The Optimization of Execution Speed for CGEM Simulation

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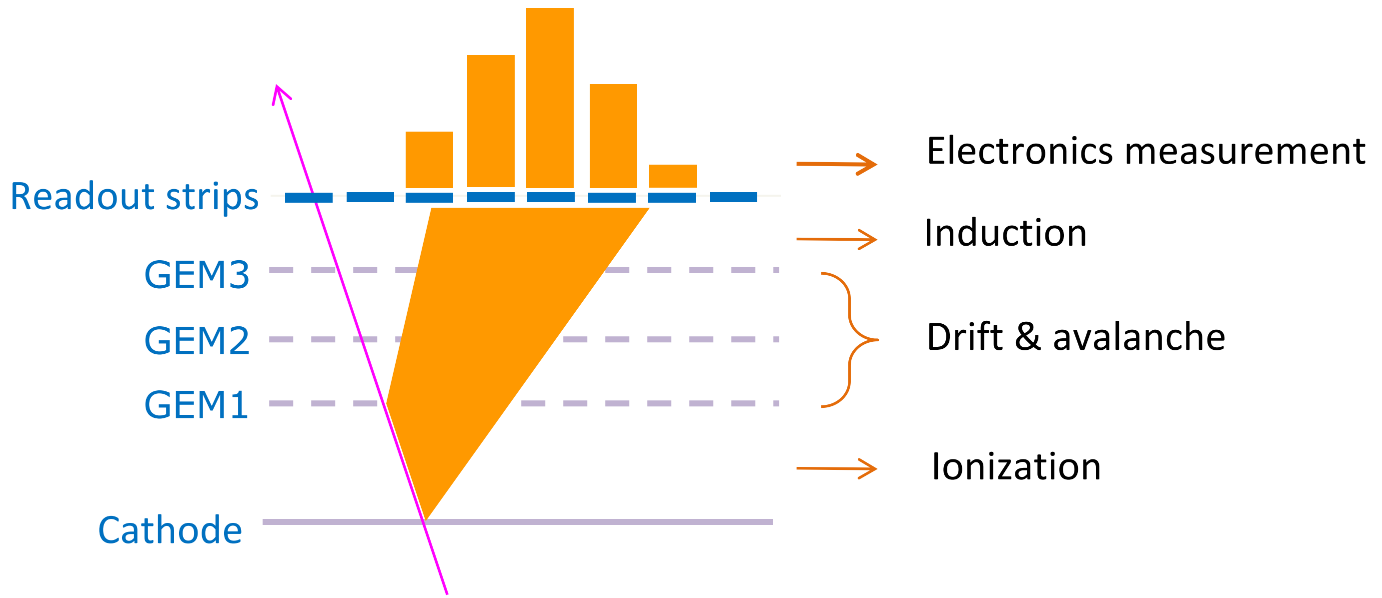
Introduction of CGEM-IT

BESIII's inner track chamber has been upgraded with cylindrical GEM (CGEM)detector , it is planned to start data taking in 2025.

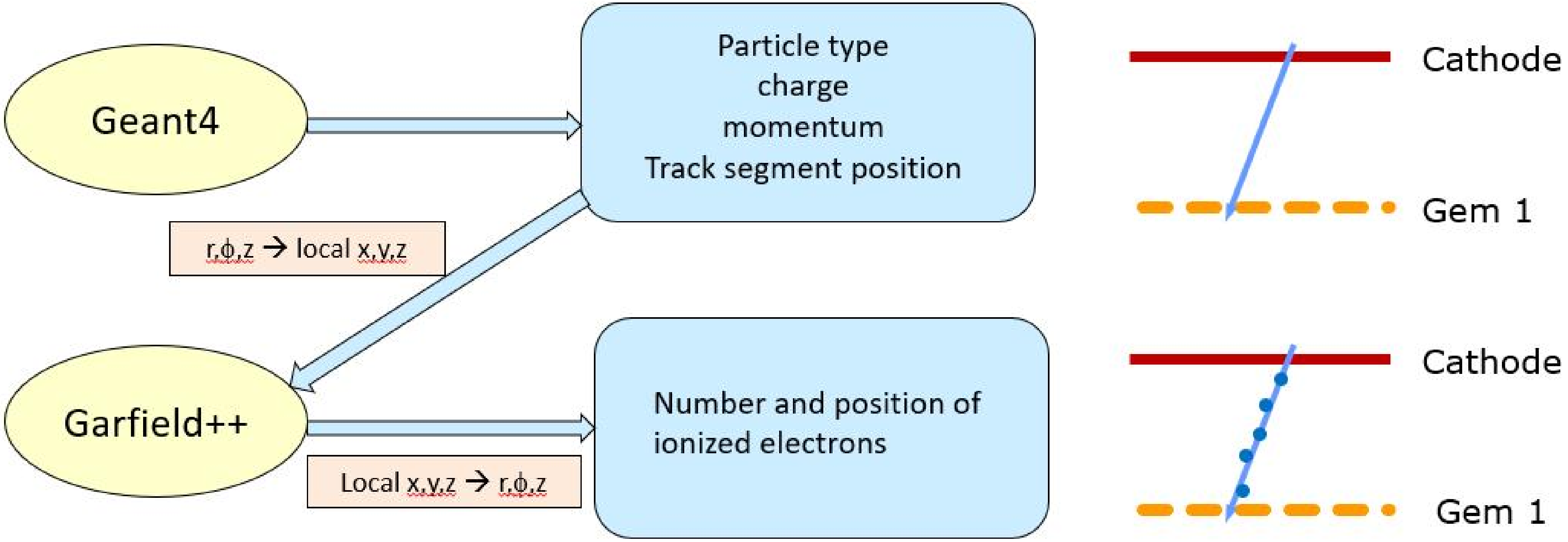


Processes in digitization of CGEM-IT

- Ionization
- Drift & avalanche
- Induction & Electronics measurement

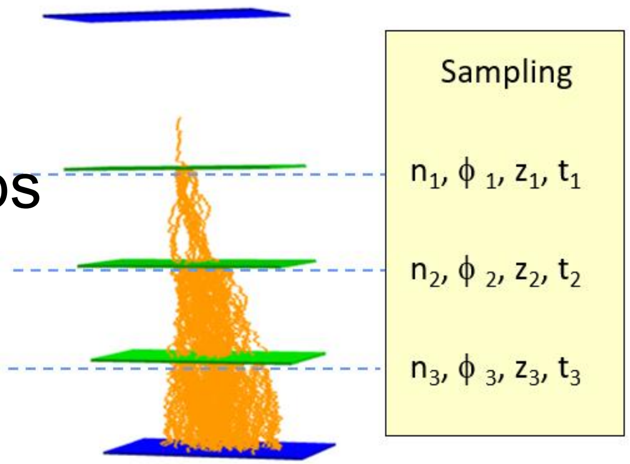
Ionization

- Geant4 generate particles’ information
- Garfield++ generate ionizated electrons
- Record the number、position and time of ionizated electrons



Drift and avalanche

- Garfield++ full simulation is time-consuming
- A parameterized model is developed
  - Sample the quantities of multiplied electrons in 3 steps
    - Number of multiplied electrons (n)
    - Position (ϕ, z)
    - Drift time (t)
  - Parameters of the model obtained from Garfield++ simulation



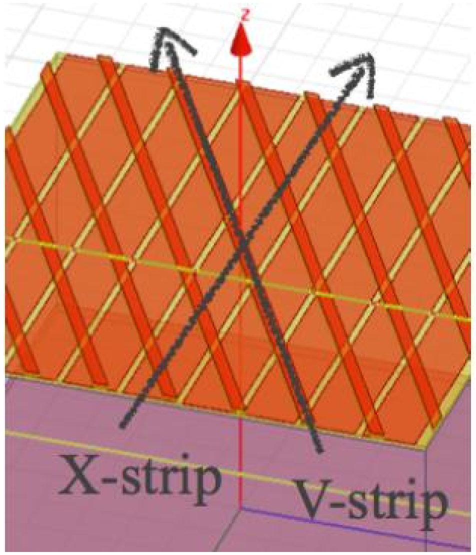
- The ionizated electrons avalanche in each GEM. Finally,millions of electrons can be generated

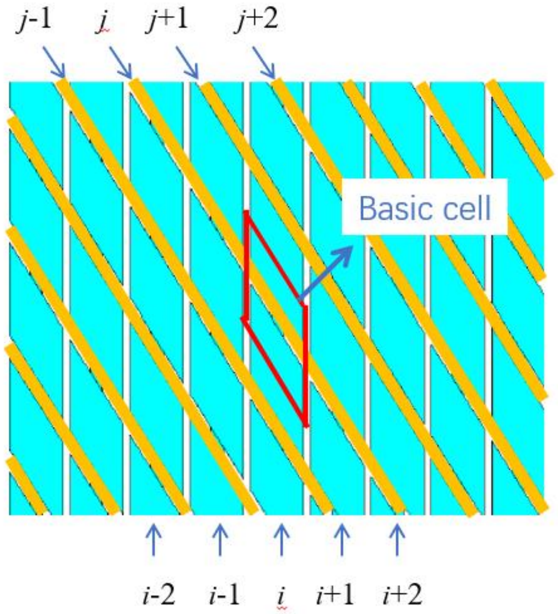
Induction

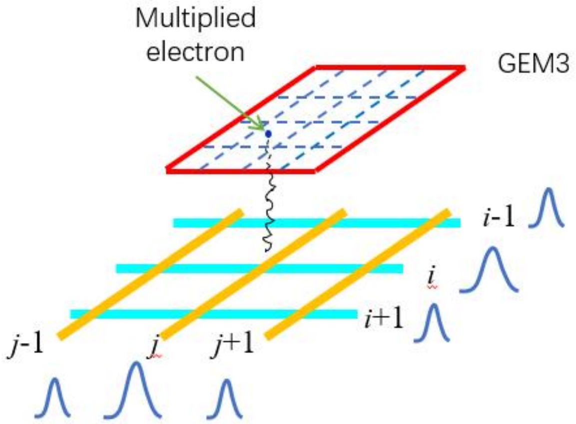
Signal simulation:

- Divide basic cell into small grids
- Save the induced signal shapes for each grid
- Sum up all signal from multiplied electrons

to get the final result for each strip



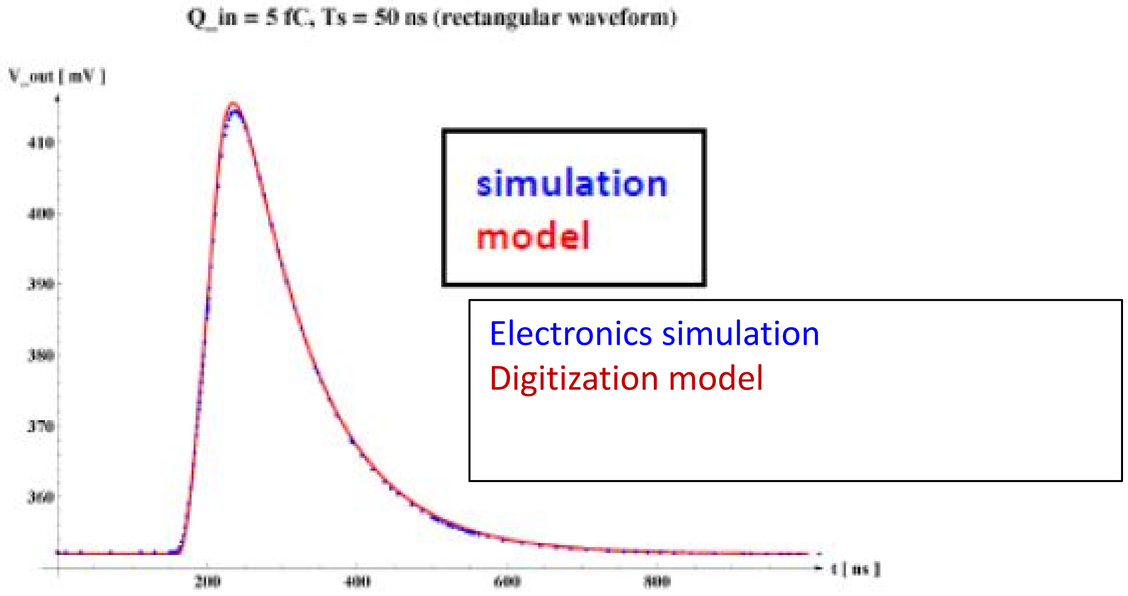




Electronics measurement

- Simulate the electronics response in anode strips

- Record the stripID and its T、Q information



rectangular waveform

Q_{in} = 5 fC

T_s = 50 ns

Digitization algorithm

Track segment from Geant4

↓

Ionization

↓

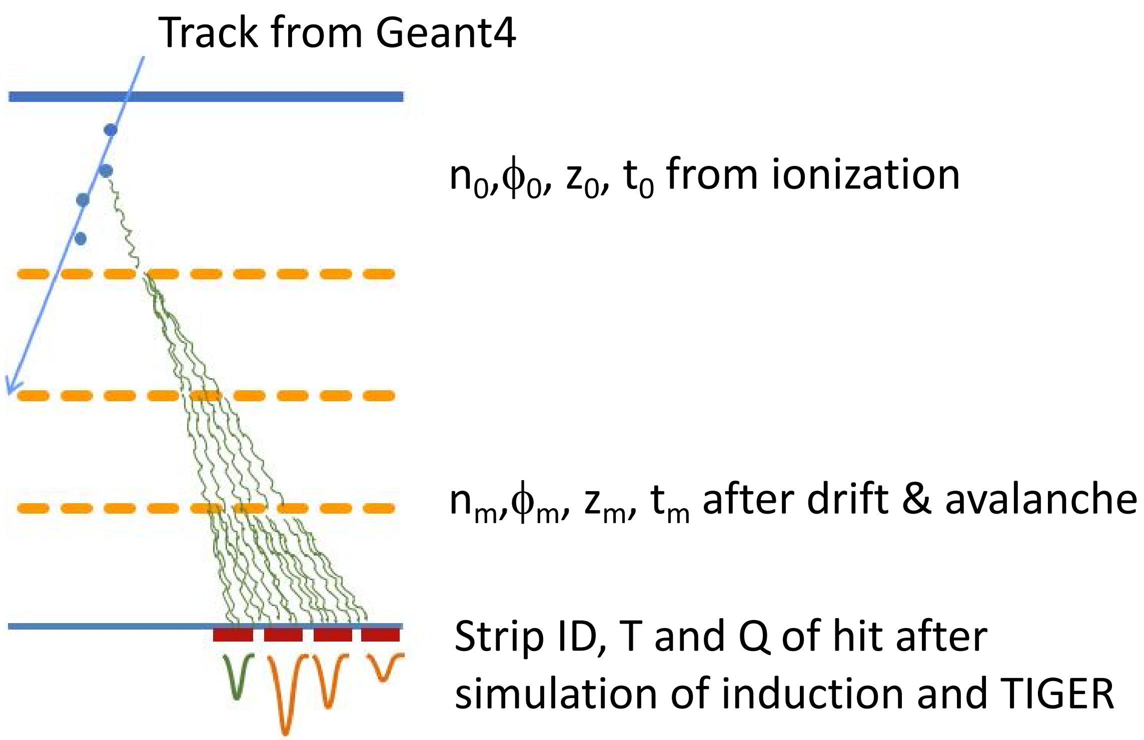
Drift & Avalance

↓

Induction & TIGER sim

↓

Strip ID, T and Q of hits



Time consumption of each module

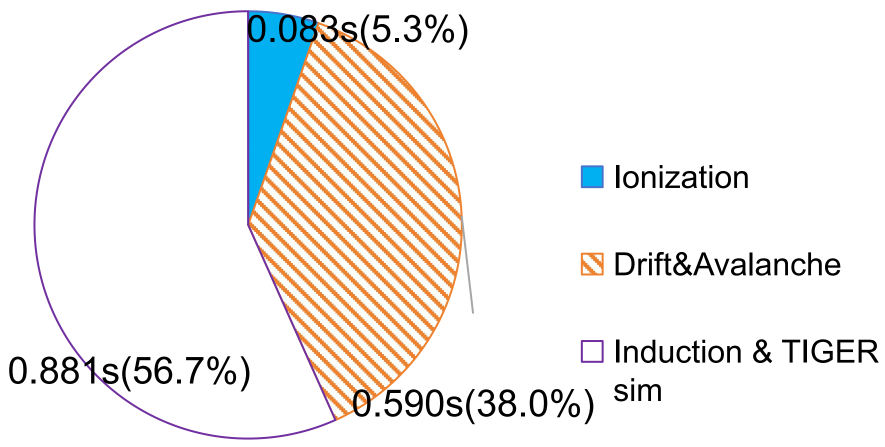
- Each event needs 1.6s execution time
- Ionization occupy very small part of time

- Drift & Avalanche :

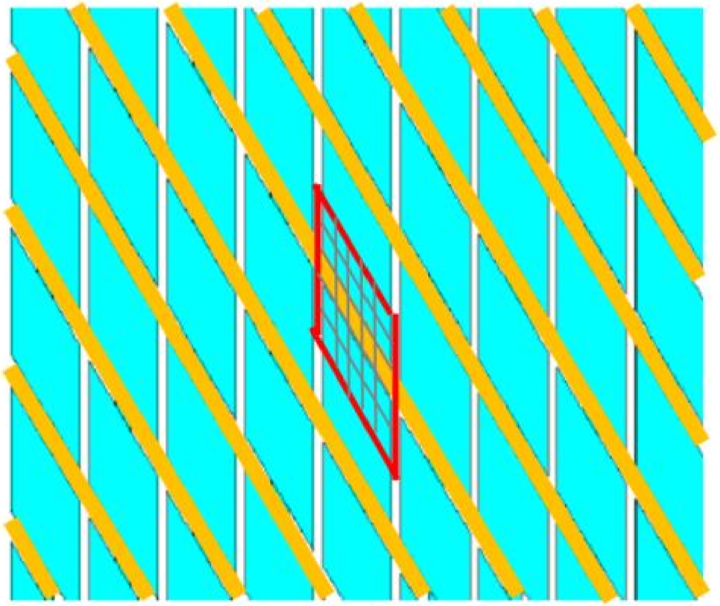
sampling times (pos&time)

- Induction & TIGER sim:

convolution & accumulation times



Optimization for Drift & Avalance module

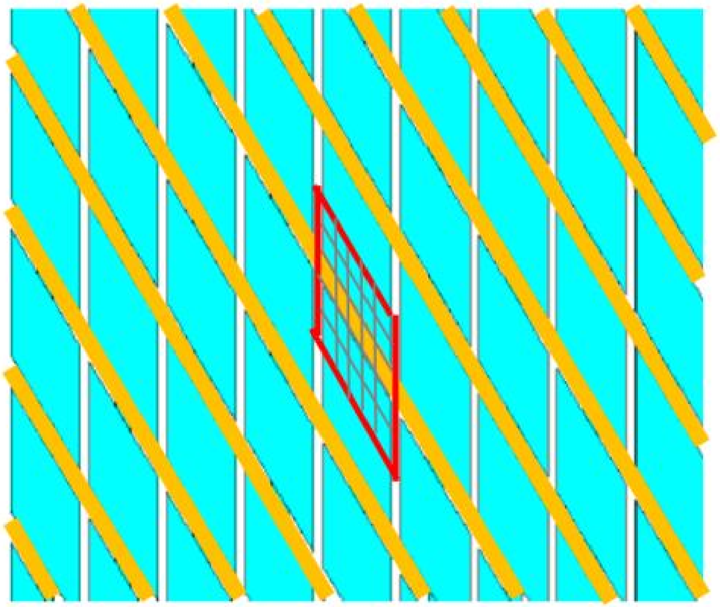


$$N_{i,j}^{GEM3}(t) = \sum P_{k,l} * N_{i-k,j-l}^{GEM2}(t)$$

- After the second multiplication, the grids with a high number of electrons tend to exhibit results that are closer to the average case after the third round of multiplication and diffusion.

- By convoluting the electron count-time distribution in each grid with the electron count-time distribution generated by a single electron after multiplication and diffusion in the surrounding grids, the final electron count-time distribution in the grid can be obtained.

Optimization for Induction & TIGER sim module



- Each small grid generates induction currents on multiple surrounding readout strips, requiring multiple convolutions & accumulations.
- The convolution algorithm utilized Fast Fourier Transform (FFT) operations. According to the convolution theorem, convolution in the time domain is equivalent to multiplication in the frequency domain.

$$\mathcal{F}\{f * g\} = \mathcal{F}\{f\} \cdot \mathcal{F}\{g\}$$

Optimization for Induction & TIGER sim module

- Two highly time-consuming components:
  - Fourier Transform and Inverse Transform:

    Each convolution operation requires performing Fourier transforms before and after the convolution, which consumes a significant amount of time.

  - Time-Domain Accumulation of Induction Currents:

    The induction currents contributed to the same strip need to be accumulated in the time domain. Each strip receives contributions from hundreds of grids, and each induction current-time distribution is divided into 2000 bins, further increasing the computational time.

Optimization for Induction & TIGER sim module

- According to the linearity property of the Fourier transform, the inverse transform and accumulation operations can be swapped.

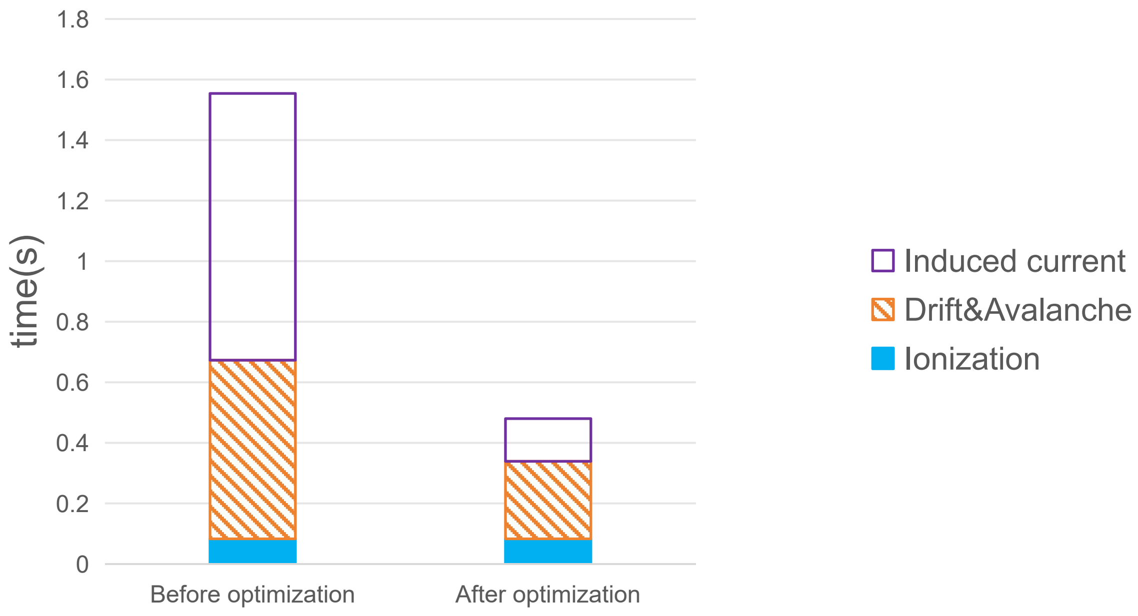
$$\mathcal{F}^{-1}(H_1(u) + H_2(u)) = \mathcal{F}^{-1}(H_1(u)) + \mathcal{F}^{-1}(H_2(u))$$

  - The accumulation in the frequency domain is significantly less time-consuming compared to accumulation in the time domain.

  - The number of inverse Fourier transforms required for each readout strip is reduced to just one.

Execution time comparison

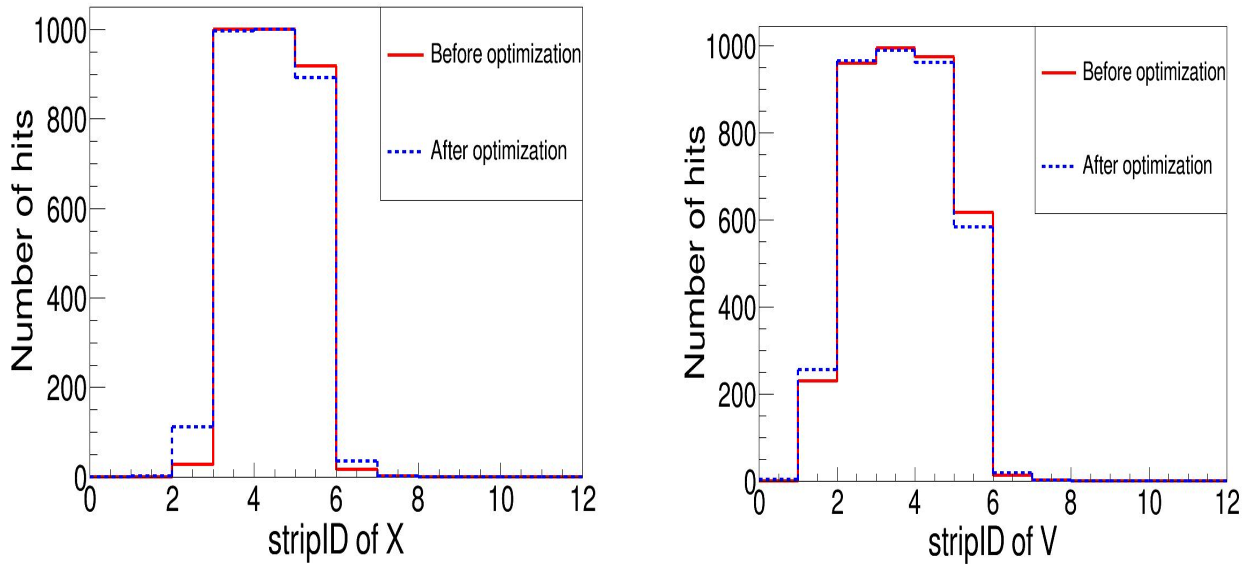
- Drift&Avalanche: Save 50% time
- Induction&TIGER sim: Save 75% time
- Total： Save 2/3 execution time



Result comparison

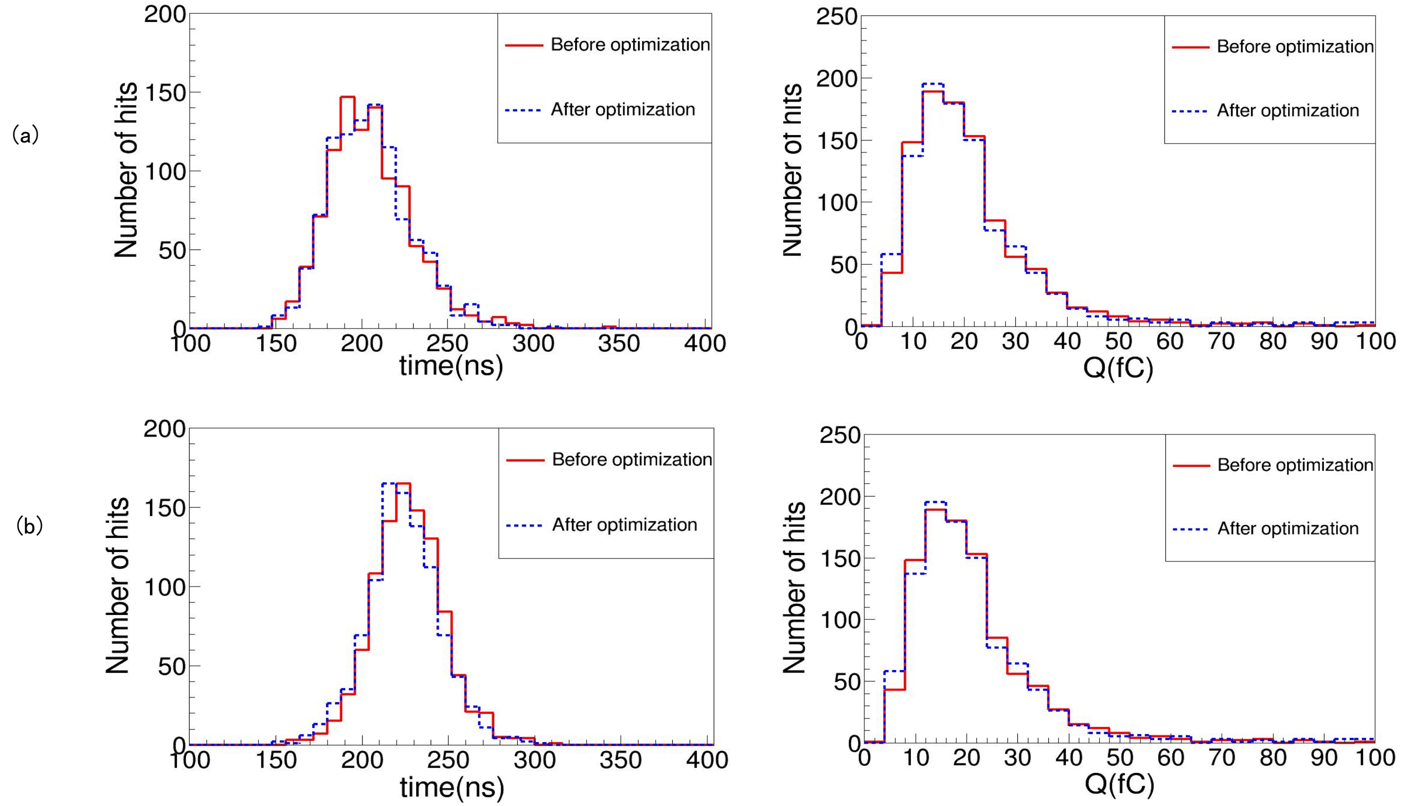
- Using the same condition, 1.5GeV electron execute 1000 times for two version.

- Record the times that strips get signals.



Hit frequence comparison

Take most hit strip for detail comparison



T、Q Signal of StripX 3 (up) StripV 4(down)

- T、Q information stay similar both in X、V strip

Summary

- CGEM-IT Digitization algorithm execution time mainly come from the mutiple sampling times of Drift&Avalanche + convolution & accumulation times of Induction & TIGER sim

- Apply convolution instead of fully sampling to Drift&Avalanche

- Optimize the convolution & accumulation algorithm to Induction & TIGER sim

- Save 2/3 execution time while keeping results stay similar.