Studies of an event-building algorithm of the readout system for HFRS-TPC

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Introduction

The High Energy Fragment Separator (HFRS) is a new generation of radioactive beamline devices with higher energy and higher intensity, consisting of a pre-separator + main separator with multiple twin TPCs for particle identification and beam monitoring. However, due to the large number of readout channels and the vast amount of data, higher requirements for data transmission, processing and storage have been posed, which bring great challenges to the development of readout electronics. Therefore, we propose a new online event building algorithm for HFRS-TPC. Our algorithm employs a hierarchical processing strategy to compress massive amounts of data, and addresses the issue of particle time disorder at high counting rates. The readout system consists of Front-End Electronics (FEEs), slave Data Acquisition units (slave DAQs), and a server.

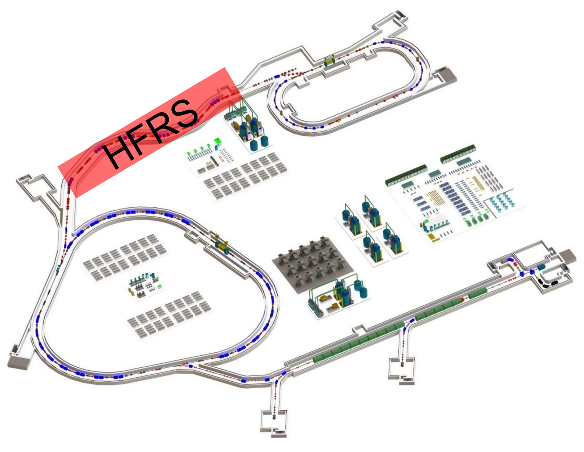

Fig.1 The Diagram of HIAF

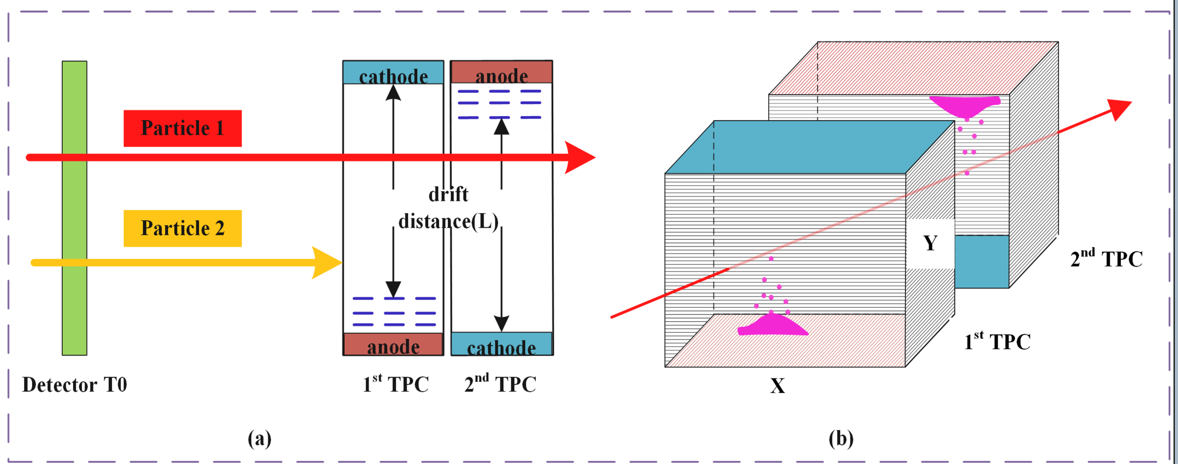

Fig. 2 Illustration of the twin TPCs.

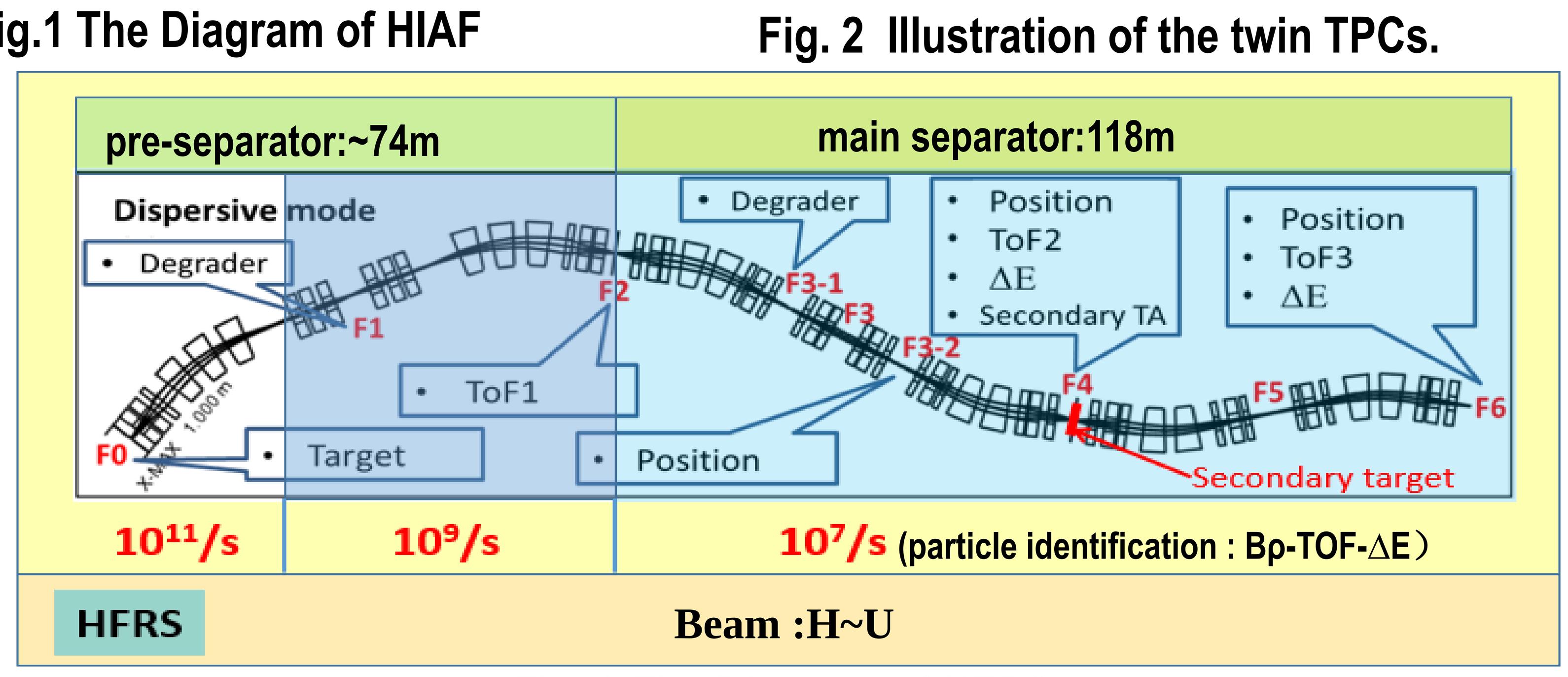

Fig. 3 The Diagram of HFRS

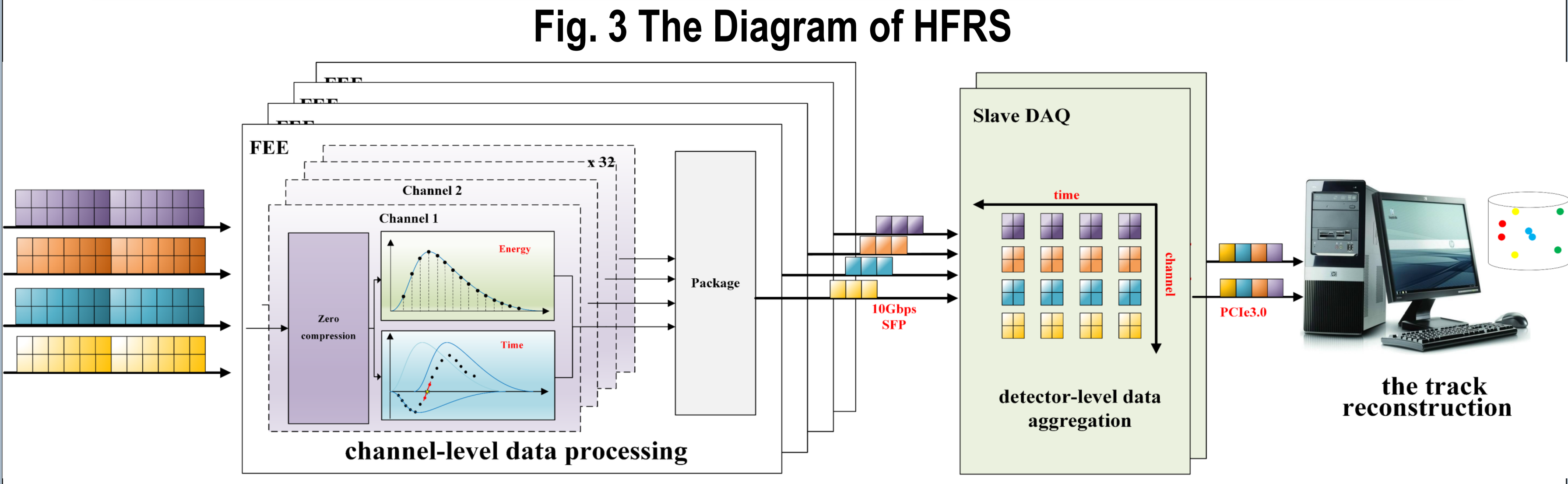

Fig. 4 Schematic diagram of the data processing system hierarchy

Design and Implementation

Based on the hierarchical processing strategy outlined in Sect. 1, the entire flow of the event-building algorithm is shown in Figure 5.

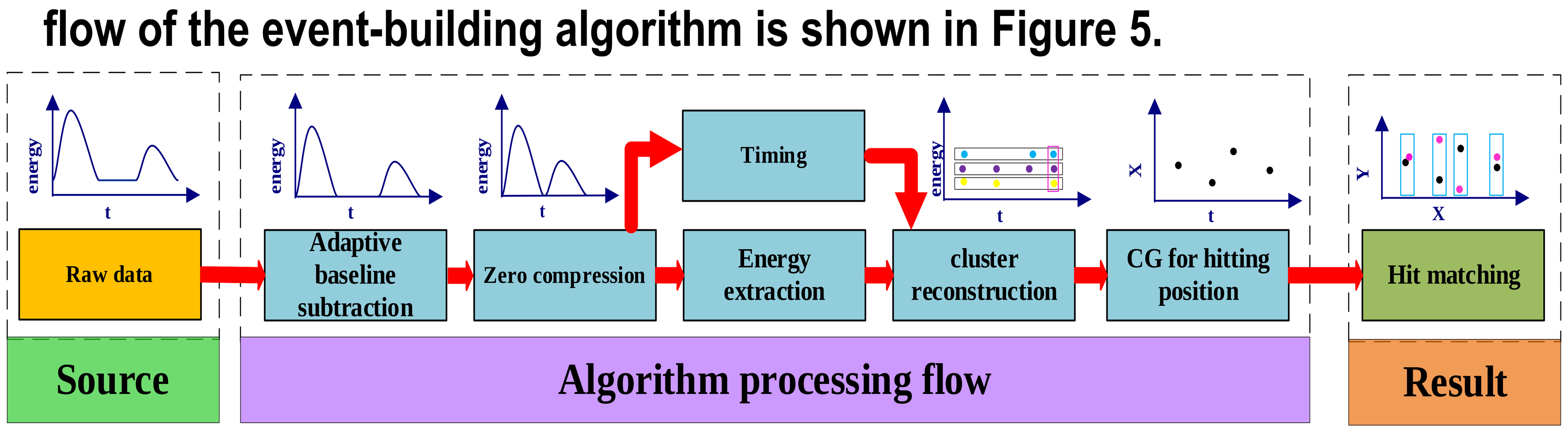

Fig.5 Workflow of the event-building algorithm

The key modules are designed as follows.

1. Timing:

When operating in trigger-less mode, event screening relies on high-precision time information. Therefore, improving timing accuracy by correcting CFD results using interpolation methods. Two data points were first located before and after the overthreshold time (*Va* and *Vb*) by CFD. We then calculated the mid-amplitude point (*Vmid*) based on *Va* and *Vb* by dividing the original time interval into two equal subregions (*a* and *b*). If *Vmid* multiplied by *Vb* is negative, we can determine that the overthreshold moment is in sub-region *b*; otherwise, it is in the other sub-region. Therefore, we reduced the time interval corresponding to the overthreshold moment to half that of the original. By repeating this process *n* times, we can increase the timing accuracy by a factor of 2^n compared to the original.

2. Cluster reconstruction:

As the counting rate of the projectiles increases, there is a strong possibility that the readout signals from different particles experience temporal confusion. Therefore, it is necessary to dynamically determine the two-dimensional merge window based on the temporal and spatial information. The first reference window is provided with the first pulse information. If the second pulse falls within the window, the reference window is adjusted according to the time and channel information of the pulse. Otherwise, the second reference window is created. All pulses in a single front-end packet are traversed in turn, according to the above rules.

3. Hit matching:

1) The relative time method: In Eq. (1), the drift distance (*L*) and drift speed (v_{drift}) of electrons for twin TPCs are predetermined. As a result, the sum of the drift time (t_{cs}) remains fixed and can be used as a constraint to achieve hit matching of twin TPCs.

$$t_{cs} = t_u + t_d - 2t_0 = L/v_{drift} \qquad (1)$$

where t_u, t_d is the absolute drift time of electrons from the twin TPCs, and t_0 is the reference time from detector T_0.

2) The absolute time method: When the counting rate is low, hit matching can be performed based on the difference in drift times being less than the particle incidence interval. The advantage is that it does not depend on t_0 information, so hit pre-matching can be done at the subsystem.

Test and Conclusion

1. Energy resolution: < 1 LSB/channel (Figure 9)
   Time resolution : < 1 ns/channel (Figure 10)
   Use the waveform from the signal source as the test input.
2. The laser signal passed through the twin TPCs (Figure 11), and the reconstructed beam spot was shown in the figure 12. It was observed that both matching algorithms could effectively recover the two-dimensional traces of incident particles under normal conditions. However, the relative time method is more suitable for severe cases because it employs a more rigorous equation as a constraint.
3. The algorithm reduces more than 98% of the data volume at a counting rate of 500 kHz/channel.

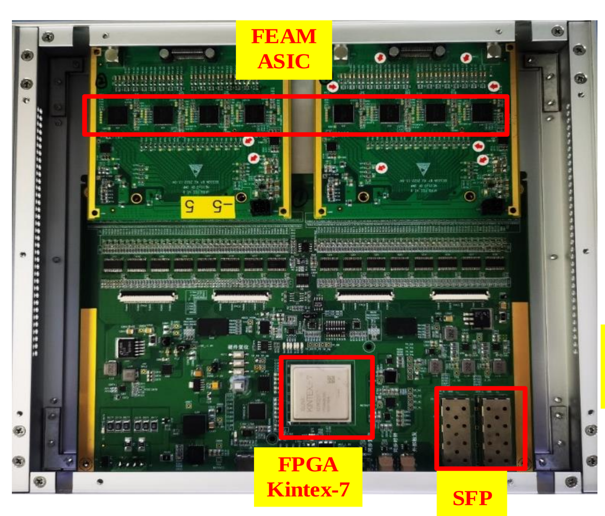

Fig. 7 Front-end electronics

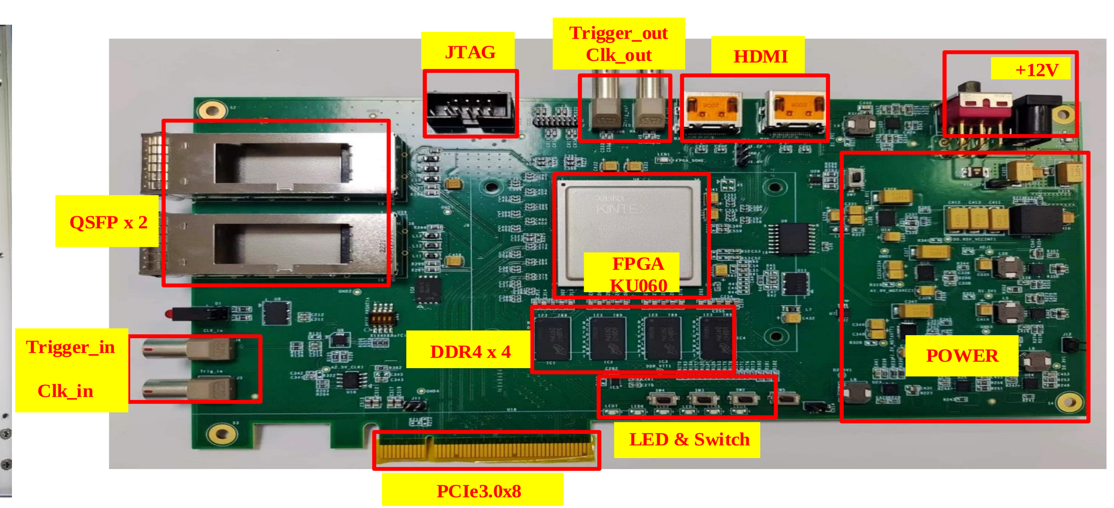

Fig. 8 Slave DAQ

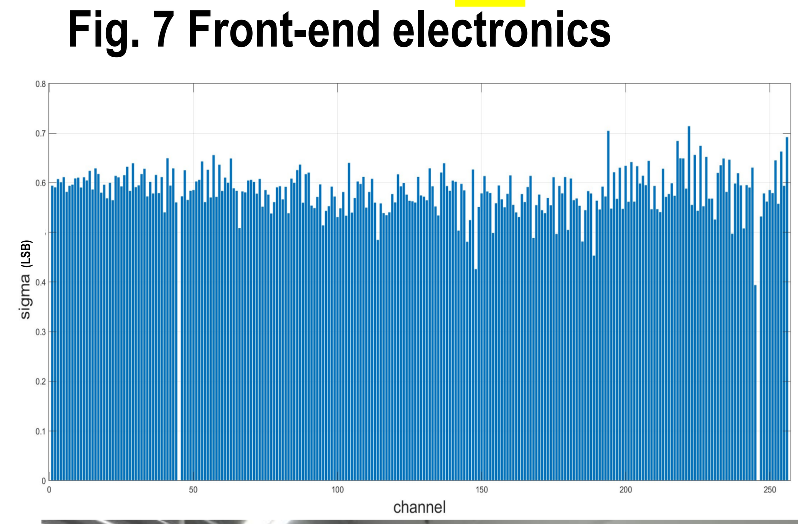

Fig. 9 Energy resolution test results

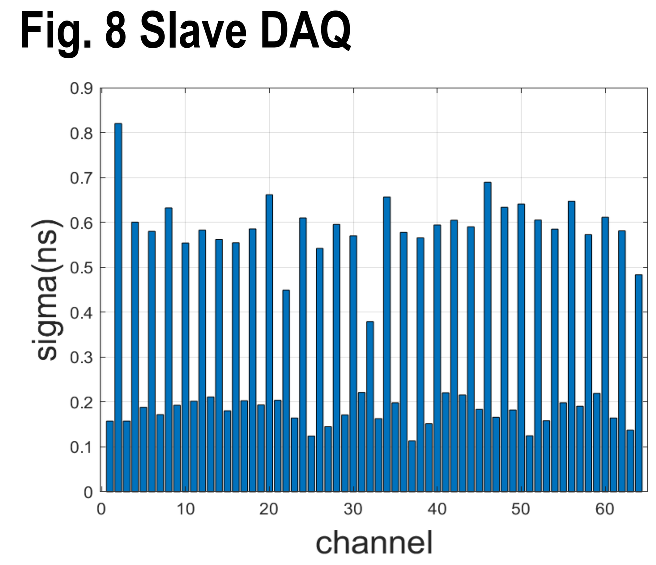

Fig. 10 Time resolution test results

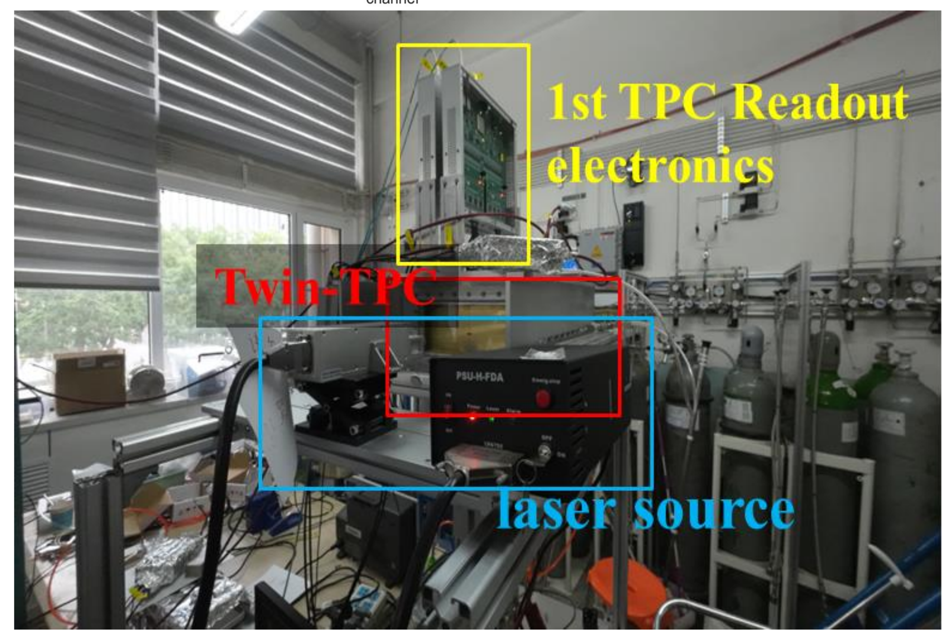

Fig. 11 The test site's photo

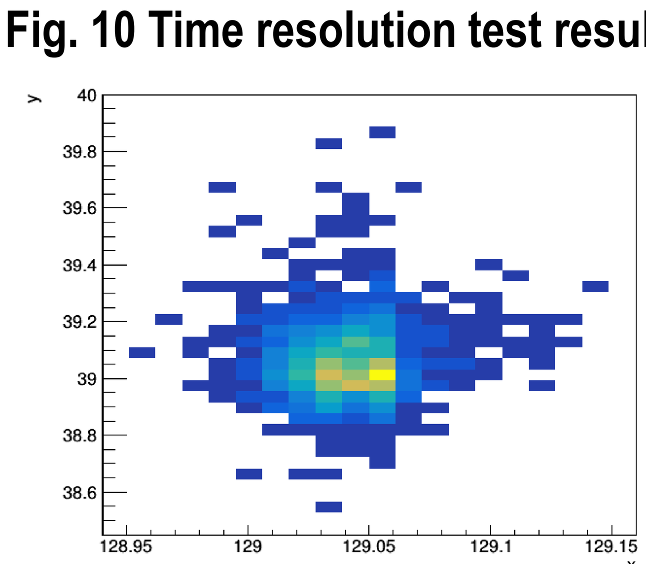

Fig. 12 The reconstructed beam spot

Papers

[1]Tian J,Sun Z, Chang S,Qian Y,Zhao H. An Event Building algorithm of the readout system for the twin TPCs in HFRS[J]. Nuclear Science and Techniques.2024(35).DOI: 10.1007/s41365-024-01434-0

[2]Tian J,Sun Z, Chang S,Qian Y,Zhao H. The HSPC—a high speed PCIe readout card for the HFRS-TPC[J]. Journal of Instrumentation. 2023(18): P12008.DOI: 10.1088/1748-0221/18/12/P12008.