A Full Trigger Data Readout Scheme for the BESIII MDC Subtrigger System

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Motivation

The BESIII luminosity upgrade will increase the background level and event complexity in the future. The MDC stereo-wire layers provide additional spatial information, making 3D track trigger algorithms a promising upgrade direction for background suppression.
To better study and develop such trigger algorithms, access to raw MDC detector data is essential.

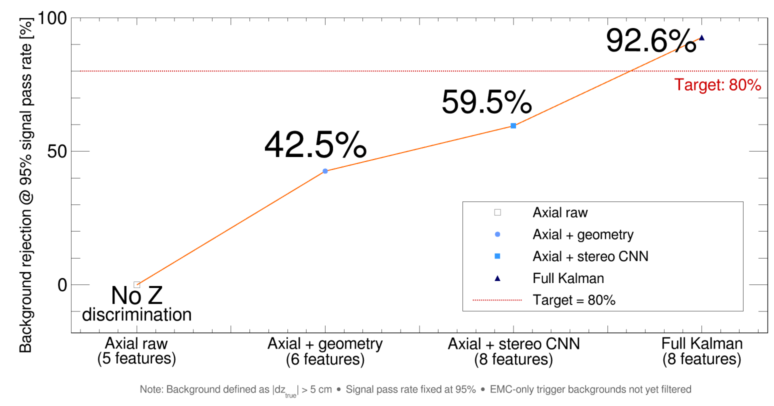
This work focuses on:

- Building a full trigger data readout path based on **the new MDC Sub-trigger FEE/BEE electronics and high-speed links**
- Designing **a data compression and block-based packaging scheme** for continuous MDC raw data
- Using **RDMA-based transmission** to read out complete data blocks to a server for offline analysis and validation

Table 1: MDC layer structure and geometry parameters.

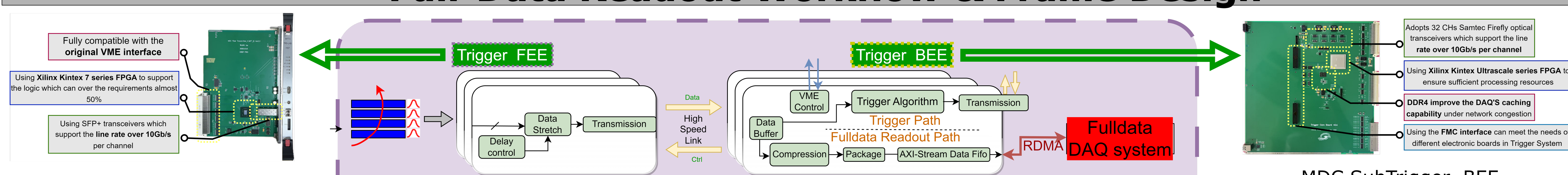
Superlayer	Type	N_{layer}	N_{wire} / layer	Radius (mm)	Length (mm)
3	A	4	76,76,88,88	197 - 246	1092 - 1272
4	A	4	100,100,112,112	262 - 311	1442 - 1612
5	A	4	128,128,140,140	327 - 375	1782 - 1952
6	U	4	160 × 4	400 - 448	2174 - 2192
7	V	4	176 × 4	464 - 514	2198 - 2216
8	U	4	208 × 4	530 - 579	2222 - 2240
9	V	4	240 × 4	595 - 642	2246 - 2264
10	A	4	256 × 4	667 - 716	2276 - 2294
11	A	3	288 × 3	732 - 763	2300 - 2306

Notation: x × n denotes n layers each with number of wire. A: axial superlayers, U: stereo superlayers with negative tilt angle, V: stereo superlayers with pos



background rejection for 3d tracking algorithnm

Full-Data Readout Workflow & Frame Design



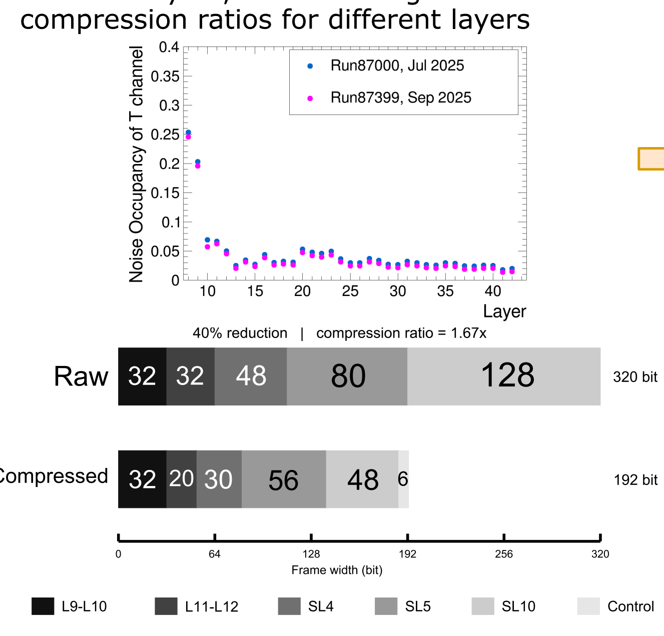
MDC SubTrigger FEE

Full-data Readout Hardware & Firmware

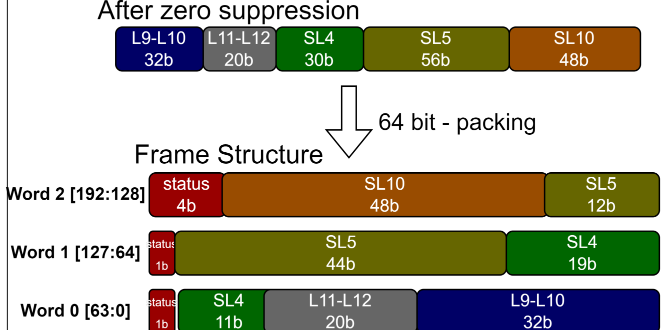
MDC SubTrigger BEE

01 Raw Data and Compression

- The detector's original bitmap contains many '0' and only a few '1', so zero compression is the most effective compression strategy; Meanwhile, the hit rates vary across different superlayers.
- In response to the different fire rates at different layers, we also designed different compression ratios for different layers



02 Block Builder & Frame



- Add Header & Trailer
- Timestamp
- Frame counter
- Data Type Control
- Payload Length
- Overflow Symbol

One Block (example)

Mode 0 (Compressed)

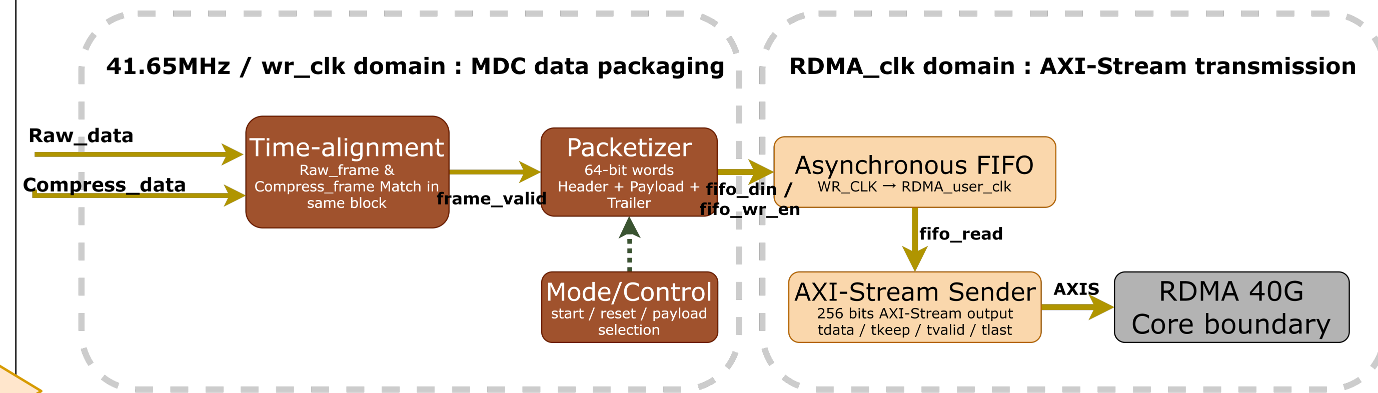
$192\ \text{bit} \times 256 = 49152\ \text{bit}$

$= 6144\ \text{Byte}$

$\text{Header} + \text{Trailer} = 128\ \text{bit}$

$\text{Total} = 6160\ \text{Byte}$

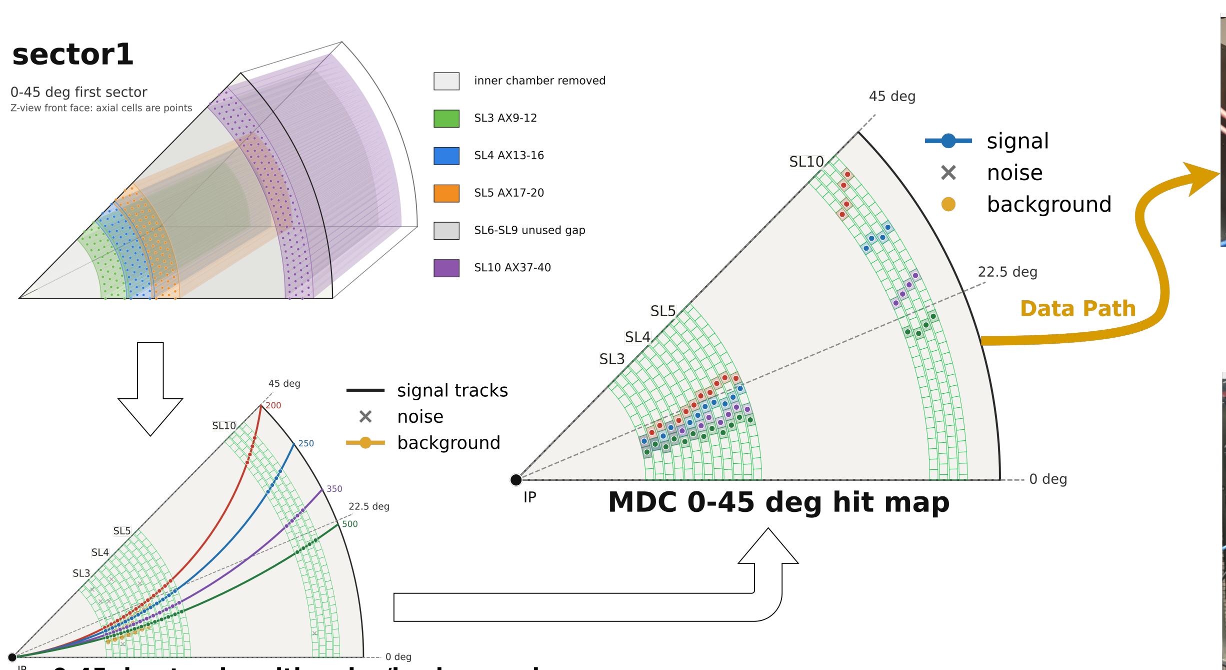
03 Packetizer & AXI-Stream



MDC Full Data Readout: Packaging Stage Firmware Diagram

- 4 x 64-bit words Logical block boundaries are packed into one 256-bit AXI beat (AXI beat boundaries)
- Compressed and raw frames are serialized into different numbers of 64-bit words, then packed into continuous 256-bit AXI beats without changing the original block order
- Using RDMA (40G) as the data readout method. For detailed RDMA implementation and performance evaluation, please refer to **Chang Xu's poster**: "No.134:**FPGA based RDMA for BEE Readout**".

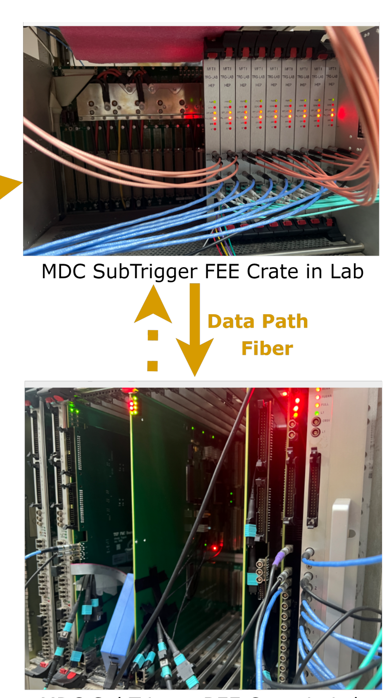
Results & Validation



0-45 deg tracks with noise/background

MDC 0-45 deg hit map

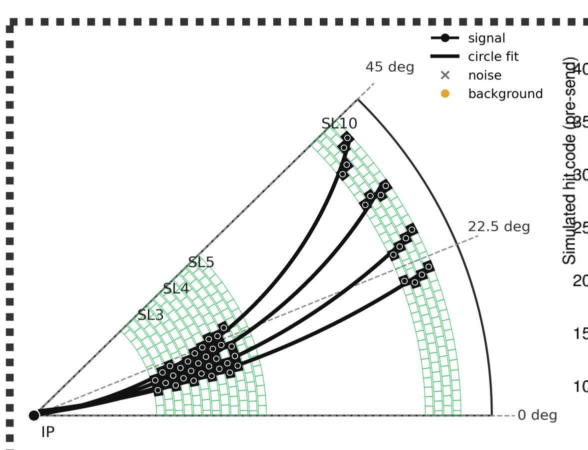
Simulated Hits Generation



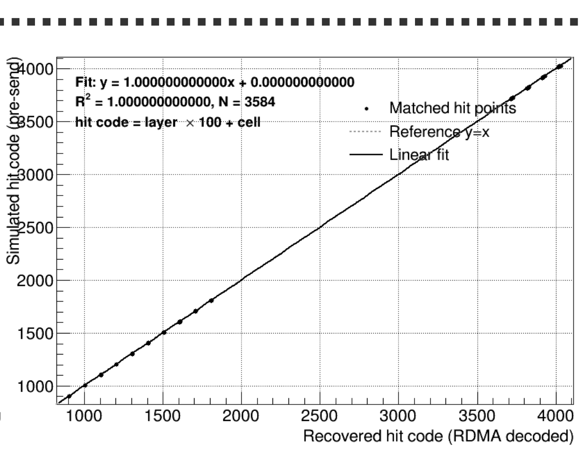
MDC SubTrigger FEE Crate in Lab

MDC SubTrigger BEE Crate in Lab

Development and test platform in Laboratory



MDC 0-45 deg fitted tracks



RDMA Recovered Hits vs Pre-send Simulated Hits

Conclusions:

- **The RDMA data were correctly filled back into the MDC hit map,** the recovered hit positions and fitted tracks are consistent with the expected simulated pattern
- **The recovered hit codes match the original simulated hit codes.** The linear fit gives $y = x$ and $R^2 = 1.000000$, showing that no hit loss or wrong decoding was observed in this test.

Future Work & Extension

- **Improve the readout control mechanism to keep full-data transmission stable under high-rate conditions**
- **Provide reliable MDC raw hit data for 3D track-trigger studies, helping to develop and test new trigger algorithms**

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