - **Recording waveform with 14bit 125MHz ADC.**
    - shape the signals into broad gaussian shapes with a 10-pole Bessel Filter.
  - **Analyze the waveform and identify pulses.**
  - **Need to establish the method to identify pulses**

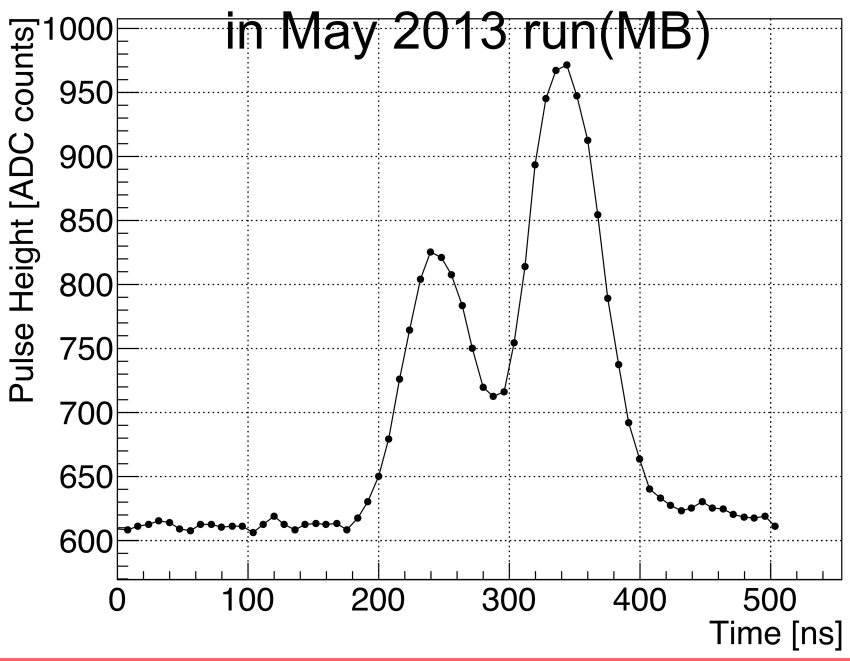


PMT signal (CsI) recorded by an oscilloscope



Recorded waveform at ADC module after filter

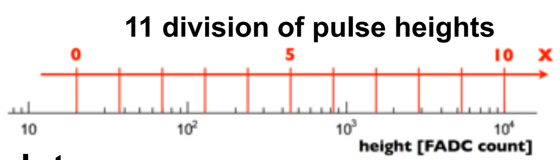
Event with Overlapped Pulses in May 2013 run(MB)

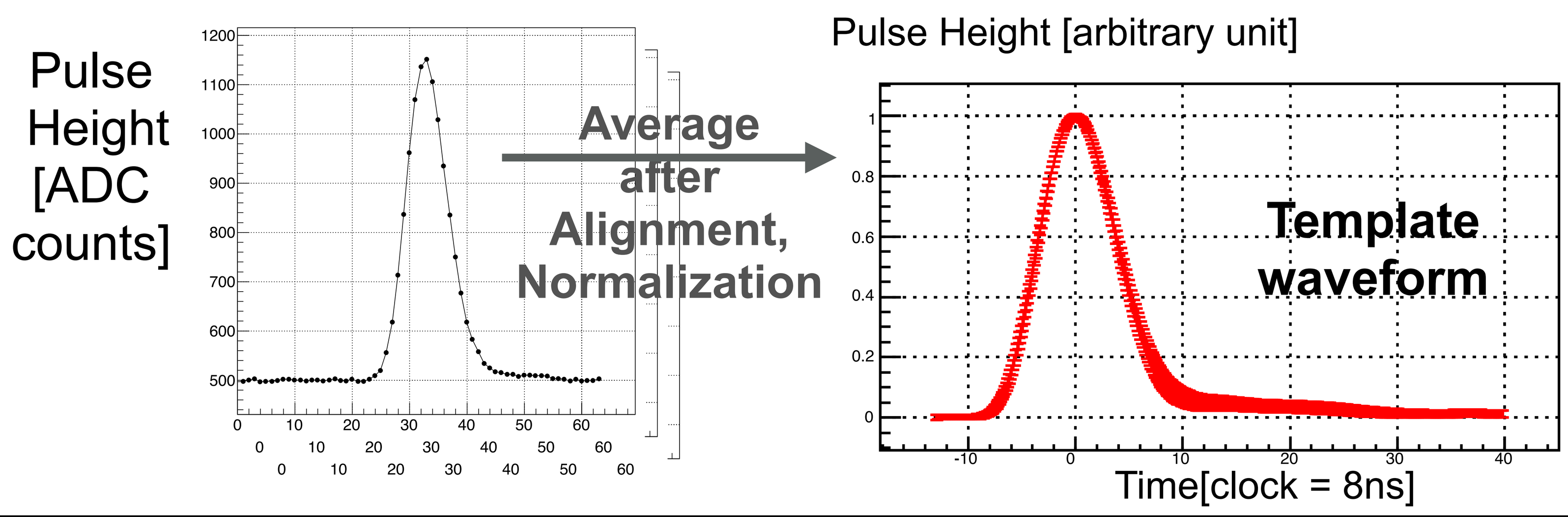


Pulse Identification with Template Fitting

Template for fitting

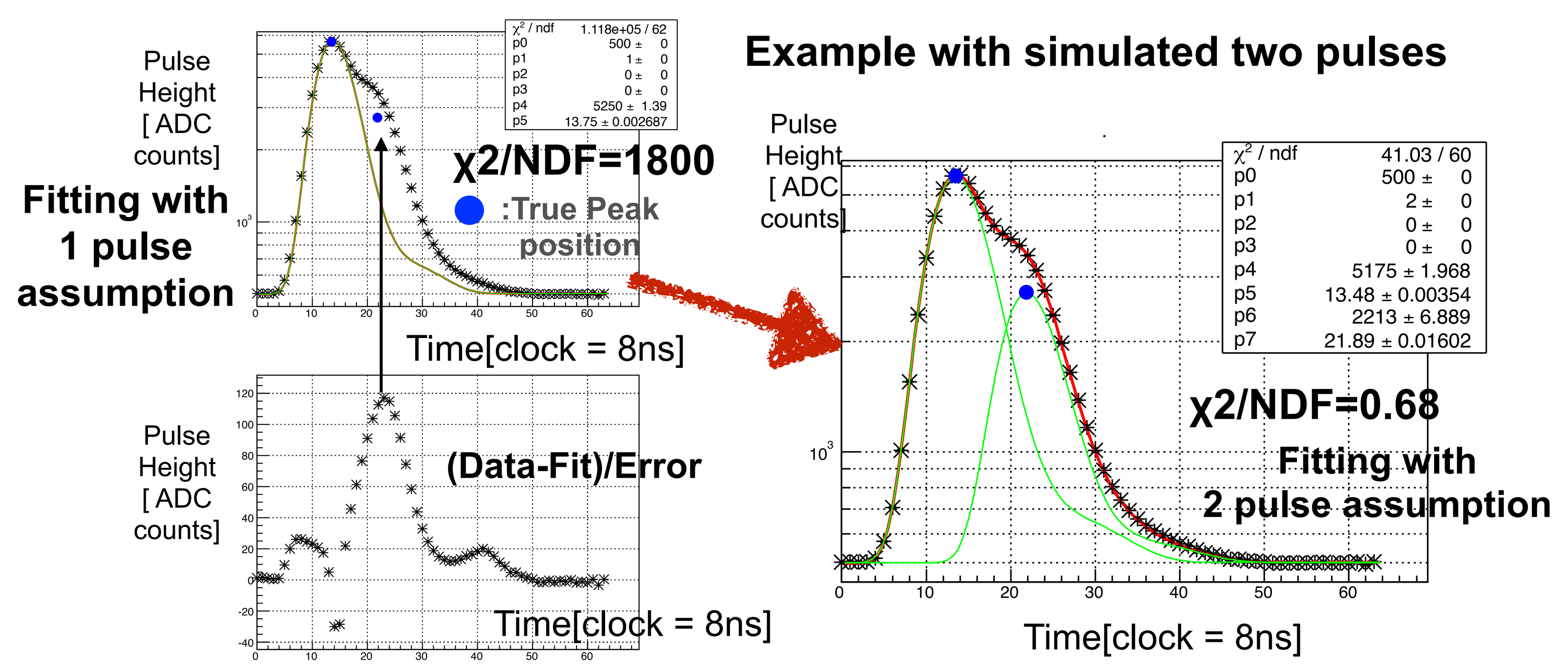
- Use "template": typical pulse shape for fitting.
- Prepare template for each detector.
  - separate template for 11 regions of pulse height.
  - Make template by averaging the waveform from many events.





Pulse Identification with template fitting

- Start from fitting with 1pulse assumption.
- If χ2/NDF>threshold→ Assume one more pulse to fit and try fitting.
  - Use peak of (Data- Fit)/Error as candidate of additional peak.
- Iterate this procedure until χ2/NDF becomes low enough.

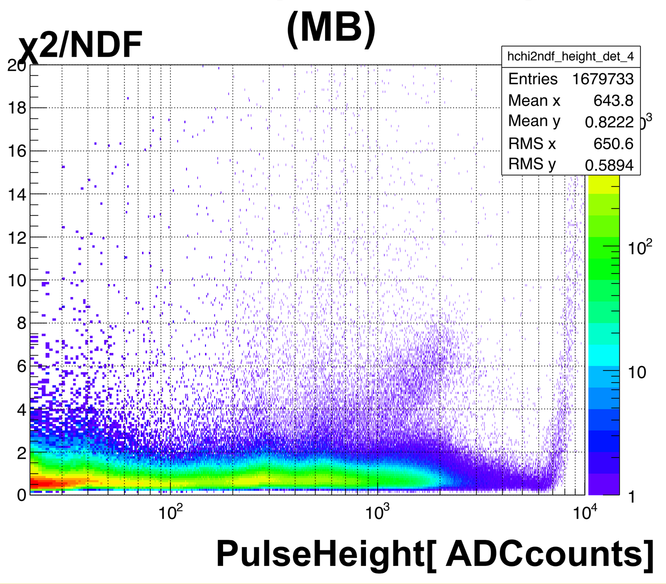


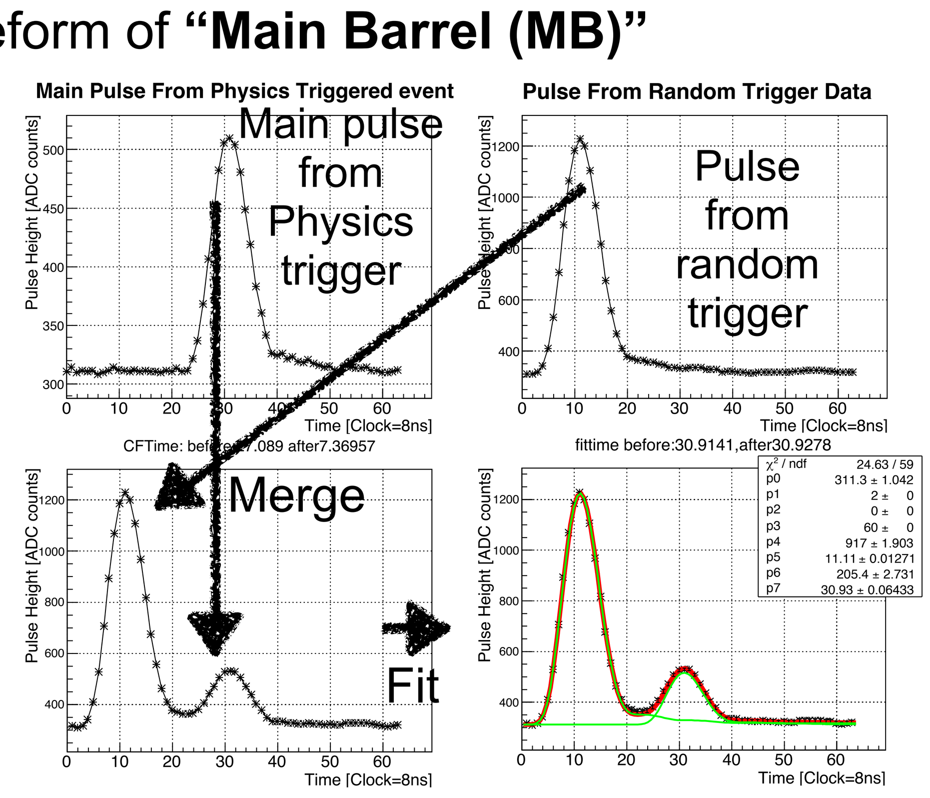
Performance of pulse identification

Evaluate performance with merging two waveforms with single pulse

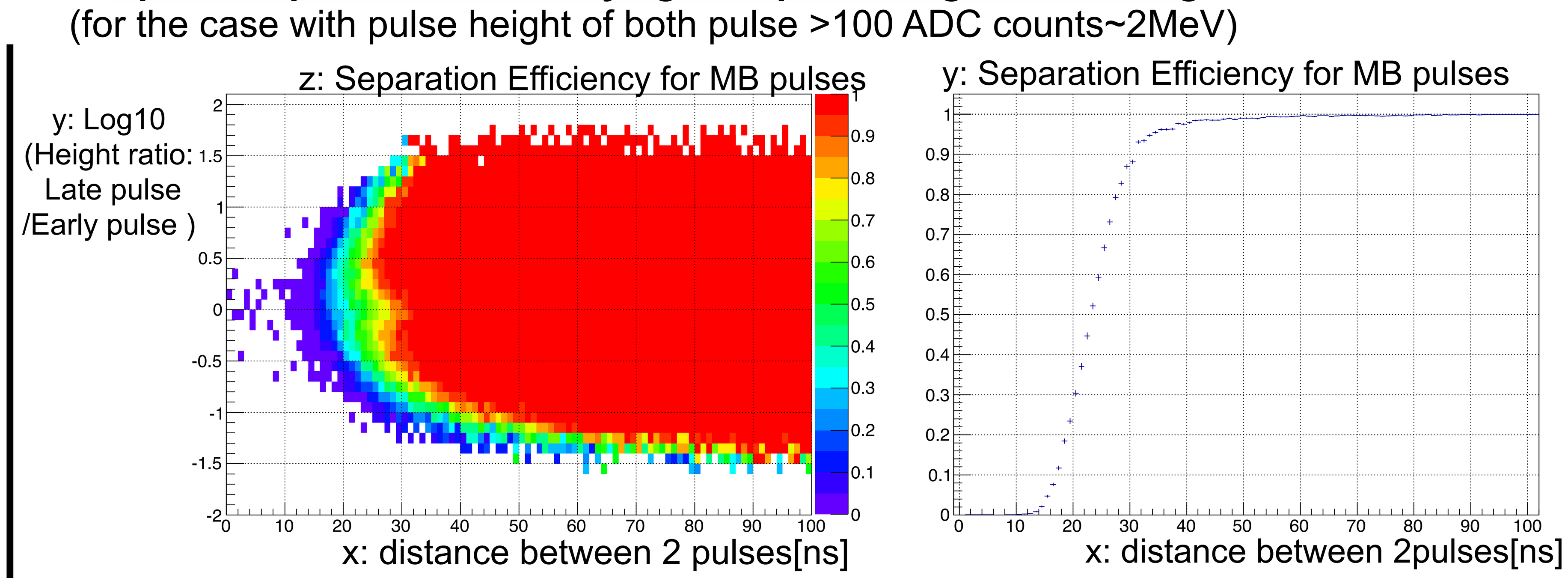
- Generate waveform of overlapped pulses from data taken in the physics run.
  - Merge two waveforms of event with single pulse from Physics and Random trigger data.
  - Select single pulse event by requiring χ2/NDF<2 for fitting with single pulse assumption.
- Set threshold for χ2/NDF at 5 for Pulse Identification.
- Evaluate performance for the waveform of **"Main Barrel (MB)"**

χ2/NDF for fitting cosmic-ray event with 1pulse assumption (MB)



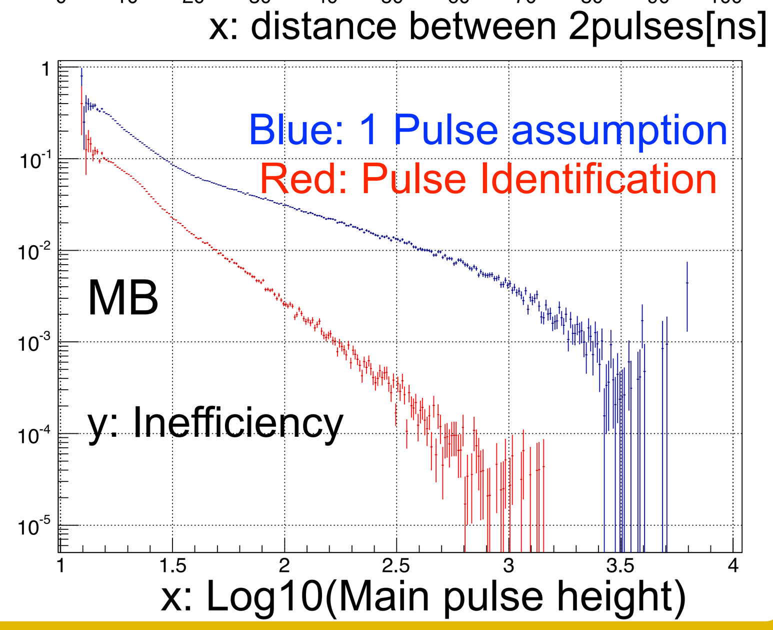


2 pulse separation efficiency against pulse height and timing
(for the case with pulse height of both pulse >100 ADC counts~2MeV)



Evaluate Inefficiency due to accidental pulse overlapping

- Compare timing of main pulse before and after merging random trigger pulses.
- **Inefficient events: events with timing shifted more than 30 ns after merging.**
- Compare inefficiency between timing with 1pulse assumption or pulse identification.



Conclusion

We established a method to discriminate pulses from waveform using pulse shape template. Overlapped pulses with distance more than 30 ns can be separated.