Realistic Trigger Simulation for COMET Phase-II

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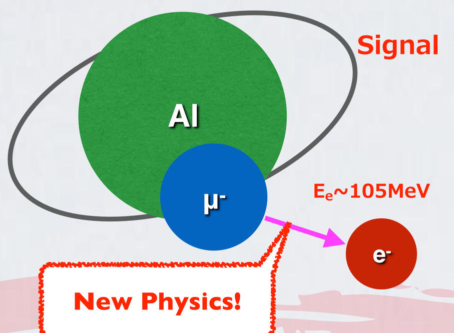
Abstract: The COMET experiment aims to search for a muon-to-electron (μ-e) conversion with single event sensitivities of 3×10^{-15} and 3×10^{-17} in Phase-I and Phase-II, respectively. This process is strictly forbidden in the Standard Model (SM) while many physics models beyond the SM predict the detectable μ-e conversion rate. Hence it would be a clear evidence of new physics if the μ-e conversion is observed. To achieve our sensitivity goal, more than 10^{20} of total muons are required and such a high huge number of particles potentially leads to the extremely high hit rate in our detector system. Thus, it is essential to highly suppress the trigger rate due to those backgrounds that can also worsen the DAQ efficiency while maintaining the high trigger efficiency for signal electrons. In addition, there is a possibility to further improve the Phase-II target sensitivity by optimising the experimental design, that may also increase the rate of incoming particles inside the detector. Therefore the design of the trigger and readout electronics is crucial for the COMET Phase-II experiment to achieve the best physics sensitivity. In this study, the first realistic trigger simulation has been implemented for Phase-II and the preliminary results are presented.

I. COMET Experiment

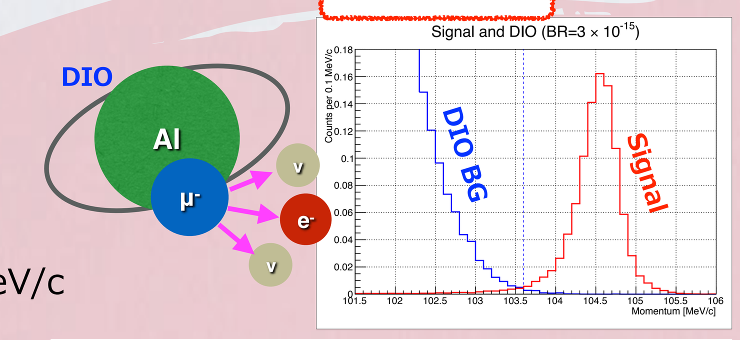
Physics Motivations

- Investigate the new physics Beyond the SM (BSM) by searching for the μ-e conversion with the Single Event Sensitivity of 3×10^{-15} and $\sim10^{-17}$ in Phase-I [1] and Phase-II [2]
- *BR*(μN→eN) is negligible in SM ($O(10^{-50})$)
  - ➡**Many BSMs predict sizeable *BR*(μN→eN), *O*(10^{-15})**
- **μ-e conversion = clear evidence of new physics**



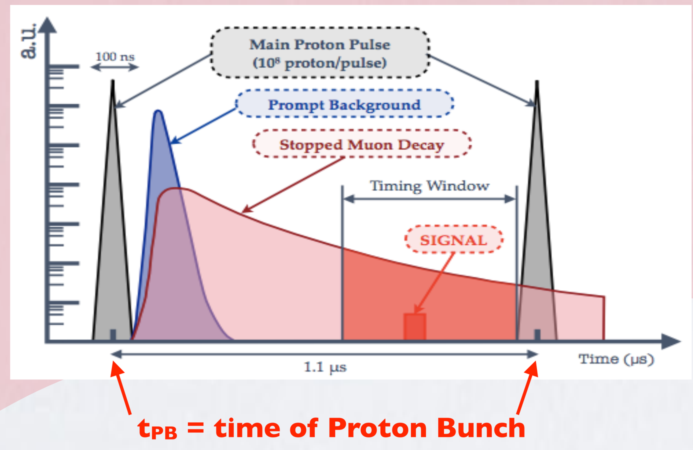
Signal and Backgrounds

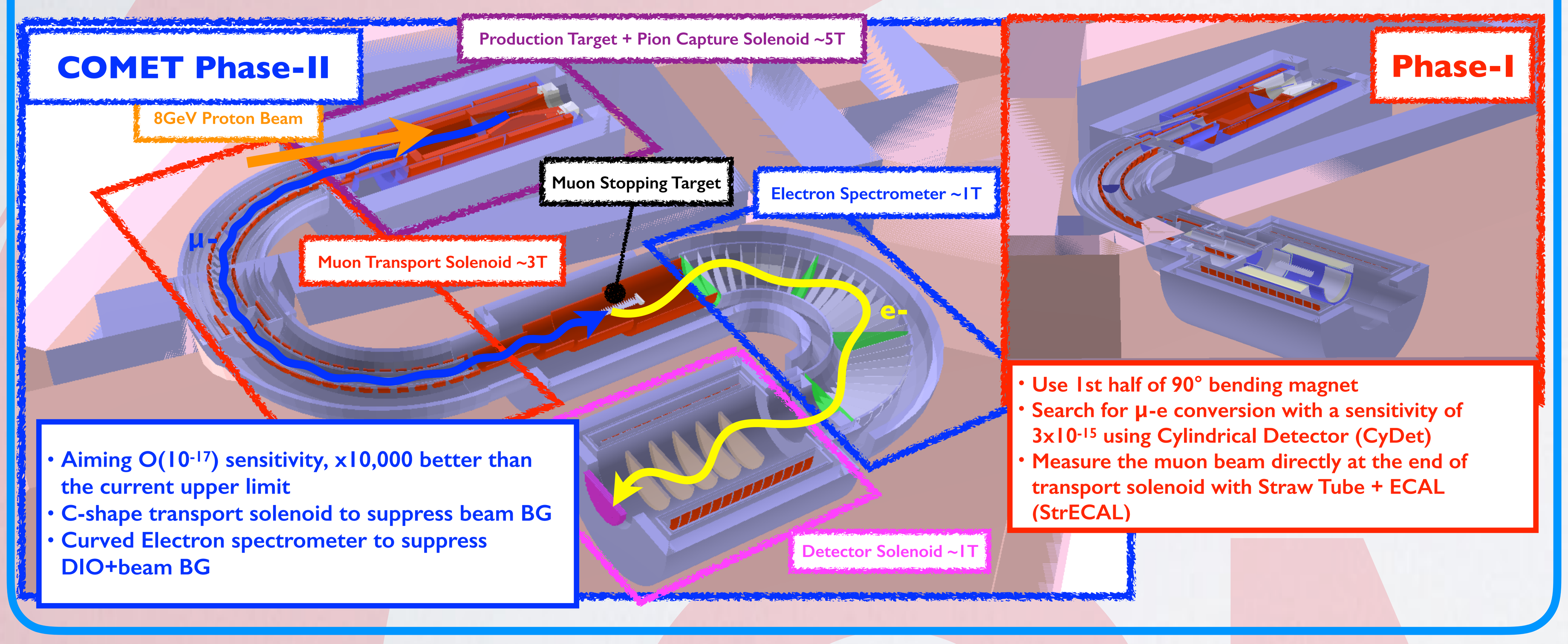
- Signal: ***105MeV single electron***
- Intrinsic BG: Decay In Orbit(DIO), broad spectrum <105MeV/c
  - ➡σ_p<200keV/c is required
- Beam origin BG: μ/π decays in-flight, etc.
  - ➡**Bunched beam + Off-time measurement**
  - ➡**Long μ/π transportation**



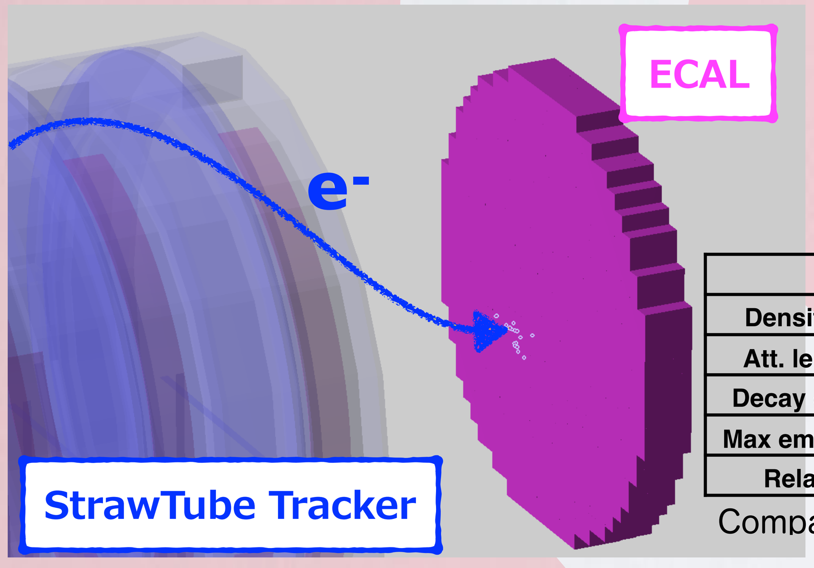
COMET Experiment

- Experiment will be done@J-PARC
  - Phase-I using 90° of muon transport solenoid
- Using the world most intense μ beam 10^{8-9} Hz
  - ➡**Extremely high hit rate both in Phase-I and Phase-II**





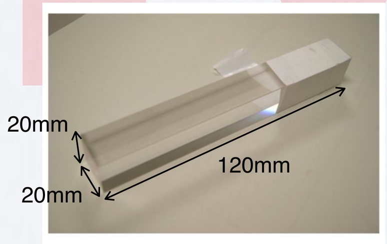
II. ECAL Detector in COMET

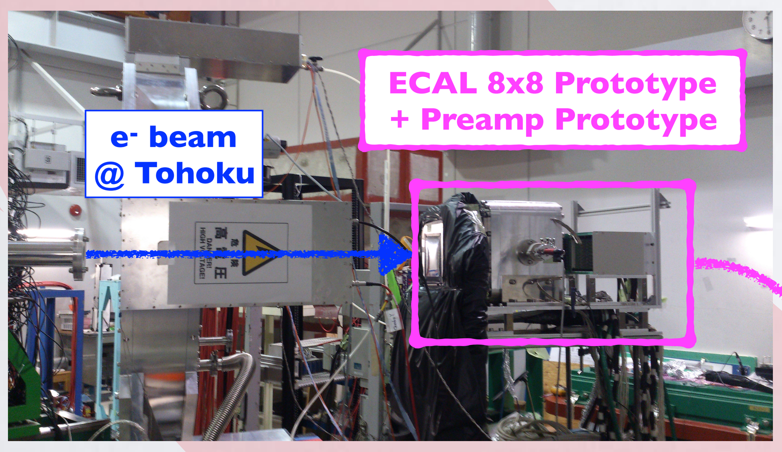


- **Consists of ~2,000 LYSO crystals**
- **Timing and energy measurement**
- **Primary trigger generation**

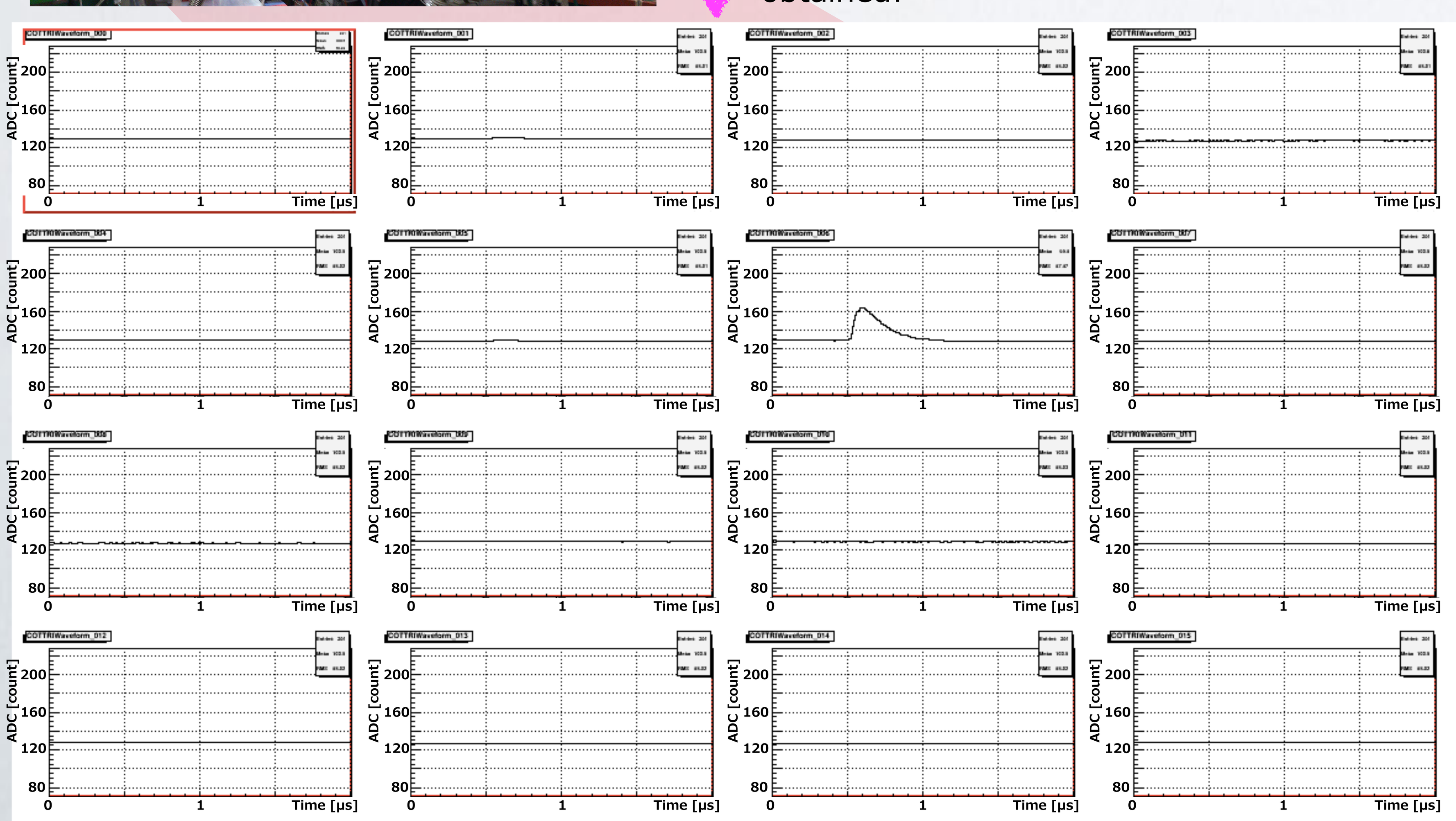
	NaI(Tl)	GSO	LYSO
Density, g/cm³	3.67	6.71	7.1
Att. length, cm	2.6	1.38	1.12
Decay const., ns	230	30-60	41
Max emission, nm	415	430	420
Relative LY	100	20	70-80

Comparisons of scintillator characteristics



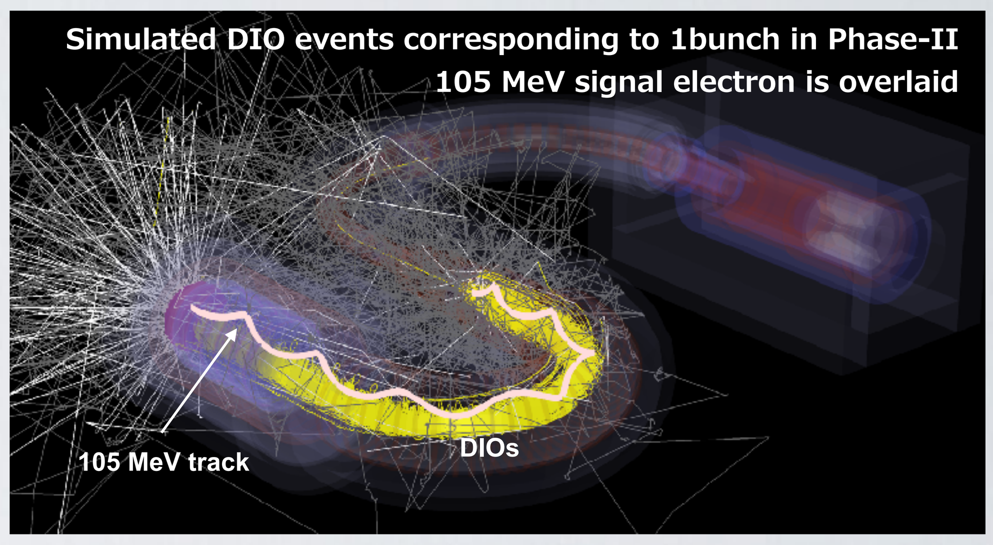


- Detector performance was measured in the beam test with various energy electrons incl. 100MeV → See Kou OISHI's poster
- Trigger line (2x2 crystal's signals are summed) waveforms were also measured by using the prototype trigger electronics
  - Realistic detector/electronics response was obtained!



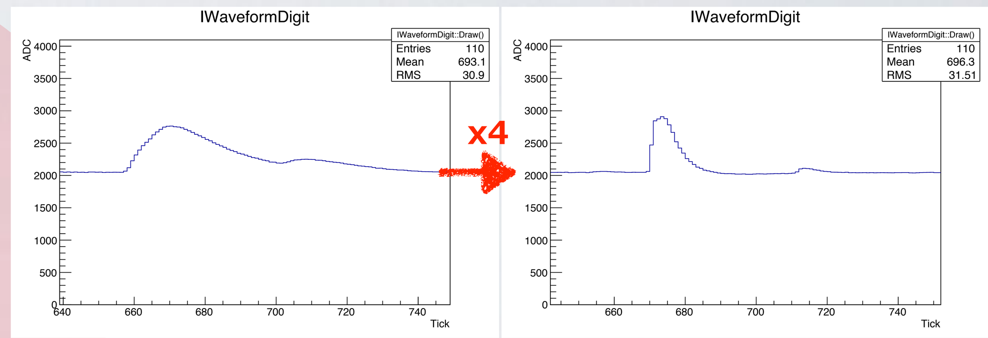
III. Trigger Simulation

- Stop μ- events are generated by assuming:
  - 8GeV/54kW proton beam, bunch separation 1.17μs
  - 2.8×10^{-3} (stop μ-)/POT based on the current simulation design
- Detector and electronics responses are from the measurements
- Finite sampling speed and ADC resolution are introduced



Then…

- Pileup is found to be more sever than the high energy tail of single DIO
  - Shaping time of Preamplifier is shorten by factor 4 in simulation
- Trigger simulation was done for pure signal events & DIO by changing several parameters
  - Sampling speed (40-120MSPS), ADC resolution (8 or 12 bit), gain (1 or 2)



Example of 2x2 crystal summed waveform w/ realistic DIO simulation

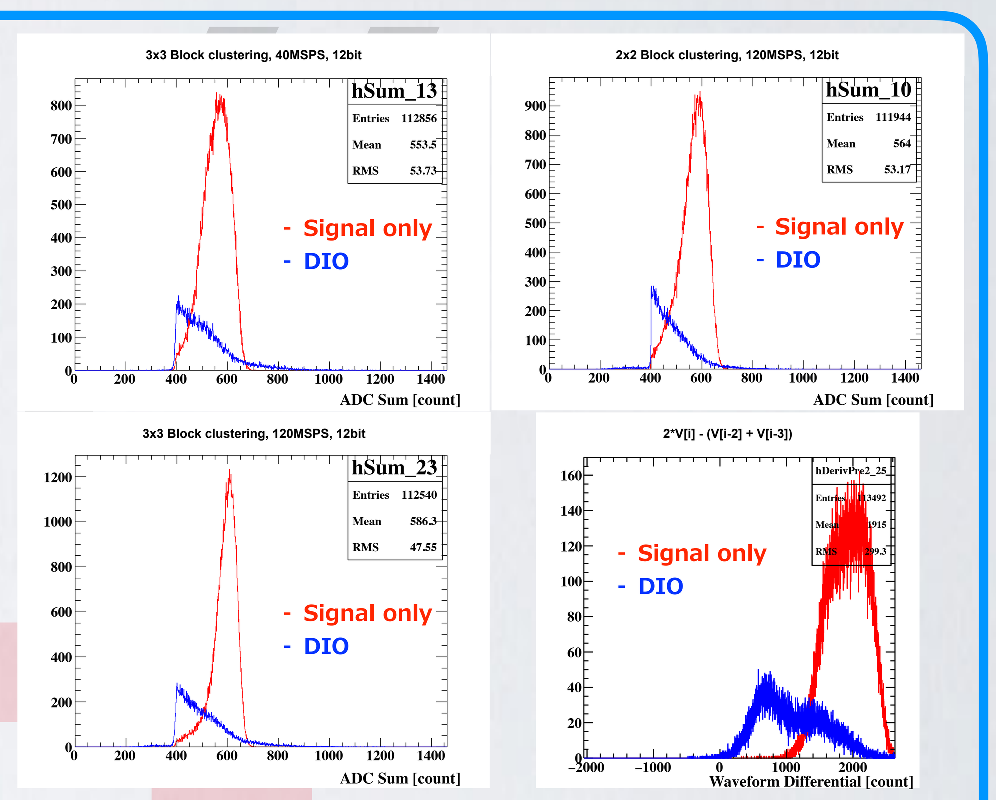
Example of 2x2 crystal summed waveform w/ realistic DIO simulation + 4time shorter shaping

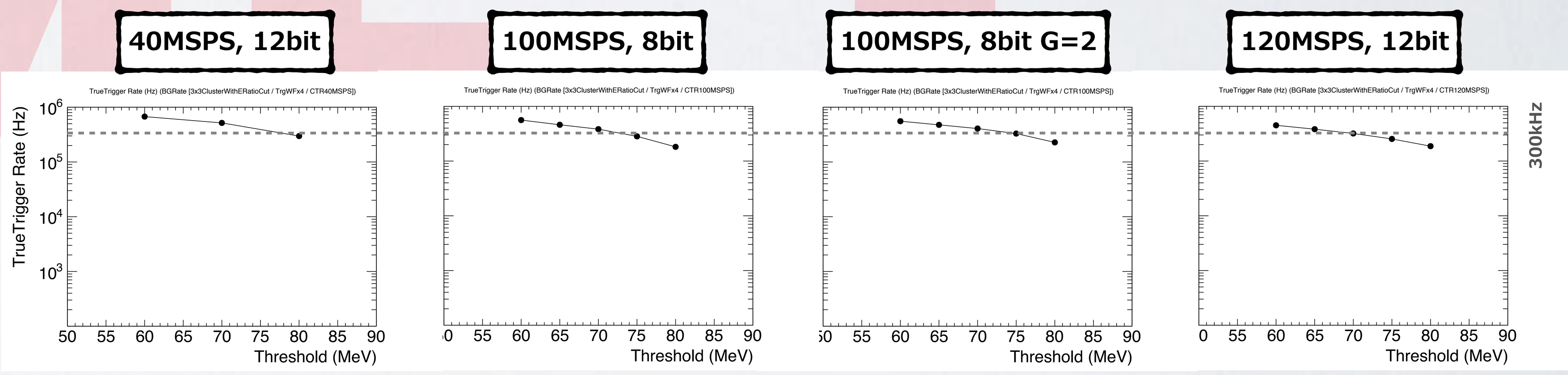
IV. Results

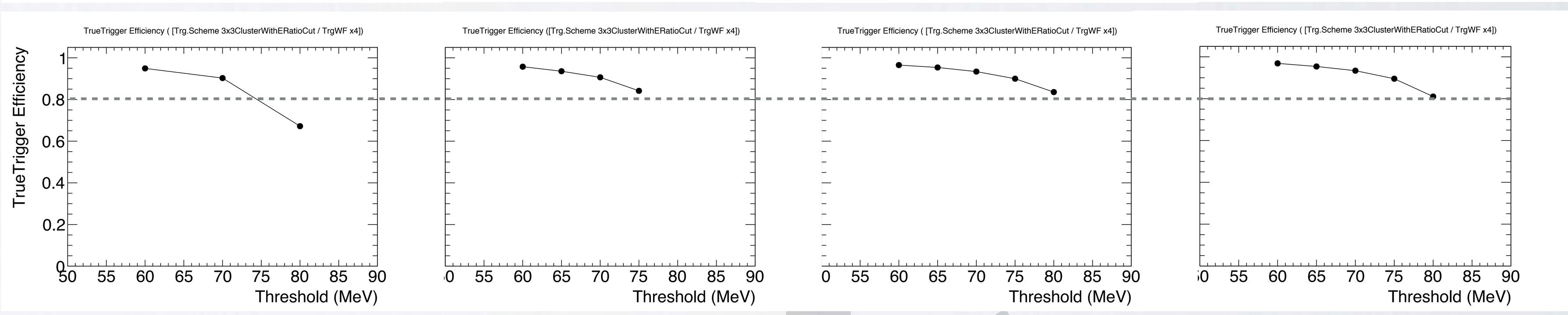
- In Height sum at same tick, 3x3 clustering with faster sampling shows the best signal to DIO separation
- Waveform differential (V[i]-V[i-2]) shows good signal to DIO separation therefore is also introduced into the trigger algorithm
- Two settings show **<300***kHz trigger rate in DIO events while keeping more than **80****% of trigger efficiency for signal

* 300kHz is just an arbitrary chosen number

** Of course this should be as large as possible







V. Summary and Prospects

Summary

- The COMET Experiment aims to search for the μ-e conversion with the single event sensitivity of $O(10^{-17})$ in Phase-II
- Very high incoming particle rate ~O(MHz) is expected in Phase-II and piled up low energy (<50MeV) particles can induce the high trigger rate in ~100MeV signal region
- First realistic trigger simulation is performed by considering the realistic detector and electronics response with finite sampling speed & resolution
  - More than 80% efficiency with <300kHz trigger rate is achievable with existing commercial ADC chip, >=8bit & >=100MSPS

Prospects

- Prompt beam has not been included and should be done soon
- COMET Phase-II geometry will be still being optimised and not fixed
  - Potentially cause more background, but that can also become better
- The design of trigger electronics / algorithm for Phase-II will be started based on this study

References

[1] COMET Collaboration, *COMET Phase-I Technical Design Report*, arXiv:1812.09018 .

[2] COMET Collaboration, *Conceptual Design Report for Experimental Search for Lepton Flavor Violating μ- - e- Conversion at Sensitivity of 10-16 with a Slow-Extracted Bunched Proton Beam COMET*, http://comet.kek.jp/Documents_files/comet-cdr-v1.0.pdf .