Streaming Readout VI
Virtual Workshop (originally Jefferson Lab)
13 May 2020 to 15 May 2020

Streaming DAQ used for the eTOF in STAR

Integration of the CBM free-streaming readout chain
into
the triggered systems at STAR

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Outlook

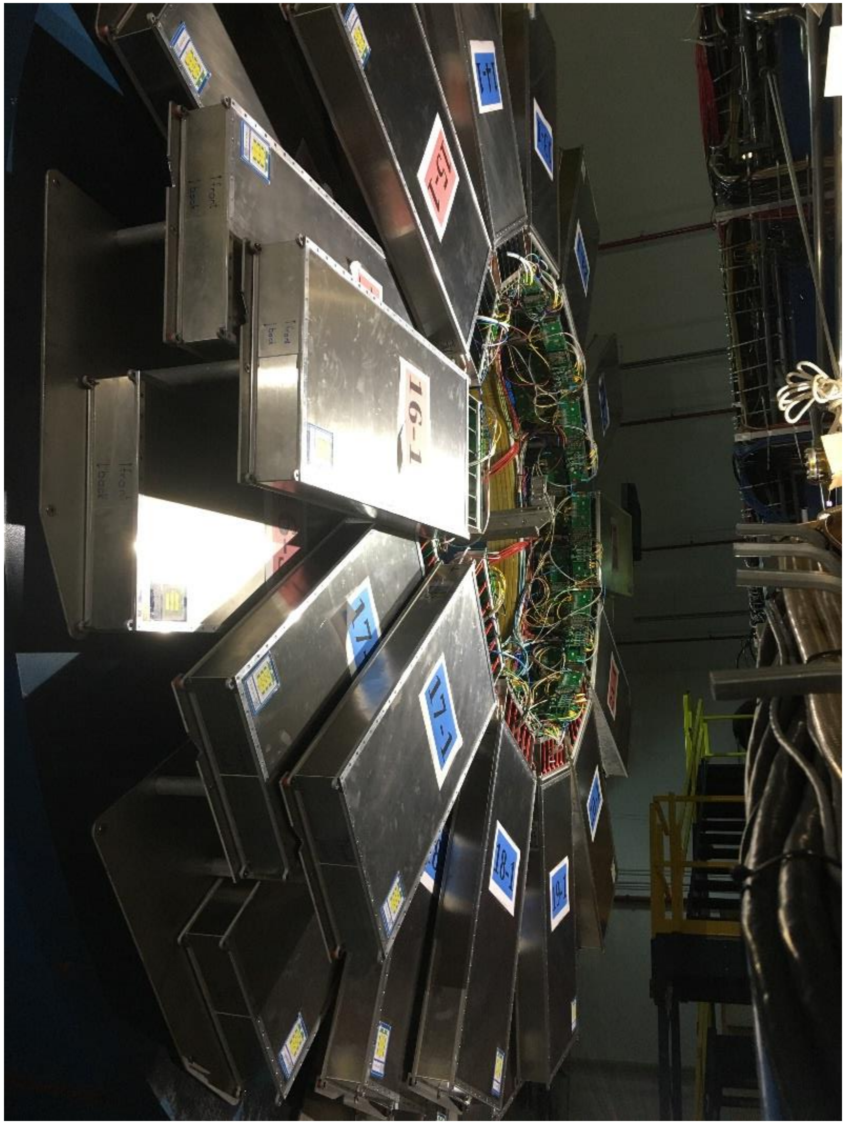
I. Introduction

II. Hardware side

III. Hardware/Software interface

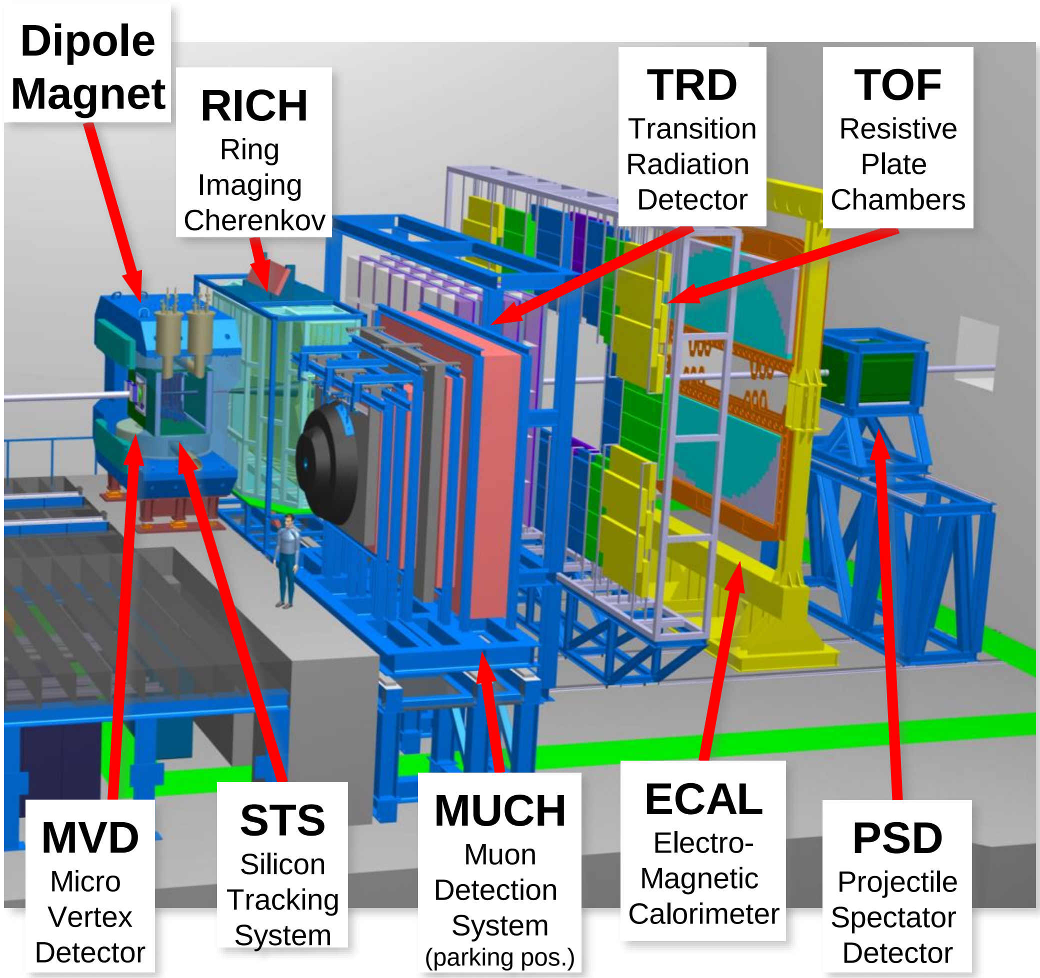
IV. Software side

V. Status

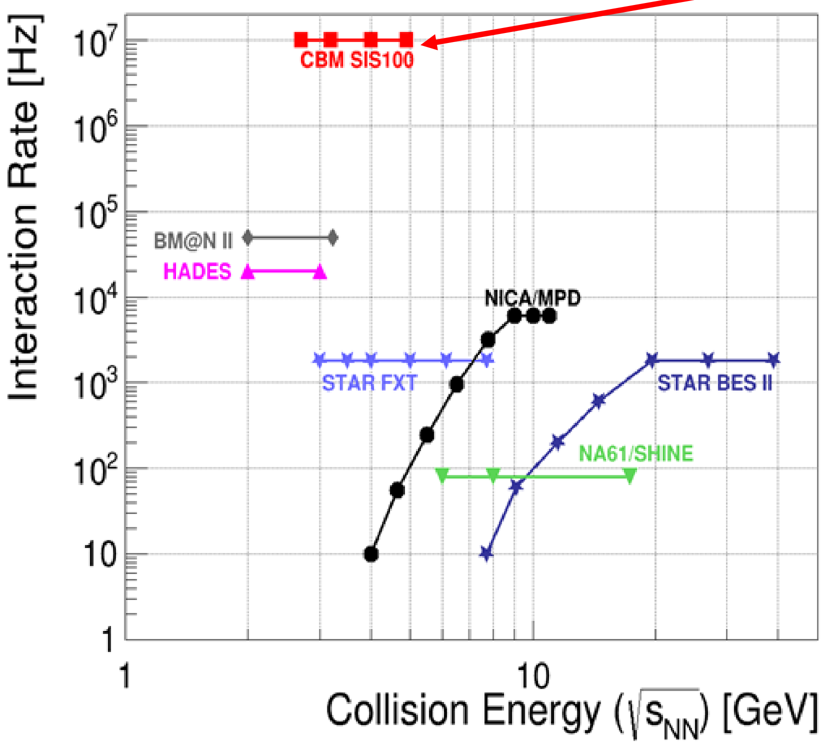


Introduction: CBM

- Heavy-Ion fixed target experiment
- To be built on a beamline of the SIS100 synchrotron at the new FAIR facility in Darmstadt, Germany
- Physics program: investigate rare probes and potential phase transitions in the region of high baryon-densities
- Up to 10 AGeV Au
- Up to 30 GeV p
- Acceptance: $2° < \theta_{Lab} < 25°$
- “High precision High statistics”



Introduction: CBM readout



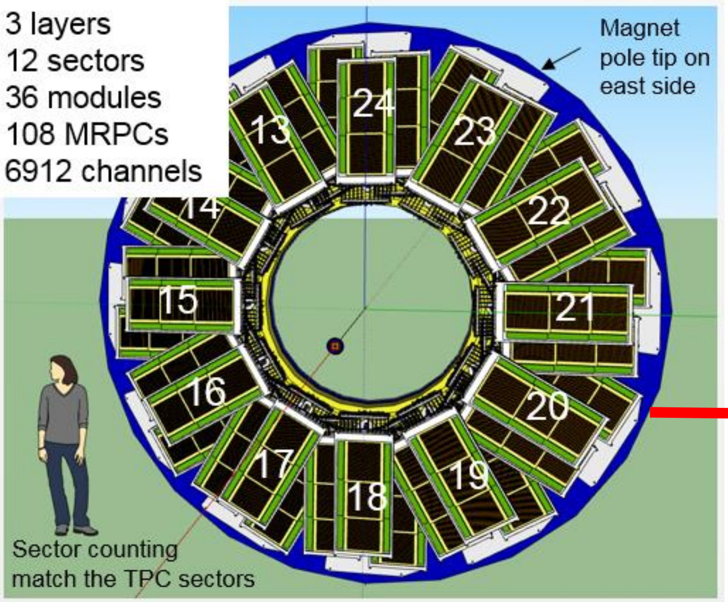
- Very high interaction rate environment:
  10^5 – 10^7/s (A+A), up to 10^9/s (p+A)
- Non-trivial criteria for event selection
- Fast detectors with radiation tolerant free-streaming readout electronics
- High-speed Data AQuisition (DAQ) system
- FPGA based readout chains
- About 1-2 TByte/s bandwidth to the High Performance computing farm, where the First Level Event Selector (FLES) is running
- State of the art computing infrastructure allowing for online event reconstruction
- Online event selection to reduce data by a factor 100-1000 for archiving at ~1 GByte/s

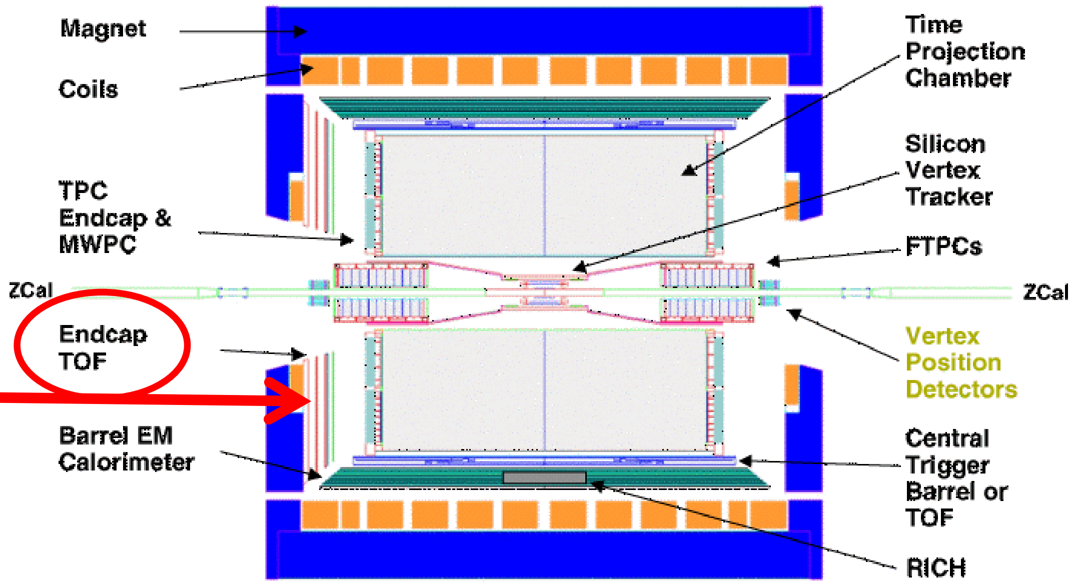
Introduction: STAR and eTOF

What is the eTOF project

arXiv: 1609.05102

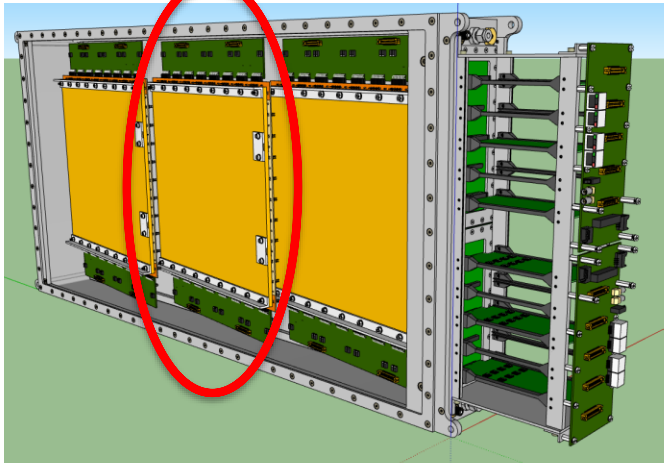
- eTOF project is a joint project between CBM and STAR
- eTOF project is part of the BESII detector upgrade at STAR
- It comprises the installation, commissioning and operation of CBM TOF modules positioned at the east pole tip of the STAR apparatus during the BESII campaign and physics analysis of data obtained with eTOF
- CBM institutions involved: CCNU, GSI & FAIR, TSU, TUD, UHD, USTC





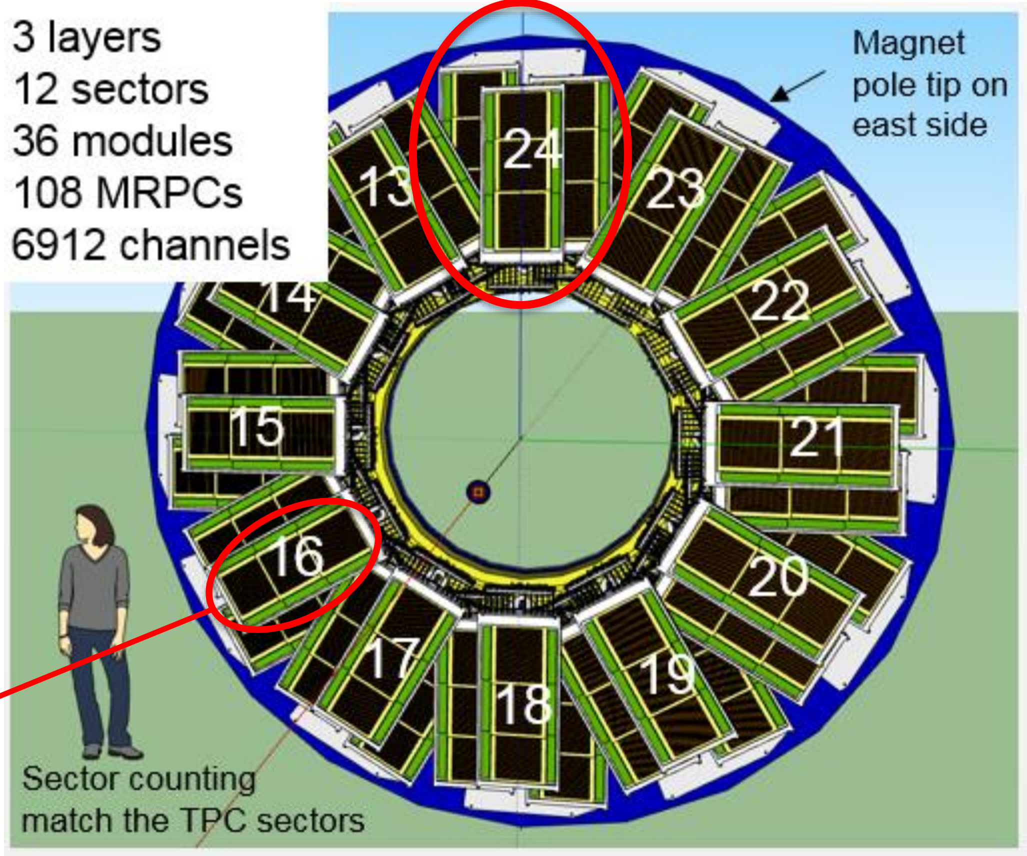
eTOF Detector/Module/Sector

MRPC detector

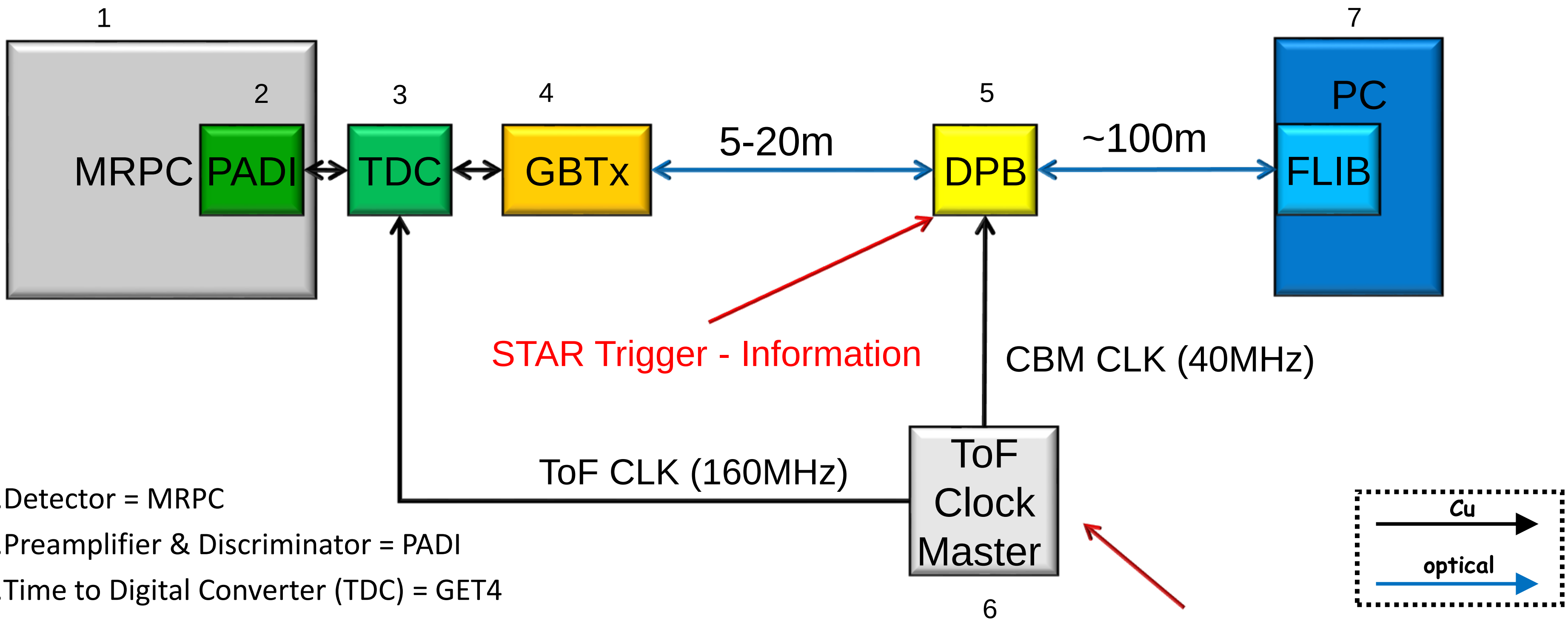


eTOF module

Sector



MRPC readout for CBM and eTOF



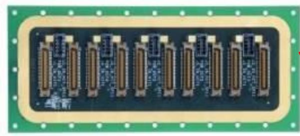
1. Detector = MRPC
2. Preamplifier & Discriminator = PADI
3. Time to Digital Converter (TDC) = GET4
4. GBTx = Data Concentrator ASIC from CERN = **1st concentrator stage**
5. Data Processing Board (DPB) = **2rd concentrator stage** (AFCK in MTCA Crate)
6. Clock Master (CLOSY) & Clock Distribution for ToF
7. PC = storage Device with FLIB (First Level event selector Input Board, PCIe Card)

- **for eTOF**
- **with STAR Trigger information**
- **with STAR Clock (CBM Master Clock)**
- **with pulser on trigger for calibration and quality check**

MRPC front-end electronics

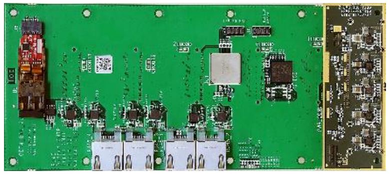
- PADI: Preamplifier board 32 CH

- Feed through PCB



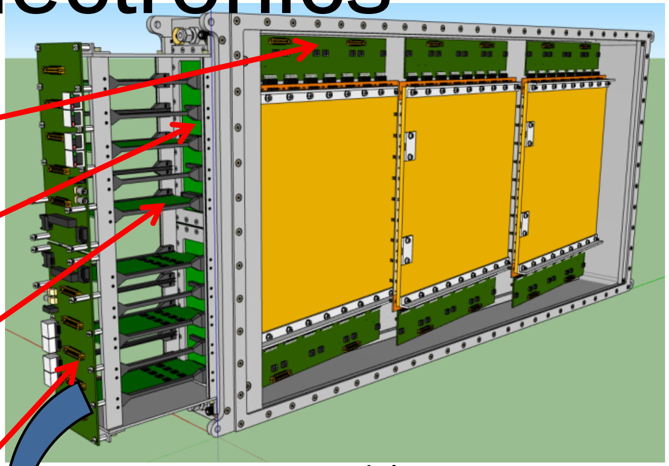
- GET4: TDC board 32 CH

- Backplane with GBTx / SCA



- AFCK: FPGA board

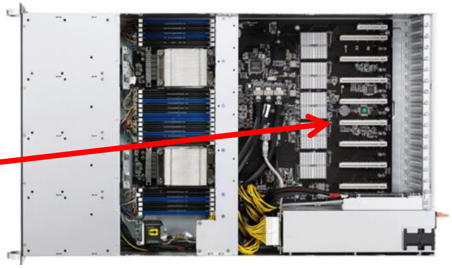
- FLIB: FPGA PCI express card



eTOF module

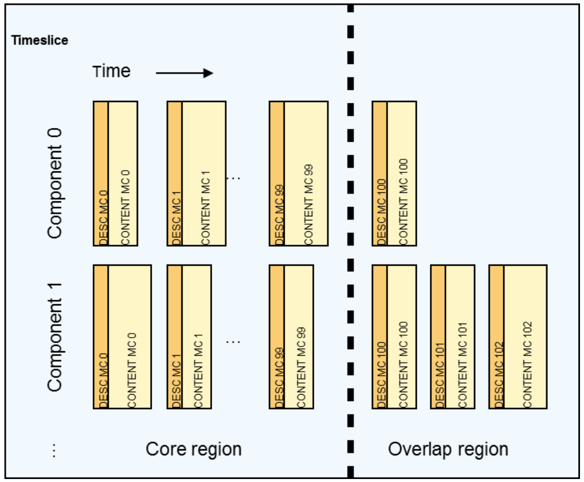
µTCA crate

PC



Timeslices and Microslices

- Definitions and concepts from the CBM readout chain
- MicroSlice (uS) = self-contained data container from a single DPB and for a given period of time
  - Output of the DPB in CBM
    - ⇒ generated in FW
  - Constant width in experiment time
  - Typical period of time: 10's of μs to ms (1.024 ms in 2020 eTOF)
  - One per DPB/sector for each time interval in eTOF
- TimeSlice (TS) = container collecting the uS for all DPBs in a system and for a given number of uS
  - Built by FLESNET (CBM DAQ prototype)
    - ⇒ generated in SW
  - Typical number of uS: 10-100 (10 for 2020 eTOF)
    - ⇒ Eq. time range: ms to s (10.24 ms in 2020 eTOF)
  - Includes overlap uS
  - One for full eTOF for each time interval



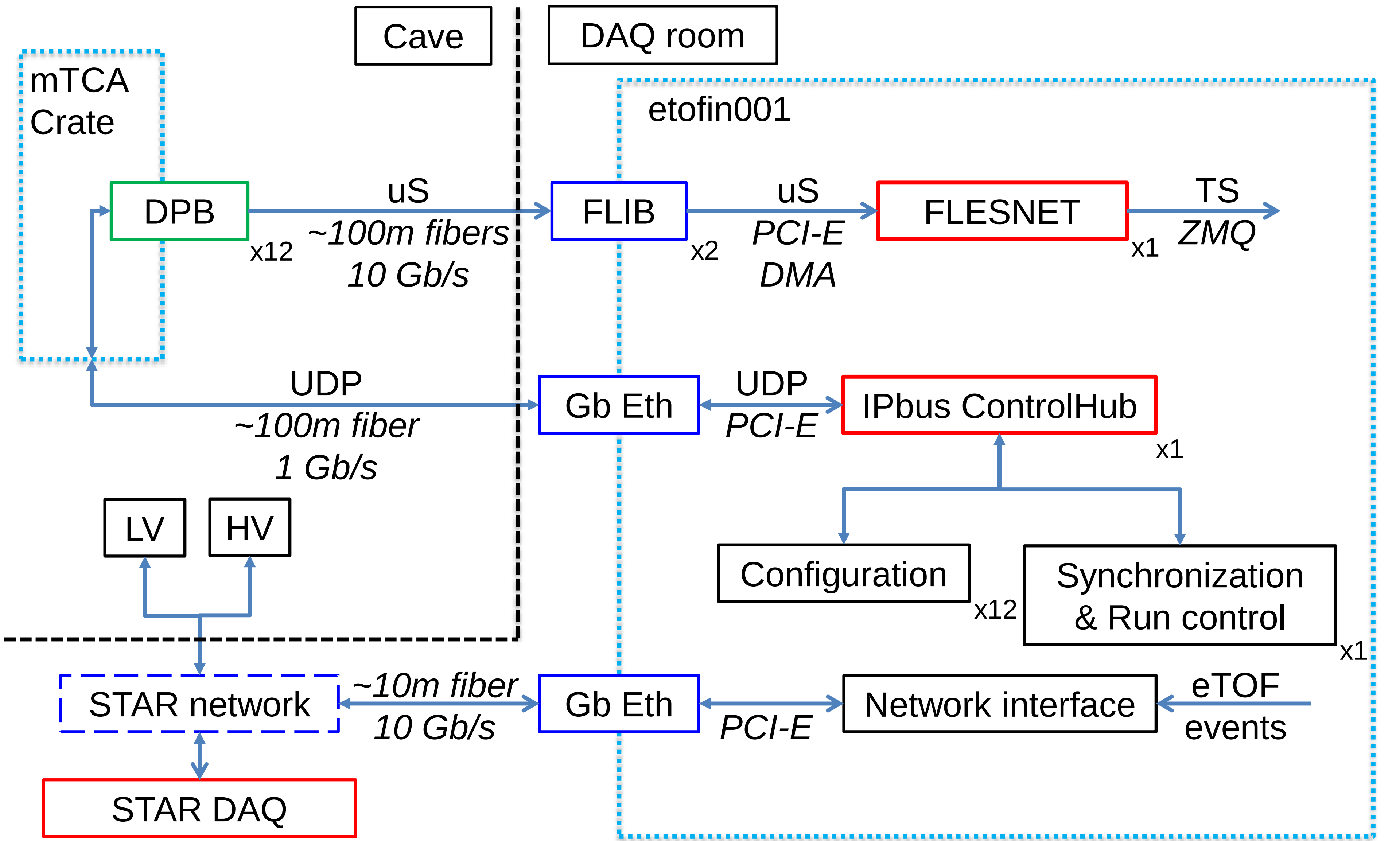
Raw Messages Format

- 64 bits messages
- Used from DPB output to unpacking in CBMROOT software
- Identical in all CBM prototypes and eTOF
- Goal: minimize modification of fields by FPGA FW while allowing support of CBM data taking in the coming years
- 9 message types, 5 used in normal eTOF operations
  - Hit messages: Channel Index, ASIC Index, Time ~50 ps precision, TOT
  - Epoch: Time with 25.6 μs precision and ~15 hours range
  - Errors from front-end
  - ASIC Pattern message from FW, indicating change of state in single frontend link
  - Trigger messages encoding the trigger signal received from STAR: CBM time, STAR time, Trigger token, Trigger and DAQ command type

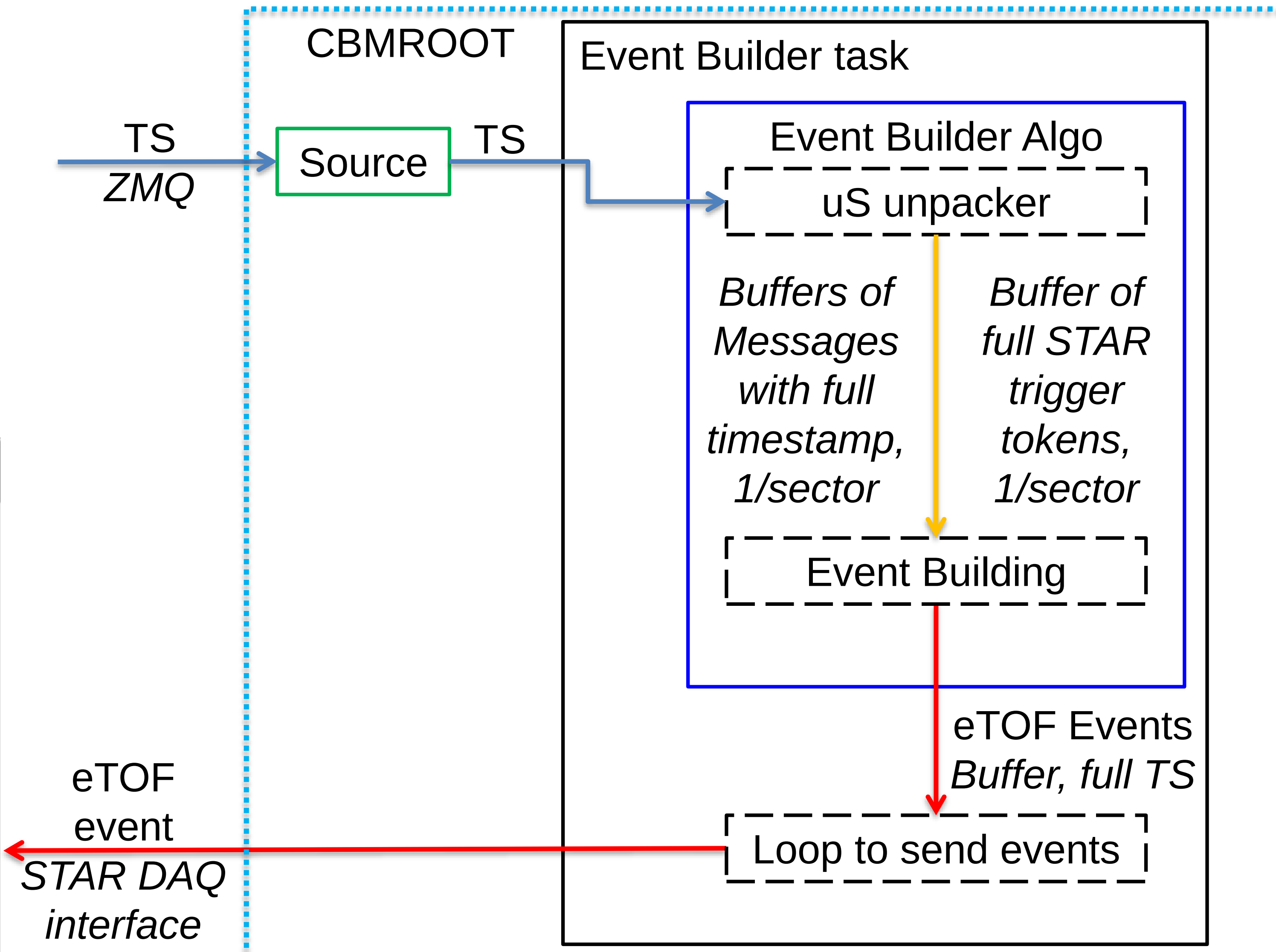
Message type
Msg Subtype
Pattern Type

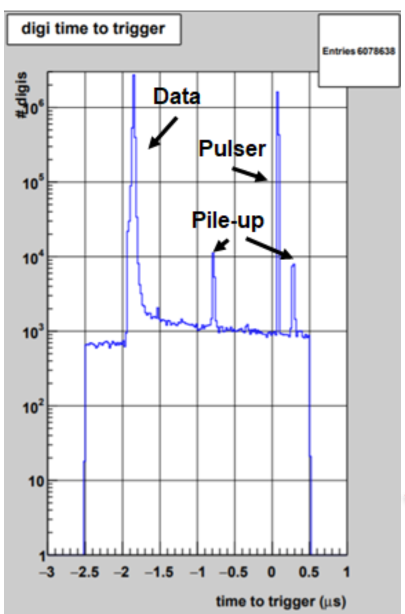
<table>
<tr><th rowspan="2">System</th><th rowspan="2">Message</th><th colspan="64">Bits format</th></tr>
<tr><th>63</th><th>62</th><th>61</th><th>60</th><th>59</th><th>58</th><th>57</th><th>56</th><th>55</th><th>54</th><th>53</th><th>52</th><th>51</th><th>50</th><th>49</th><th>48</th><th>47</th><th>46</th><th>45</th><th>44</th><th>43</th><th>42</th><th>41</th><th>40</th><th>39</th><th>38</th><th>37</th><th>36</th><th>35</th><th>34</th><th>33</th><th>32</th><th>31</th><th>30</th><th>29</th><th>28</th><th>27</th><th>26</th><th>25</th><th>24</th><th>23</th><th>22</th><th>21</th><th>20</th><th>19</th><th>18</th><th>17</th><th>16</th><th>15</th><th>14</th><th>13</th><th>12</th><th>11</th><th>10</th><th>9</th><th>8</th><th>7</th><th>6</th><th>5</th><th>4</th><th>3</th><th>2</th><th>1</th><th>0</th></tr>
<tr><td rowspan="15">TOF</td><td>GET4 Hit 32b</td><td rowspan="15" colspan="16">DPB ID: MAC 16 LSB</td><td rowspan="8" colspan="8">ASIC index (8b)</td><td>0</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td colspan="2">Ch</td><td colspan="12">Coarse time (12b)</td><td colspan="7">Finetime (7b)</td><td>D</td><td colspan="8">TOT (8b)</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>GET4 Hit 24b</td><td>1</td><td>/</td><td>/</td><td>/</td><td>/</td><td>E</td><td colspan="2">Ch</td><td colspan="12">Coarse time (12b)</td><td colspan="7">Finetime (7b)</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>GET4 Epoch</td><td>L</td><td colspan="31">Epoch (31b)</td><td>S</td><td>DL</td><td>EL</td><td>MF</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td>GET4 Slow Ctrl</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td colspan="2">Ch</td><td>E</td><td colspan="2">Type</td><td colspan="24">GET4 SLC message data (24b)</td><td>0</td><td>0</td><td>1</td><td>0</td></tr>
<tr><td>GET4 System</td><td colspan="2">SubT</td><td>L</td><td>/</td><td colspan="32">Data (32b)</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>GET4 Error</td><td>0</td><td>0</td><td>L</td><td>Ro</td><td>/</td><td>/</td><td>/</td><td>/</td><td colspan="21">Additional Info from error msg (21b) (Channel/edge, TDC time, DLL phase)</td><td colspan="7">Data (7b)</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>GET4 Unknwn</td><td>0</td><td>1</td><td>L</td><td>/</td><td colspan="32">Unknown GET4 message data (32b)</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>FW Error</td><td>1</td><td>0</td><td>L</td><td>R/S</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>MISS Pattern</td><td>0</td><td>0</td><td>/</td><td>/</td><td colspan="4">Indx (4b) (0-7)</td><td>1</td><td>1</td><td>/</td><td>/</td><td colspan="32">Mismatch flag pattern (32b, 1b per ASIC)</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>ASIC Pattern</td><td>0</td><td>1</td><td>/</td><td>/</td><td colspan="4">Indx (4b) (0-7)</td><td>1</td><td>1</td><td>/</td><td>/</td><td colspan="32">ASIC enable flag pattern (32b, 1b per ASIC)</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>SYNC Pattern</td><td>1</td><td>0</td><td>/</td><td>/</td><td colspan="4">Indx (4b) (0-7)</td><td>1</td><td>1</td><td>/</td><td>/</td><td colspan="32">Resync request on SYNC pattern (32b, 1b per ASIC)</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>STAR Trig. A</td><td>/</td><td>/</td><td>/</td><td>/</td><td colspan="40">gDPB Timestamp MSB (40b)</td><td>0</td><td>1</td><td>0</td><td>0</td></tr>
<tr><td>STAR Trig. B</td><td>/</td><td>/</td><td>/</td><td>/</td><td colspan="24">gDPB Timestamp LSB (24b)</td><td colspan="16">Last STAR reset timestamp MSB (16b)</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>STAR Trig. C</td><td>/</td><td>/</td><td>/</td><td>/</td><td colspan="40">Last STAR reset timestamp Mid bits (40b)</td><td>0</td><td>1</td><td>1</td><td>0</td></tr>
<tr><td>STAR Trig. D</td><td>/</td><td>/</td><td>/</td><td>/</td><td colspan="8">Last STAR reset ts LSB (8b)</td><td colspan="12">0 (12b Filler)</td><td colspan="4">Trig cmd (4b)</td><td colspan="4">DAQ cmd (4b)</td><td colspan="12">Token (8b)</td><td>0</td><td>1</td><td>1</td><td>1</td></tr>
</table>

Hardware/Software interface



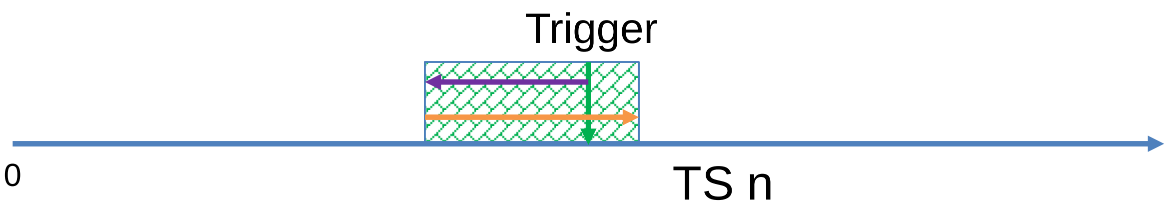
Steps from raw data to eTOF events



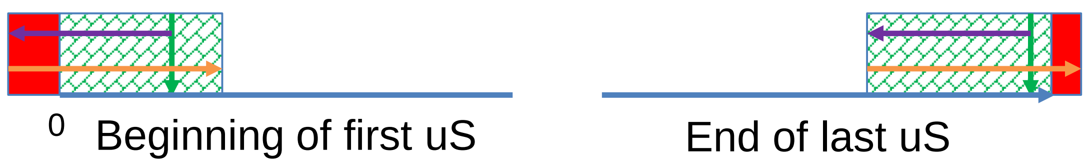


Event building with TimeSlice overlap

Event building in standard case



Problem at edges of TS if only data in “core” used



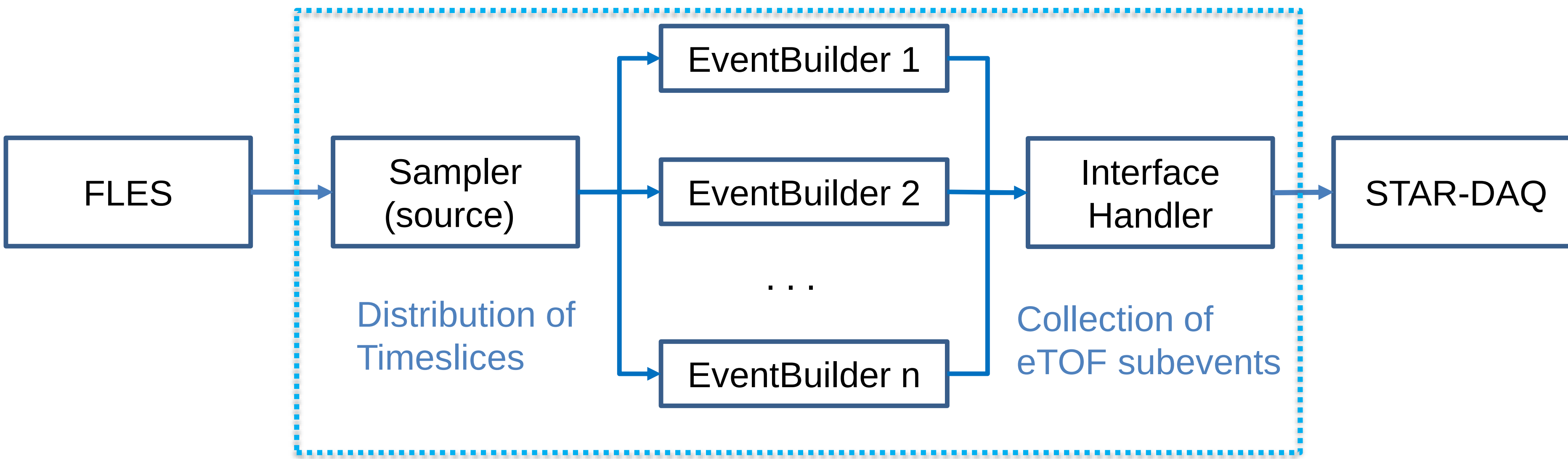
Solution using the overlap MS

- Reject triggers at beginning of TS up to “-Trigger window start”
- Accept triggers in overlap uS up to “-Trigger window start”
- Accept hits in overlap uS up to “Trigger window duration”

eTOF MQ event building

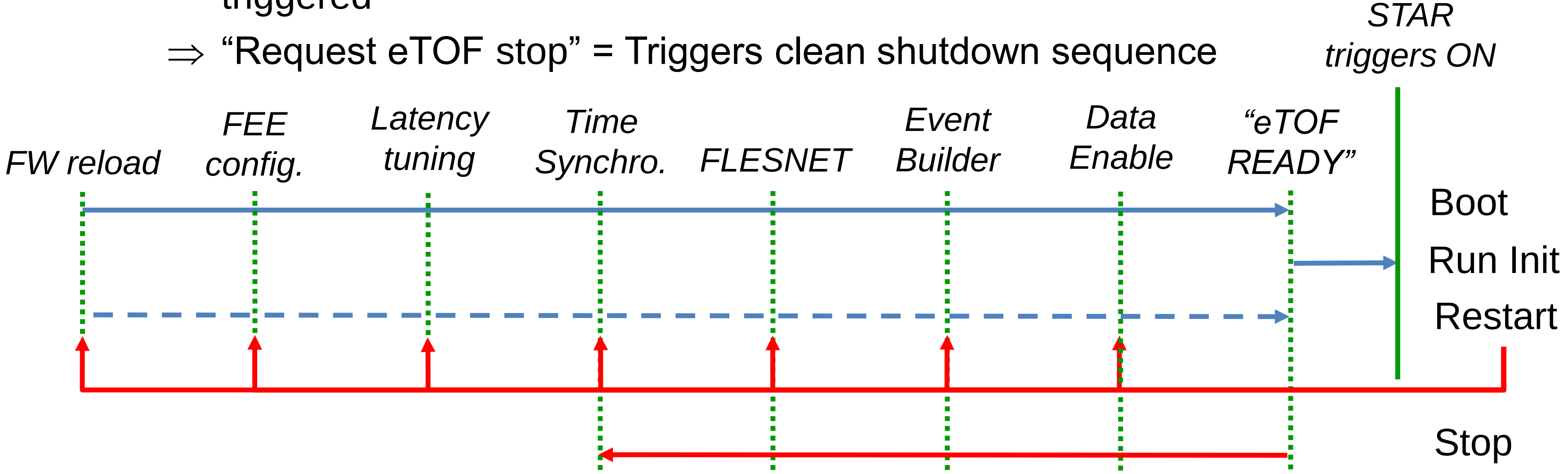
- Compute intensive task: extract time interval (3μs) around STAR trigger token from continuous data stream
- Input data rate: 12 x (5 – 50) MB/s

- Hardware platform (node etofin001): 48 cores
  => Many free cores after DAQ + configuration + Monitoring processes accounted
- Parallel tasks (devices) within FairMQ framework (https://github.com/FairRootGroup/FairMQ)



Shift crew interface

- "etofin001" (central node of eTOF) configured to reload all needed FW, SW and configuration on boot, until a stable "Ready for data taking" state is reached
  - ⇒ Includes everything from FW loading through FEE configuration and DAQ startup to event builder
  - ⇒ Order of 10-20 minutes until "eTOF ready" state reached
- Two commands available to the shift crew:
  - ⇒ "Request eTOF restart" = Triggers a recovery procedure, can be automatically triggered
  - ⇒ "Request eTOF stop" = Triggers clean shutdown sequence

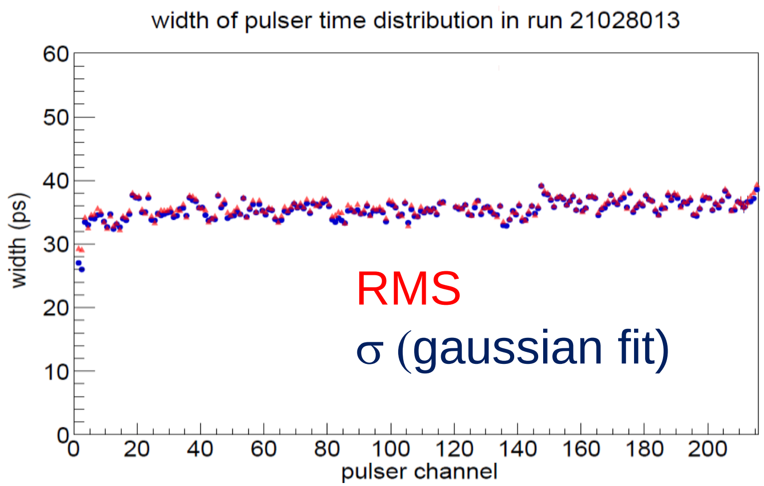


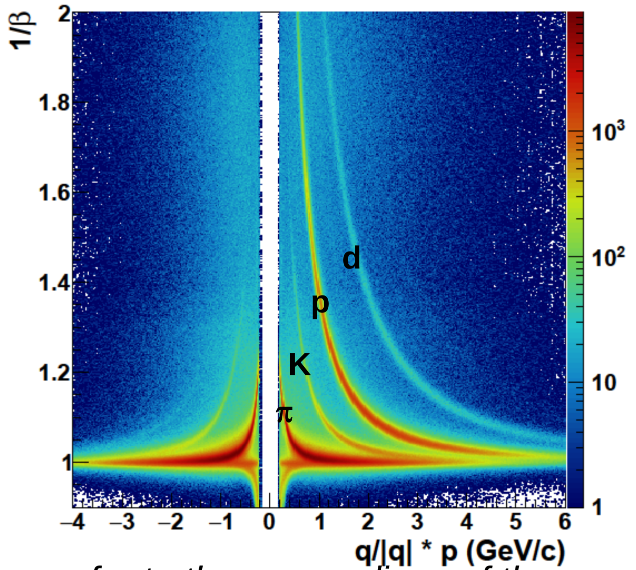
Status and results

Technical status:

- Full eTOF detector successfully used in run 20 of the STAR BES II campaign (~14 weeks operation)
- Data taking of BES II on hold due to COVID-19 (~12 planned weeks left)
- Experts' control, recovery and tuning needed for the first weeks of beamtime, following a major upgrade in Autumn 2019
- Multiple weeks of data taking without expert intervention subsequently

Data quality assessment and analysis results:





Some preliminary plots available if questions, for more details please refer to the proceedings of the XVth RPC conference by I. Deppner, to be published soon

Conclusion

- eTOF@STAR = use CBM-TOF developments to provide a high-performance end-cap TOF wheel for the STAR Beam-Energy-Scan II
- Needed integration a free-streaming readout chain in a triggered system at the Hardware and Software level
- Integration realized with a custom board for the STAR signals and an event builder within the CBM analysis framework
  - ⇒ Most of the eTOF setup, software included, is common to the current CBM-TOF prototypes or using common concepts
- Now operating stable for multiple weeks in the STAR experiment for the BES II campaign
- First results of data quality and physics analysis promising
- Experience gained during the setup and early operation of eTOF@STAR really helping CBM developments

Thank you for your attention

Physikalisches Institut, Uni. Heidelberg:

- N. Herrmann (Project coordination, MQ event building)
- I. Deppner (Project coordination, HW assembly and operation)
- E. Rubio (DPB FW)
- P. Weidenkaff (Data analysis)

GSI, Darmstadt:

- D. Emschermann (DAQ and network)
- J. Fruehauf (Electronics)
- P.-A. Loizeau (DAQ, Configuration, event builder)

TU Darmstadt

- F. Seck (Data analysis)

Rice University, Houston:

- G. Eppley (Project coordination, system operation during run)

FIAS, Frankfurt (FLIB FW, FLESNET)

BNL (STAR DAQ interface)

Tsinghua University, Beijing (MRPC detectors)

USTC, Hefei (MRPC detectors)

CCNU, Wuhan (DPB FW, Slow control)